APS March Meeting 2016
Baltimore, Maryland
http://www.aps.org/meetings/march/index.cfm
8:00AM A3.00001 Order From disorder in Frustrated Spin Systems¹ PIERS COLEMAN, Rutgers Univ — This talk will review the phenomenon of “Order from disorder”: the mechanism by which fluctuations remove a degeneracy within a frustrated spin system. An important consequence of order-from-disorder, is the ability of frustrated Heisenberg spin systems to overcome the Mermin-Wagner theorem, developing new forms of discrete order, even when the spins themselves remain disordered with a finite correlation length. The most well-known example, is the two-dimensional frustrated $J_1 - J_2$ Heisenberg model, which undergoes a finite temperature Ising phase transition into a stripy or “nematic” state, even though the spins do not order until absolute zero[1,2]. Nematic ordering of this kind is believed to occur in the iron-based superconductors, such as $BaFe_{1−x}As_2$. More recently, it has been possible to theoretically study the triangular-honeycomb versions of the $J_1 - J_2$ model, called a windmill model[3-4], in which order-from-disorder drives the development of six-state clock order. Remarkably, in this case, order-from-disorder leads to an intermediate power-law spin phase, despite the underlying Heisenberg spins.


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8:36AM A3.00002 Love triangles, quantum fluctuations and spin jam SEUNG-HUN LEE, University of Virginia — When magnetic moments are interacting with each other in a situation resembling that of complex love triangles, called frustration, a large set of states that are energetically equivalent emerge. This leads to exotic spin states such as spin liquid and spin ice. Recently, we presented evidence for the existence of a topological glassy state, that we call spin jam, induced by quantum fluctuations.[1,2] The case in point is SrCr$_9$O$_{17}$ (SCGO), a highly frustrated magnet, in which the magnetic Cr ions form a quasi-two-dimensional triangular system of bi-pyramids. This system has been an archetype in search for exotic spin states. Understanding the nature of the state has been a great intellectual challenge. Our new experimental data and theoretical spin jam model provide for the first time a coherent understanding of the phenomenon. Furthermore, the findings strongly support the possible existence of purely topological glassy states. Reference: [1] Spin jam induced by quantum fluctuations in a frustrated magnet, J. Yang et al., Proc. Natl. Acad. Sci. U.S.A. Vol. 127, 11519-11523 (2015). [2] Glassiness and exotic entropy scaling induced by quantum fluctuations in a disorder-free frustrated magnet, I. Kich, S.-H. Lee, K. lida, Nature Communications 5, 3497 (2014).

9:12AM A3.00003 The many faces of order-by-disorder in rare-earth pyrochlore magnets MICHEL J P GINGRAS, University of Waterloo — Order-by-disorder (ObD) is a concept of central importance in the field of frustrated magnetism. Saddled with large accidental degeneracies, a subset of states, those that support the largest quantum and/or thermal fluctuations, may be selected to form true long-range order. More formally, one often begins describing a system in terms of some order parameter $m$ with the low-energy description framed in terms of an effective action $\Gamma(m)$. In each ObD scenario, one starts from an artificial limit where there is an accidental degeneracy; that is the effective action at this point, $\Gamma_0(m)$, has an accidental symmetry. One may then view ObD phenomena as cases where the corrections to $\Gamma_0(m)$ arise through some form of fluctuation corrections, may be thermal, quantum or virtual, towards an enlarged higher energy Hilbert space. In the rare-earth pyrochlore oxides, of formula $R_2M_2O_7$, the trivalent magnetic rare-earth ions $R^{3+}$ (e.g $R$=Gd, Er, Yb; $M$=Ti, Sn is non-magnetic) reside on a three-dimensional pyrochlore lattice of corner-sharing tetrahedra. This architecture is prone to a high degree of magnetic frustration, with the $R_2M_2O_7$ pyrochlore materials having been found over the past twenty years to display a gamut of exotic phenomena. In this talk, I will discuss three such phenomena: (i) the intermediate partially-ordered multiple-$k$ state between 0.7K and 1K in the Gd$_2$Ti$_2$O$_7$ Heisenberg antiferromagnet; [3] (ii) the ordered $\psi_2$ state selection in the $XY$ Er$_2$Ti$_2$O$_7$ antiferromagnet [4] and (iii) the puzzling high sample sensitivity of the Yb$_2$Ti$_2$O$_7$ “quantum spin ice” candidate [5]. I will argue that in all three cases, some form of fluctuation corrections to their simplest $\Gamma_0(m)$ description play a significant role in the state selection and experimentally observed behaviors.


9:48AM A3.00004 Order by Disorder in the XY Pyrochlore Antiferromagnet Er$_2$Ti$_2$O$_7$$^1$, BRUCE D. GAULIN, McMaster University — Crystal field effects associated with Er$^{3+}$ magnetic moments in Er$_2$Ti$_2$O$_7$ give rise to local XY anisotropy and effective quantum $S=1/2$ spins which are antiferromagnetically coupled on this materials cubic pyrochlore lattice [1]. Er$_2$Ti$_2$O$_7$ orders into a non-collinear antiferromagnetic $\Psi_2$ state below ~1.2 K, in zero magnetic field, but the mechanism for its ground state selection has been a puzzle for more than a decade. We have carried out inelastic neutron scattering measurements on single crystal samples of Er$_2$Ti$_2$O$_7$ at low temperatures and in the presence of a strong [110] magnetic field, allowing us to determine the underlying spin Hamiltonian for this quantum antiferromagnet [2, 3]. These results point to ground state selection via an order-by-quantum-disorder mechanism [3], and a concomitant order-disorder gap of ~ 0.05 meV has also been observed [4], associated with the pseudo-Goldstone modes in the low field ordered state. In addition, we have explored the sensitivity of the ground state selection to magnetic dilution by preparing and studying single crystals of the Er$_2$$_{1-x}$Y$_x$Ti$_2$O$_7$ [5]. These studies are particularly topical in light of two theoretical predictions [6,7] that the $\Psi_2$ ordered state may be unstable to formation of the related $\Psi_1$ phase at low temperatures, in the presence of quenched disorder. [1] J.D.M. Champion et al., Phys. Rev. B 68, 020401 (2003).

¹Research supported by NSERC of Canada and the Canadian Institute for Advanced Research
10:24AM A3.00005 Quantum order-by-disorder and excitations in anisotropic kagome-lattice antiferromagnets. ALEXANDER CHERNYSHCHEV, University of California, Irvine — Our recent works have advanced theoretical understanding of the quantum effects in kagome-lattice antiferromagnets and have provided insights into the quantum order-by-disorder mechanism, important for a broad class of frustrated spin systems. In particular, we have challenged a general expectation that the quantum and thermal order-by-disorder mechanisms always select the same ground state. We have shown that the non-linear terms in the quantum Hamiltonian of the anisotropic kagome-lattice antiferromagnets can yield a rare example of the ground state that is different from the one favored by thermal fluctuations. We have also demonstrated that the order selection is generated by topologically non-trivial tunneling processes, yielding a new energy scale in the system. Related to the ground-state selection mechanism are the non-linear effects in the spectra of the kagome-lattice systems. Further progress has been made in understanding spectral properties of realistic kagome-lattice antiferromagnets such as Fe-jarosite, for which we have demonstrated a remarkable wipe-out effect for a significant portion of the spectrum. This phenomenon is related to an existence of the so-called “flat mode,” a ubiquitous feature of the kagome-lattice and other highly-frustrated antiferromagnets, and is due to a resonant-like decay processes involving two of such modes. We argue that ESR can be used as a phenomenon protected from the effect of many-body correlations. We show that this is not the case in a two-dimensional Fermi liquid (FL) with spin-orbit coupling (SOC). Referenced by topologically non-trival tunneling processes, yielding a new energy scale in the system.

Monday, March 14, 2016 8:00AM - 11:00AM – Session A5 GMAG DCMP FIAP: Magnetic Resonance and Spin-Dependent Optical Phenomena in Semiconductors 301 - Masashi Shiraishi, U. Kyoto

8:00AM A5.00001 Optimizing Frequency-Modulated CW EDMR in silicon. LIHUANG ZHU, KIPP VAN SCHOOTEN, CHANDRASEKHAR RAMANATHAN, Dartmouth College — Electrically detected magnetic resonance (EDMR) is a powerful method of probing dopant and defect spin states in semiconductor devices. Moreover, at the single dopant level, these spin states are heavily investigated as potential qubit systems, though facile electronic access to single dopants is exceedingly difficult. We therefore characterize detection sensitivities of frequency-modulated CW-EDMR of phosphorus donors in silicon Si:P using a home-built 2.5 GHz system (80 mT) at 5 K. An arbitrary waveform generator controls the frequency modulation, allowing us to optimize the signal to noise ratio (SNR) of both the dangling bond and phosphorus donor signals against multiple experimental parameters, such as modulation amplitude and modulation frequency. The optimal range of frequency modulation parameters is constrained by the relaxation time of the phosphorus donor at 5 K, resulting in the same sensitivity limit as field modulated CW-EDMR, but offers some technical advantages; e.g. reducing the relative contribution of magnetic field induced currents and eliminating the need for field modulation coils. We further characterize the EDMR SNR in Si:P as a function of optical excitation energy by using a narrow line laser, tunable across donor exciton and band gap states.

8:12AM A5.00002 Electron Spin Resonance in a 2D Fermi Liquid with Spin-Orbit Coupling. SAURABH MAITI, MUHAMMAD IMRAN, DMITRII MASLOV, University of Florida — Electron spin resonance (ESR) is usually interpreted as a single-particle phenomenon protected from the effect of many-body correlations. We show that this is not the case in a two-dimensional Fermi liquid (FL) with spin-orbit coupling (SOC). Depending on whether the magnetic field is below or above some critical value, ESR in such a system probes up to three collecter chiral-spin modes, augmented by the presence of the field, or the Larmor mode, augmented both by SOC and FL renormalizations. We argue that ESR can be used as a probe not only for SOC but also for many-body physics.

8:24AM A5.00003 Electric dipolar spin resonance in systems with a valley dependent g-factor. MARKO RANCIC, GUIDO BURKARD, Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — We theoretically investigate the electric dipole spin resonance (EDSR) in a single Si/SiGe quantum dot in the presence of a magnetic field gradient, e.g., produced by a micromagnet. The control of electron spin states can be achieved by applying an oscillatory electric field, which induces periodic oscillations in real space of the electron spin inside the dot. This motion inside a magnetic field gradient produces an effective periodic in-plane magnetic field, and allows for driven spin rotations near resonance. The magnetic field gradient induces a valley dependent g-factor and a valley dependent Rabi frequency. Our first goal is to quantitatively and qualitatively describe valley dependent g-factors and the valley dependent Rabi frequencies using a microscopic model. A valley dependent g-factor combined with inter-valley scattering gives rise to a novel electron spin decoherence mechanism. The second goal of our study is to describe the drop of coherence in the presence of inter-valley scattering, and furthermore, to discuss the interplay between valley and spin relaxation. All relevant decoherence mechanisms are quantitatively evaluated by solving a Lindblad master equation.

8:36AM A5.00004 Electrically and optically detected spin echo of hopping carriers in organic semiconductors. VAGHARSH MKHITARYAN, VIATCHESLAV DOBROVITSKI, Ames Laboratory, Iowa State University, Ames, Iowa 50011 — We develop a theory for electrically and optically detected primary (2-pulse) and stimulated (3-pulse) spin echo produced by the polaron pairs coupled to the nuclear spins in organic semiconductors. The theory employs fully quantum description of the nuclear and polaron spins, and explains how the structure of the echo signal (electron spin echo envelope modulation, ESEEM) depends on the statistics and rate of the polaron hopping. For the primary spin echo the envelope modulation is strong for slow hopping; both modulation amplitude and dephasing time T2 decrease with increasing hopping rate. As the hopping rate increases further, T2 starts to increase again due to motional narrowing, while the primary echo signal becomes exponential without modulation. The stimulated spin echo signal also shows strong envelope modulation for slow polaron hopping. For faster hopping the stimulated echo (unlike the primary echo) shows a modulation, which does not disappear for fast hopping, and has the frequency of the nuclear Larmor precession. Besides describing the recent spin echo measurements in π-conjugated polymers [1], our work provides a way to directly determine the polaron hopping dynamics from the spin echo experiments. [1] H. Malissa et al, Science 345, 1487 (2014).

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DNP experiments

Experimentally, this collective behavior of spins can be probed in the steady state OMAR of organic light-emitting diodes (OLEDs) at room temperature by the OMAR effect [Baker et al., Nat. Commun. 3, 898 (2012)]. When semiconductor under bipolar injection, and in the presence of small magnetic fields conductivity of thin layers of organic semiconductors at low static magnetic fields (< 10 mT). When radio frequency (rf) radiation is applied to an organic semiconductor under bipolar injection, and in the presence of small magnetic fields B, magnetic resonance can occur, which is observed as a change of the conductance of the organic semiconductor. 

In order to quantitatively access and discriminate between these mechanisms, we investigate the inhomogeneous broadening of polaron spin-resonances using spatially detected magnetic resonance (EDMR) spectroscopy at various magnetic fields between 3mT and 12T. While random local hyperfine fields cause an external field-independent line broadening, band-edge excitons give rise to a distribution of the charge carrier g-factors. This Δg effect leads to a resonance line-width contribution that is proportional to the external magnetic field. We observe an EDMR line that is largely field-independent in the low-magnetic field, but shows substantial broadening of line shape at higher fields.

9:12AM A5.00007 Magnetoresistance detected spin collective in organic light-emitting diodes, JOHN M LUPTON, Univer of Utah, PAUL L BURN, Centre for Organic Photonics & Electronics, School of Chemistry & Molecular Biosciences, The University of Queensland, JOHN M LUPTON, Department of Physics and Astronomy, University of Utah and Institut fuer Experimentelle und Angewandte Physik, Universitat Regensburg, CHRISTOPH BOEHME, Department of Physics and Astronomy, University of Utah — Organic magnetoresistance (OMAR) typically refers to the significant change in the conductivity of thin layers of organic semiconductors at low static magnetic fields (< 10 mT). When radio frequency (rf) radiation is applied to an organic semiconductor under bipolar injection, and in the presence of small magnetic fields B, magnetic resonance can occur, which is observed as a change of the conductance of the OMAR effects [Baker et al., Nat. Commun. 3, 898 (2012)]. When B and the resonant driving field are stronger than local hyperfine fields, an ultrastrong coupling regime emerges, which is marked by collective spin effects analogous to the optical Dicke effect [Roundy and Raikher, Phys. Rev. B 88, 125206 (2013)]. Experimentally, this collective behavior of spins can be probed in the steady state OMAR of organic light-emitting diodes (OLEDs) at room temperature by observation of a spin reversal of the OMAR change under rf irradiation. Furthermore, in the presence of strong driving fields, an ac Zeeman effect can be observed through OMAR [Waters et al., Nat. Phys. 11, 910 (2015)], a unique window to observe room temperature macroscopic spin quantum coherence.

9:24AM A5.00008 Microwave frequency modulation for improving polarization transfer in DNP experiments, MALLORY GUY, CHANDRASEKHAR RAMANATHAN, Department of Physics and Astronomy, Dartmouth College — Dynamic nuclear polarization (DNP) is a technique that transfers the inherently high electron polarization to surrounding nuclear spins via microwave irradiation at the Larmor frequency of the electron spin. In the DNP experiment, the amplitude and frequency of the applied microwaves are constant. However, by adding time dependence in the form of frequency modulation, the electron excitation bandwidth is increased, thereby increasing the number of electron spins active in the polarization transfer process and improving overall efficiency. Both triangular and sinusoidal modulation show a 3 fold improvement over monochromatic irradiation. In the present study, we compare the nuclear spin polarization after DNP experiments with no modulation of the applied microwaves, triangular and sinusoidal modulation, and modulation schemes derived from the sample’s ESR spectrum. We characterize the polarization as a function of the modulation amplitude and frequency and compare the optimal results from each modulation scheme. Working at a field of 3.34 T and at a temperature of 4 K, we show that by using a modulation scheme tailored to the electronic environment of the sample, polarization transfer is improved over other modulation schemes. Small-scale simulations of the spin system are developed to gain further insight into the dynamics of this driven open system. This understanding could enable the design of modulation schemes to achieve even higher polarization transfer efficiencies.

9:36AM A5.00009 Resonant and Time-Resolved Spin Noise Spectroscopy, XINLIN SONG, BRENNAN PURSLEY, VANESSA SIH, University of Michigan — Spin noise spectroscopy is a technique which can probe the system while it remains in equilibrium. It was first demonstrated in atomic gases and then in solid state systems. Most existing spin noise measurement setups digitize the spin fluctuation signal and then analyze the power spectrum. Recently, pulsed lasers have been used to expand the bandwidth of accessible dynamics and allow direct time-domain correlation measurements. Here we develop and test a model for ultrafast pulsed laser spin noise measurements as well as a scheme to measure spin lifetimes longer than the laser repetition period. For the main excitation, analog electronics are used to capture correlations from the extended pulse train, and the signal at a fixed time delay is measured as a function of applied magnetic field. [1]


9:48AM A5.00010 Modification of electron spin properties in a GaAs epilayer by an in-plane electric field, MICHAEL MACMAHON, VANESSA SIH, Department of Physics, University of Michigan, Ann Arbor, MI 48109 — The interaction of electron spins with accelerating electric fields in bulk gallium arsenide results in many effects that are relevant to proposed spin-based devices. For example, in-plane electric fields have been shown to change the g-factor, generate spin polarization, and decrease the spin lifetime. Most such studies have used only very low electric fields, typically less than 100 V/cm. We investigate the dependence of spin lifetime on electric field at high electric fields and separate the contribution due to heating.

This work was supported in part by ONR and the Rackham Graduate School.


10:00AM A5.00011 3T and nonlocal 4T Hanle measurements of spin accumulation in the persistent photoconductor Al$_{0.3}$Ga$_{0.7}$As:Si

The persistent photoconductivity facilitates in situ incremental photo-doping of the AlGaAs channel, which enables direct comparisons of the 3T and 4T Hanle results on the same device over a broad range of carrier densities across the insulator-metal transition. Although their magnitudes differ by about an order of magnitude, the 3T and 4T Hanle signals exhibit broad similarities in their dependencies on the injection current and carrier density, as well as the resulting spin lifetimes. Specifically, at each bias current, the magnitudes of both the 3T and 4T Hanle signals are observed to decrease exponentially with increasing carrier density of the AlGaAs deep into the metallic state. The spin lifetimes extracted from the 3T and 4T Hanle curves, both via the FWHM, naturally decrease with increasing carrier density as the channel.

1Work supported by NSF grant DMR-1308613.

10:12AM A5.00012 Wurtzite Spin-Lasers

Lasers in which spin-polarized carriers are injected provide paths to different practical room temperature spintronics devices, not limited to magnetoresistive effects [1]. While theoretical studies of such spin-lasers have focused on zinc-blende semiconductors as their active regions, the first electrically injected carriers at room temperature were recently demonstrated in GaN-based wurtzite semiconductors [2], recognized also for the key role as highly-efficient light emitting diodes [3]. By focusing on a wurtzite quantum well-based spin-laser, we use accurate electronic structure calculations to develop a microscopic description for its lasing properties. We discuss important differences between wurtzite and zinc-blende spin-lasers.


10:24AM A5.00013 Manipulation of spin transfer torque using light

We report the spin transfer torque induced by a spin-polarized current on a nanomagnet as the current flows through a semiconductor-nanomagnet-semiconductor junction that is externally controlled by shining the junction off-resonantly with a laser. The Fano-like quantum interference between this localized state and the continuum spectrum is different in the two spin channels and hence it dramatically alters the spin transport, leading to the coherent control of the spin transfer torque.

This work is supported by EU-FP7 Marie Curie Initial Training Network INDEX.

10:36AM A5.00014 Microscopic description of a spin laser

Spin lasers provide interesting possibilities for spintronics applications at room temperature [1]. They have the same elements of a conventional laser, but the injected carriers are spin polarized which allows the output light polarization to have either positive or negative helicity. These devices are commonly implemented as VCSELs, which have the advantage of tuning the photon energy by the cavity design. We investigate a spin VCSEL with a AlGaAs/GaAs quantum well active region using band structure calculations and spin-dependent optical gain. In addition to the desirable properties for steady-state operation and cavity designs, we also show that by applying a uniaxial strain, large values of birefringence > 200 GHz can be realized [2]. Combined with spin injected carriers, the birefringence in the device allows polarization dynamics much faster than photon intensity dynamics [3].


This work is supported by FAPESP (2011/19333-4, 2012/05618-0 and 2013/23393-8), CNPq (246549/2012-2), DFG (GE 1231/2-1), NSF-ECCS, DOE-BES and US ONR.

10:48AM A5.00015 Modulating Spin Relaxation with Light and a Novel Spintronic Room Temperature Infrared Photodetector

We report modulating the spin relaxation rate in an InSb nanowire with infrared (IR) light. The nanowire is fashioned into a spin valve with cobalt and nickel contacts using electrochemical self-assembly. The spin relaxation length is long in the dark since 96% of the electrons occupy the lowest conduction subband at room temperature, which results in near elimination of the D’yakonov-Perel’ (DP) spin relaxation. Under IR illumination, electrons are excited to higher subbands by IR photons, resulting in the revival of the DP relaxation and a threefold shortening of the spin relaxation length. This change of the resistive spin valve and therefore has applications in a novel spintronic IR photodetector that can ideally work at room temperature with infinite light-to-dark contrast ratio, infinite detectivity and zero dark current if all other spin relaxation mechanisms are eliminated and spins can be injected into the nanowire and detected with 100% efficiency. This work is supported by the NSF under grant CMMI-1301013.


This work is supported by the NSF under grant CMMI-1301013.

Monday, March 14, 2016 8:00AM - 10:48AM —
Session A6/GMAG DMP: Metal Oxide Nanoparticles 302 - Erik Brok, NIST
8:00AM A6.00001 Magnetic ordering in lanthanide-molybdenum oxide nanostructure arrays. JOSEPH HAGMANN, SON LE, National Institute of Standards and Technology, LYNN SCHNEEMEYER, PATTI OLSEN, Montclair State University, TIGLET BESARA, THEO SIEGSTE, Florida State University, DAVID SEILER, CURT RICHTER, National Institute of Standards and Technology — Reduced ternary molybdenum oxides, or bronzes, offer an attractive materials platform to study a wide variety of remarkable physical phenomena in a system with highly varied structural chemistry. Interesting electronic behaviors, such as superconductivity, charge density waves, and magnetism, in these materials arise from the strong hybridization of the 4d states of high-valent Mo with O p orbitals. We investigate series of molybdenum bronze materials with Lanthanide-MoO42 composition that can be described as a three-dimensional array of metallic MoO12 nanostuctures computationally predicted to contain a single charge with spin separated by insulating MoO3 tetrahedra. This study reveals novel magnetic ordering in Lanthanide-MO12O44 systems arising, not from the inclusion of magnetic elements, but rather from an exchange interaction between cubic MO12O44 units. Here, we report the magnetometry and transport behaviors of a series of Lanthanide-MoO42 materials, emphasizing an observed low-temperature phase transition signifying the onset of antiferromagnetic ordering between the arrayed nanostructures, and relate these behaviors to their experimentally-characterized structures to reveal the intriguing physics of these correlated electronic systems.

8:12AM A6.00002 Thermogravimetric and Magnetic Studies of the Oxidation and the Reduction Reaction of SmCoO3 to Nanostructured Sm2O3 and Co, BRIAN KELLY, Department of Physics and Astronomy, University of Delaware, RONALD CISSCHICK, Department of Chemistry and Biotechnology, University of Delaware, GERALD POIRIER, Advanced Materials Characterization Laboratory, University of Delaware, KARL UNRUH, Department of Physics and Astronomy, University of Delaware — The SmCoO3 to nanostructured Sm2O3 and Co oxidation and reduction reaction has been studied by thermogravimetric analysis (TGA) measurements in forming gas (FG) and inert N2 atmospheres, x-ray diffraction (XRD) and vibrating sample magnetometry (VSM). The TGA measurements showed two clearly resolvable reduction processes when heating in FG, from the initial SmCoO3 phase through an intermediate nanostructured mixture of Sm2O3 and CoO when heated to 330C for several minutes, and then the conversion of CoO to metallic Co when heated above 500C. These phases were confirmed by XRD and VSM. Similar measurements in N2 yielded little mass change below 900C and coupled reduction processes at higher temperatures. Isoconversional measurements of the CoO to Co reduction reaction in FG yielded activation energies above 2eV/atom in the nanostructured system. This value is several times larger than those reported in the literature or obtained by similar measurements of bulk mixtures of Sm2O3 and CoO, suggesting the nanostructuring was the source of the large increase in activation energy.

8:24AM A6.00003 Roles of Surface and Interface Spins in Exchange Coupled Nanostructures1, MANH-HUONG PHAN, Department of Physics, University of South Florida, Tampa, FL 33620, USA — Exchange bias (EB) in magnetic nanostructures has remained a topic of global interest because of its potential use in spin valves, MRAM circuits, magnetic tunnel junctions, and spintronic devices. The exploration of EB on the nanoscale provides a novel approach to overcoming the superparamagnetic limit and increasing the theromomagnetic effect of magnetic nanoparticles, a critical bottleneck for magnetic data storage applications. Recent advances in chemical synthesis have given us a unique opportunity to explore the EB in a variety of nanoparticle systems ranging from core/shell nanoparticles of Fe32O44/Co/CoO, and Fe32O44/CoO to hollow nanoparticles of γ-Fe2O3 and hybrid composite nanoparticles of Au/Fe32O44. Our studies have addressed the following fundamental and important questions: (i) Can one decouple collective contributions of the interface and surface spins to the EB in a core/shell nanoparticle system? (ii) Can the dynamic and static response of the core and shell be identified separately? (iii) Can one tune “minor loop” to “exchange bias” effects in magnetic hollow nanoparticles by varying the number of surface spins? (iv) Can one decouple collective contributions of the inner and outer surface spins to the EB in a hollow nanoparticle system? (v) Can EB be induced in a magnetic nanoparticle by forming its interface with a non-magnetic metal? Such knowledge is essential to tailor EB in magnetic nanostructures for spintronics applications. In this talk, we will discuss the aforementioned findings in terms of our experimental and atomistic Monte Carlo studies.

8:24AM A6.00004 Synthesis and magnetic properties of highly crystalline Fe32O44 nanorods. R DAS, K STOJAK REPA, V KALAPPATTL, Univ. of South Florida, J ALONSO, Univ. of South Florida, BCMaterials, MH PHAN, H SRIKANTH, Univ. of South Florida — Anisotropic one-dimensional magnetic nanostructures have drawn considerable attention due to their large surface to volume ratio, which drastically influences physical and chemical properties. In the past decade, most attention has been paid to the synthesis of Fe32O44 nanoparticles (NPs), mainly focusing on a spherical morphology. In this work, we report the first systematic study of the magnetic properties of highly crystalline Fe32O44 nanorods (NRs), which were synthesized by the hydrothermal method. XRD and TEM confirmed the formation of highly crystalline Fe32O44 NRs with narrow size distribution. For high aspect ratio NRs (65:1), room temperature saturation magnetization is close to that of bulk Fe32O44 (~90emu/g) and much larger than that of spherical NPs of the same volume (60-70emu/g). DC magnetization vs. temperature data display a sharp change in the magnetization at 120K, which is attributed to the Verway transition, whose presence affirms the excellent crystallinity of Fe32O44 NRs. Owing to their high effective anisotropy and saturation magnetization, the Fe32O44 NRs show enhanced heating efficiency relative to their spherical NP counterparts when tested in a standard hyperthermia set-up.

9:00AM A6.00005 Ferroic ordering and charge-spin-lattice order coupling in Gd doped Fe32O44 nanoparticles. SUVRA LAHA, EAHAB ABDELHAMID, MAHESHKA PALIWADANA ARACHCHIGE, Wayne State University, AMBESH DJIX, Indian Institute of Technology Jodhpu, GAVIN LAWES, Wayne State University, VAMAN NAID, University of Michigan Dearborn, RATNA NAID, Wayne State University — Rare earth doped spinel nanoparticles have been extensively studied for their potential applications in magneto-optical recording and as MRI contrast agents. In the present study, we have investigated the effect of gadolinium doping (1-5 at.%) on the magnetic and dielectric properties of Fe32O44 nanoparticles synthesized by the chemical co-precipitation method. The structure and morphology of the as-synthesized gadolinium doped Fe32O44 (Gd-Fe32O44) nanoparticles were characterized by XRD, SEM and TEM, and the magnetic properties were measured by a Quantum Design physical property measurement system. We find that the penetration of excess Gd4+ ions into Fe32O44 spinel matrix significantly influences the average crystallite size and saturation magnetization in Gd-Fe32O44. The average crystallite size, estimated from XRD using Scherrer equation, increases with increasing Gd doping percentage and the saturation magnetization drops monotonically with excess Gd4+ ions. Interestingly, Gd3+ Fe32O44 develops enhanced ferroelectric ordering at low temperatures. The details of the temperature dependence dielectric, ferroelectric and magnetocapacitance measurements to understand the onset of charge-spin-lattice coupling in Gd-Fe32O44 system will be presented.

9:12AM A6.00006 A comparison of methods for the determination of the magnetocrystalline anisotropy constant in an Fe32O44-based ferrofluid. RONALD TACKETT, MEGAN ALLYN, Kettering University, VIJAYENDRA GARG, ADERAIDAL DE OLIVEIRA, University of Brasilia, PREM VAISHNAVA, Kettering University — The dynamics of the relaxation behavior of superparamagnetic nanoparticles is governed by many factors such as the anisotropy constant, composition, size and nature of coating of the nanoparticles particles. We report values of the anisotropy constant (K) for magnetic nanoparticle (size ~12 nm) coated with dextran and suspended in water by dc and ac magnetization measurement, MOsbsauer spectroscopy and the temperature dependent specific absorption rate (SAR) measurement. The magnetite nanoparticles were synthesized by co-precipitation and characterized by X-ray diffraction (XRD) and Transmission electron microscopy (TEM). The K values from dc magnetic susceptibility, MOsbsauer spectroscopy, ac magnetic susceptibility, and that obtained by temperature dependent SAR measurements are all within the range of the accepted values in the literature. Merits and demerits of the four methods of determining K values will be discussed. We will also report on the temperature dependence of the anisotropy constant and the NEel relaxation constant.
9:36AM A6.00007 Effect of magnetic anisotropy and particle size distribution on temperature dependent magnetic hyperthermia in Fe3O4 ferrofluids. MAHESHIKA PALIHWANADANA ARACHCHIGE, Wayne State University, HUMESHKAR NEMALA, Illinois Wesleyan University, VAMAN NAIK, University of Michigan Dearborn, RATNA NAIK, Wayne State University — Magnetic hyperthermia (MHT) has a specific potential as a non-invasive cancer therapy technique. Specific absorption rate (SAR) which measures the efficiency of heat generation, mainly depends on magnetic properties of nanoparticles such as saturation magnetization (Ms) and magnetic anisotropy (K) which depend on the size and shape. Therefore, MHT applications of magnetic nanoparticles often require a controllable synthesis to achieve desirable magnetic properties. We have synthesized Fe3O4 nanoparticles using two different methods, co-precipitation (CP) and hydrothermal (HT) techniques to produce similar XRd crystallite size of 12 nm, and subsequently coated with dextran to prepare ferrofluids for MHT. However, TEM measurements show average particle sizes of 13.8 3.6 nm and 14.6 3.6 nm for HT and CP samples, implying the existence of an amorphous surface layer for both. The MHT data show the two samples have different SAR values of 110 W/g (CP) and 40W/g (HT) at room temperature, although they have similar Ms of 70 4 emu/g regardless of their different TEM sizes. We fitted the temperature dependent SAR using linear response theory to explain the observed results. CP sample shows a larger magnetic core with a narrow size distribution and a higher K value compared to that of HT sample.

9:48AM A6.00008 The investigation of smart magnetic nanoparticles for use in the hyperthermia treatment of cancer. MEGAN ALLYN, Kettering University, PARASHU KHAREL, South Dakota State University, PREM VAISHNAV, RONALD TACKETT, Kettering University — The magnetic fluid hyperthermia (MFH) treatment of cancer has emerged as a possible low-side-effect alternative to traditional chemotherapy- and radiation-based therapy. As the nanoparticles absorb energy from a low amplitude RF magnetic field they heat up; however, currently used hyperthermia systems require external temperature monitoring as the nanoparticles can easily heat to temperature greater than the desired window between 42C and 46C. To combat this, we are investigating smart magnetic nanoparticles whose Curie temperatures fall within the desired range. In order to do this, we have doped non-magnetic cations onto the structure of the AFM LaMnO3. We report synthesis of LaxM1-xMnO3 (M = Ba, Ca, Sr; x = 0.10 0.25) nanoparticles via sol-gel method for use in temperature-controlled MFH. These nanoparticles were characterized via powder x-ray diffraction and found to have the expected R-3 c perovskite structure. For elemental analysis, energy dispersive spectroscopy was performed using scanning electron microscopy. The temperature dependence of the magnetization was investigated using vibrating sample magnetometry (VSM) to determine the Curie temperature of the ensembles. The results of the change in temperature vs time and SAR values will be presented.

10:00AM A6.00009 Magnetically Stimulated Release of a Model Drug From a Magnetic Drug Carrier. TOM RILEY, BEN EVANS, None — The use of particles in the micro and nanometer ranges has become increasingly important as therapeutic tools in medicine. In particular, magnetically-active particles may allow for magnetically-controlled release of drugs at targeted locations. The drugs can be delivered directly to cancerous tumors at desired concentrations. While hydrogel-based microspheres have been commonly proposed for such purposes, there is also a need for a lipophilic magnetic microsphere for delivery of poorly-soluble pharmaceuticals. We have created a well-dispersed suspension of iron oxide nanoparticles in a silicone matrix, and have used the material to manufacture microspheres in sizes ranging from 100nm to 50 microns. Our spheres are stable in aqueous suspensions, yet their silicone matrix is uniquely suited for the transport and delivery of hydrophobic pharmaceuticals. A high concentration of magnetic nanoparticles (50 wt%) enables magnetic localization, magnetic heating (hyperthermia), and magnetic stimulation to trigger drug release. Using fluorescein as a model drug, we use UV-visible spectroscopy to show a slow native release rate of the hydrophobic fluorescein from the spheres. We use these measurements to quantify the loading capacity of the microspheres, and we show results of magnetically-stimulated drug release using a DM100 field applicator (nanoScale Biomagnetics).

10:12AM A6.00010 Electric field control of the magnetic order parameter of magnetic pillars embedded in a ferroelectric matrix. MICHAEL FITZSIMMONS, Oak Ridge National Lab, Q WANG, Argonne National Lab, A CHEN, T LOOKMAN, Q.X. JIA, Los Alamos National Lab, D.A. GILBERT, J.A. BORCHERS, NIST, B HOLLADAY, S SINHA, UCSD — Using polarized beam small angle neutron scattering (SANS) we quantitatively measured the influence of an electric field on correlation of magnetism in a ferroelectric/ferrimagnetic nanocomposite. The nanocomposite consists of 12 nm wide pillars of CoFe2O4 (dark regions, inset figure left), a room temperature ferrimagnet, embedded in a ferroelectric, BaTiO3, matrix (light regions, inset figure right). We used a model-free method to extract the correlations of the magnetic structure from the SANS data (figure below). We found a 700 kV/cm electric field induced a change of magnetization of 2% (scattering geometry, inset figure left). We explain our results using a simple representation for free energy that attributes coupling between electric polarization and magnetic order parameters to strain.

10:24AM A6.00011 Characterization and Magnetic Properties of Nano-ferrite ZnFe2-xLaxO4 prepared by Co-precipitation method. ALY ABOU-ALY, Physics department, Faculty of Science, Alexandria University, Alexandria, Egypt, DOAA BAKEER, Physics department, Faculty of Science, Damanhur University, Damanhur, Egypt, NAYERA MOHAMMED, RAMADAN AWAD, MARWA HASEBBO, Physics department, Faculty of Science, Alexandria University, Alexandria, Egypt — Nano size spinel ferrite with nominal compositions ZnFe2-xLaxO4, 0 ≤ x ≤ 0.3 were prepared using stoichiometric amounts of ZnCl2, FeCl3, 6H2O and LaCl3, 7H2O by Co-precipitation method. The structures, optical and magnetic properties of the prepared samples were investigated, and compared with similar compositions prepared by different methods. The X-ray powder diffraction analysis shows single-phase cubic spinel structure up to x = 0.2. The lattice parameter “a” significantly increases with increasing x, which confirms the substitution of La at Fe sites. The crystal size, estimated by different methods, has been found in the range of 7-14 nm. This crystallite size is found to be less than that prepared by sol gel combustion method. The FTIR spectra indicate the presence of absorption bands in the range of 390-561cm-1. The magnetic hysteresis was studied using vibrating sample magnetometer (VSM). The saturation magnetization, coercivity and remnents magnetization have nonsystematic change as the La-substitution increases. This is because the magnetic properties of Nano- ferrites are strongly dependent on the cation distribution among tetrahedral and octahedral sites in the cubic spinel structure.
8:00AM A18.00001 In-plane current induced spin orbit effects in nanometer scale Hall bar of β-W/Ta/CoFeB/MgO/Ta multilayers 1, AVYAYA J. NARASIMHAM, State University of New York, Albany, YU-MING HUNG, Department of Physics, New York University, MENG ZHU, SUNY Polytechnic Institute, Albany — The giant spin Hall effect (GSH) is caused by spin orbit interactions in a semiconductor or metal that result in a spin current that is transverse to the charge current. Recent spin Hall effect studies in the beta phase metals Ta and W show that transverse spin currents are strong enough to switch an adjacent magnetic layer. Films with perpendicular magnetic anisotropy (PMA) can exhibit uniform magnetizations and higher thermal stability. Inserting a 1 nm Ta insert-layer between the CoFeB and W induces PMA which is confirmed by vibrating sample magnetometer and anomalous Hall voltage measurements. \( \beta-W/(S)/Ta/(1) \) channel and the adjacent CoFeB/MgO/Ta layers are patterned into a 100 nm wide Hall bar. The effect of in-plane current induced change in coercivity while sweeping in-plane magnetic field are studied. An empirical model to quantitatively understand the switching will be presented.

1SRC-NRI-INDEX -Spin Logic

8:12AM A18.00002 Spin Orbit Torque in TbCo Films with Bulk Perpendicular Magnetic Anisotropy, KOHEI UEDA, MAXWELL MANN, AIK-JUN TAN, GEOFFREY S. D. BEACH, MIT — Spin-orbit torque (SOT) has generated considerable interest for manipulating magnetization in spintronic devices with ultra-low dissipation. Recent research has demonstrated that highly efficient magnetization control can be driven by current-induced SOT in ferromagnet/heavy metals bilayers with strong spin orbit coupling. However, most work on SOT has focused on ultra-thin films with interfacial perpendicular magnetic anisotropy (PMA), whereas future devices will require bulk PMA for sufficient thermal stability. Recently, Zhao et al reported SOT induced magnetization switching in a bulk PMA material; however, the films examined were still rather thin. Here we examine spin orbit torques in TbCo alloy films with bulk PMA, sandwiched between top and bottom Ta layers. By performing conventional harmonic and current-induced switching measurements, we quantified the current-induced effective fields generated by damping-like (DL) and field-like (FL) torques. The DL torque is much larger than FL torque, and corresponds to an effective spin Hall angle consistent with that of Ta. Owing to the relatively small saturation magnetization of these ferrimagnetic materials, the current-induced effective field is comparable to that observed in nm-thick Co films, despite the much larger film thicknesses used here. These results demonstrate ferromagnetic alloys with bulk PMA can be engineered to simultaneously provide thermal stability and efficient SOT switching.

8:24AM A18.00003 Spin-orbit torque induced reversible coercivity change in Co/Pd multilayer thin films, SANDEEP KUMAR, Univ of California - Riverside — In this work we report reversible reduction in coercivity of Co/Pd multilayer thin films under high-density direct current biasing. We carried out in-situ focused magneto optic Kerr effect based hysteresis measurement while the specimen was under DC bias. The experiments show a reversible reduction in coercivity during the application of direct current. We propose this reduction occurs due to the spin-orbit torque (Rashba) generated at high current densities. Using an in-situ transmission electron microscope biasing experiment, we also showed the presence of disymmetric lattice structure of Co/Pd multilayers. Our results suggest that the Rashba torque is the dominant spin-orbit torque since coercivity change is a bulk phenomenon as compared to spin Hall effect.

8:36AM A18.00004 Novel current driven domain wall dynamics in synthetic antiferromagnets, SEE-HUN YANG, IBM Almaden Research Center — It was reported [1,2] that the domain walls in nanowires can be moved efficiently by electrical currents by a new type of torque, chiral spin torque (CST), the combination of spin Hall effect and Dzyaloshinskii-Moriya interaction. Recently we demonstrated that ns-long current pulses can move domain walls at extraordinarily high speeds (up to \( \sim 750 \text{ m s}^{-1} \)) in synthetic antiferromagnetic (SAF) nanowires that have almost zero net magnetization [3], which is much more efficient compared with similar nanowires in which the sub-layers are coupled ferromagnetically (SF). This high speed is found to be due to a new type of powerful torque, exchange coupling torque (ECT) that is directly proportional to the strength of the antiferromagnetic exchange coupling between the two sub-layers, showing that the ECT is effective only in SAF not in SF. Moreover, it is found that the dependence of the wall velocity on the magnetic field applied along the nanowire is non-monotonic. Most recently we predict an Walker-breakdown-like domain wall precession in SAF nanowires in the presence of in-plane field based on the model we develop, and this extraordinary precession has been observed [4]. In this talk I will discuss this in details by showing a unique characteristics of SAF sublayers’ DW boost-and-drag mechanism along with CST and ECT. [1] Kwang-Su Ryu, Luc Thomas, See-Hun Yang, and Stuart Parkin, “Chiral Spin Torque at Magnetic Domain Walls”, Nature Nanotechnology 8, 527-533 (2013). [2] Satoru Emori, Uwe Bauer, Sung-Min Ahn, Eduardo Martinez, and Geoffrey S. D. Beach, “Current-driven dynamics of chiral ferromagnetic domain walls”, Nature Materials 12, 611-616 (2013). [3] See-Hun Yang, Kwang-Su Ryu, and Stuart Parkin, “Domain-wall velocities of up to 750 m s−1 driven by exchange-coupling torque in synthetic antiferromagnets”, Nature Nanotechnology 10, 221-226 (2015). [4] See-Hun Yang, Chirag Garg, Paul Amari, Charles Rettner, and Stuart Parkin, in preparation. [5] Stuart Parkin and See-Hun Yang, “Memory on the Racetrack”, Nature Nanotechnology 10, 195-198 (2015).

9:12AM A18.00005 Spin-Hall Switching of In-plane Exchange Biased Heterostructures, MAXWELL MANN, GEOFFREY BEACH, Massachusetts Inst of Tech-MIT — The spin Hall effect (SHE) in heavy-metal/ferromagnet bilayers generates a pure transverse spin current from in-plane charge current, allowing for efficient switching of spintronic devices with perpendicular magnetic anisotropy [1,2,3,4]. Here, we demonstrate the use of an ATMT deposited adjacent to the FM establishes a large in-plane exchange bias field, allowing operation at zero HIP. We sputtered Pt(3nm)/Co(0.9nm)/Ni80Co20O(tAF) stacks at room-temperature in an in-plane magnetic field of 3 kOe. The current-induced effective field was measured in Hall cross devices by measuring the variation of the out-of-plane switching field as a function of JIP and HIP. The spin torque efficiency, dHSL/dJIP, is measured versus HIP for a sample with TAF=30 nm, and for a control in which NiCoO is replaced by TaOx. In the latter, dHSL/dJIP varied linearly with HIP. In the former, dHSL/dJIP varied nonlinearly with HIP and exhibited an offset indicating nonzero spin torque efficiency with zero HIP. The magnitude of HEB was 600 Oe in-plane. [1] D’yaikov and Perel JETP Lett., 1971. [2] Hirsch, PRL 1999. [3] Kato et al. Science, 2004. [4] Liu et al. PRL 2012.

9:24AM A18.00006 Few-nanosecond pulse switching with low write error for in-plane nano-magnets using the spin-Hall effect, SRIHARSHA ARADHYA, GRAHAM ROWLANDS, SHENGJIE SHI, JUNSEOK OH, D. C. RALPH, ROBERT BUHRMAN, Cornell University — Magnetic random access memory (MRAM) using spin transfer torques (STT) holds great promise for replacing existing best-in-class memory technologies in several application domains. Research on conventional two-terminal STT-MRAM thus far has revealed the existence of limitations that constrain switching reliability and speed for both in-plane and perpendicularly magnetized devices. Recently, spin torque arising from the giant spin Hall effect in Ta, W and Pt has shown to be an efficient spin transfer mechanism to switch magnetic bits in a three-terminal geometry [1-3]. Here we report highly reliable, nanosecond timescale pulse switching of three-terminal devices with in-plane magnetized magnetic tunnel junctions. We obtain write error rates (WER) down to \( \sim 10^{-5} \) using pulses as short as 2 ns, in contrast to conventional in-plane STT-MRAM devices where write speeds were limited to a few tens of nanoseconds for comparable WER. Utilizing micro-magnetic simulations, we discuss the differences from conventional MRAM that allow for this unprecedented and significant performance improvement. Finally, we highlight the path towards practical application enabled by the ability to separately optimize the read and write pathways in three-terminal devices. [1] L. Liu et al., Science, 336, 2012. [2] C-F. Pai et al., APL, 101, 2012. [3] M-H. Nguyen et al., APL, 106, 2015.
9:36AM A18.00007 Magnetization dynamics in LSMO/Pt nanowires in the presence of spin orbit torques , HANKYU LEE, IGOR BARSUKOV, CHRISTOPHER SAFRANSKI, ALEJANDRO JARA, YU-JIN CHEN, University of California, Irvine, ADRIAN SWARTZ, BONGJU KIM, GLAM, Stanford Univ., HAROLD HWANG, GLAM, Stanford Univ., SLAC Nat. Accel. Lab., ILYA KRIVOROTOV, University of California, Irvine — $La_2_xSr_{1-x}MnO_3$ (LSMO) possesses attractive magnetic properties for nanowire spin torque oscillators (STOs) driven by spin orbit torques: low magnetic damping, low saturation magnetization and high spin polarization. In this context, good understanding of magnetization dynamics in LSMO/Pt bilayer nanowires is important. Here, we report measurements of the spectral properties of spin-wave modes in LSMO/Pt nanowires magnetized along the two principal in-plane axes. In electrically-detected ferromagnetic resonance (FMR) we observe excitation of multiple spin wave modes, including non-aligned modes when the nanowire is magnetized perpendicular to its axis. Spectral linewidth of the FMR resonances gives quantitative information on the Gilbert damping parameter of the nanowire. In comparison to extended LSMO/Pt films, the magnetic damping in the nanowire is reduced due to the suppression of two-magnon scattering. We will present data on the effect of high bias current density applied to the wire on the frequency and linewidth of the observed spin wave resonances.

9:48AM A18.00008 Study of spin orbit torque switching in ferrimagnetic Gd$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$ alloy$^1$, NIKLAS ROSCHEWSKY, Department of Physics, University of California, Berkeley, TOMOYA MATSUMURA, TAKEKISHI KATO, Department of Electrical Engineering and Computer Science, Nagoya University Furo-cho, Chikusa-ku, SATOSHI IWATA, Advanced Measurement Technology Center, Nagoya University Furo-cho, Chikusa-ku, SURAJ CHEÉMA, JAMES CLARKSON, Department of Materials Science and Engineering, University of California, Berkeley, SAYEEF SALAHUDDIN, Department of Electrical Engineering and Computer Science, University of California, Berkeley — Magnetization switching in ferromagnetic metals (FM) with spin-orbit torques (SOT) is a well established technique. The SOT originates from spin accumulation at the interface of the FM generated by the spin Hall effect in an adjacent heavy metal. Here we report measurements of SOT in the alloy Gd$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$, where the transition metal sub-lattice and the rare earth sub-lattice couple antiferromagnetically. By varying the composition $x$ of the alloy we can tune the total magnetization. Anomalous Hall effect measurements are conducted to study the effect of SOT on the Gd$_x$(Fe$_{90}$Co$_{10}$)$_{100-x}$ alloy.

$^1$This work was supported by Department of Energy Basic Energy Sciences Award no DE-SC0012371

10:00AM A18.00009 Nanowire spin Hall oscillators: width dependence, ANDREW SMITH, Univ of California - Irvine, TOBIAS SCHNEIDER, Helmholtz-Zentrum Dresden - Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, 01328 Dresden, Germany, LIU YANG, ILYA KRIVOROTOV, Univ of California - Irvine — We present experimental studies of auto-oscillatory magnetization dynamics in nanowire spin Hall oscillators (SHOs) as a function of the wire width ranging from 0.17 m to 2 m. These SHOs consist of long Pt (7 nm)/Py (5 nm)/AIOx (2 nm) wires on a SiO$_2$ substrate. Direct current generating anti-damping spin torque is applied to a section of the wire between two leads separated by a 2 m gap, which defines the SHO active region. All devices show onset of auto-oscillations at similar critical current densities. For the 0.17 m and 0.34 m wide nanowire SHOs, auto-oscillatory modes arising from the bulk and edge eigenmodes of the nanowire are clearly seen in the emission spectra. For SHO devices based on wider wires, the bulk auto-oscillatory modes dominate the emission spectrum due to the larger wire volume occupied by the bulk modes. Our work demonstrates robust operation of nanowire-based SHOs over a wide range of nanowire widths and presents an example of a spin torque oscillator with the active area extended into the m$^2$ domain. [1] Zheng Duan et al, Nature Communications 5, 5616 (2014)

10:12AM A18.00010 Non-adiabatic spin-transfer torque independent of the spin relaxation rate, KYOUNG-WHAN KIM, NIST - Natl Inst of Stds & Tech, KYUNG-JIN LEE, Korea University, HYUN-WOO LEE, POSTECH, MARK STILES, NIST - Natl Inst of Stds & Tech — Non-adiabatic spin-transfer torques play an important role in magnetization dynamics. For example, they determine current-induced magnetic domain wall velocity. A well-known mechanism for non-adiabatic spin-transfer torques arises from spin relaxation and is directly proportional to the spin relaxation rate. Here we report mechanism that is independent of the spin relaxation rate. This mechanism is related to the recently reported intrinsic damping-like spin-orbit torque, which is proportional to an electric field but is independent of the conductivity, and hence the scattering rate. Likewise, the mechanism we report is independent of the scattering rate. It originates from the effective spin-orbit coupling that arises in systems with magnetic textures as we previously reported for related processes. In this work, we demonstrate the existence of such a spin-transfer torque, which is a contribution to the non-adiabatic spin-transfer torque and is independent of scattering rates. We also demonstrate that the magnitude of this torque can be much larger than other mechanisms for non-adiabatic spin-transfer torques, and may be the dominant contribution in some systems.

10:24AM A18.00011 Optical detection of spin Hall effect in metals, OLAF VAN T ERVE, AUBREY HANBICKI, CONNIE LI, BEREND JONKER, Naval Research Lab — Spin Hall effects in metals have been successfully measured using electrical methods such as nonlocal spin valve transport, ferromagnetic resonance or spin torque transfer experiments. These methods require complex processing techniques and measuring setups. Here we present room temperature measurements of the spin Hall effect in non-magnetic metals such as Pt and $\beta$W using a standard bench top magneto-optic Kerr effect (MOKE) system. With this system, one can readily determine the angular dependence of the induced polarization on the bias current direction. When a bias current is applied, the spin Hall effect causes electrons of opposite spin to be scattered in opposite directions, resulting in a spin accumulation at the surface of the film. The MOKE signal tracks the applied square wave bias current with an amplitude and phase directly related to the spin Hall angle. Using this technique, we show that the spin Hall angle of $\beta$W is opposite in sign and significantly larger than that of Pt. In addition, we use this technique to detect spin diffusion from $\beta$W into Al thin films, as well as spin diffusion from the topological surface states of Bi$_2$Se$_3$ into Al. We will also show direct modulation of the reflected light up to 100 kHz, using Bi doped Cu samples. This work was supported by internal programs at NRL.

10:36AM A18.00012 Spin Hall magnetoresistance in ultra thin Pt/LSMO, NA LEI, Beihang University, YU BAI, ZHAO DING, JIAN SHAO, WENGANG WEI, LIFENG YIN, YIZHENG WU, JIAN SHEN, Fudan University — Spin Hall magnetoresistance (SMR) in a non-ferro magnetic (NM/FM) bilayer is an angular dependence of resistance of the NM layer on the magnetization of FM layer [1]. It provides an easy approach to the spin Hall effect in a simple bilayer system, however similar effects mixed in the system and might complicated the data analysis and interpretation. Here we present a case of ultra thin Pt/LSMO, in which LSMO (below 7 unit cells) layer is an insulating magnetic oxide with Curie temperature of 120K. Below 120K, the SMR is paramagnetic, the magnetoresistance doesn’t disappear but even increase, which is distinct from the case of Pt/YIG [2]. Here it is neither SMR nor AMR, and an additional mechanism is required. Anomalous Hall effect was also performed, which is consistent with SMR measurement. We propose some physical pictures which could attribute to this magnetoresistance in paramagnetic state. Reference: [1] H. Nakayama, M. Althammer, Y.-T. Chen, K. Uchida, et al., Phys. Rev. Lett. 110(20), 206601 (2013). [2] K. Uchida, Z. Qiu, T. Kikkawa, R. Iguchi, E. Saitoh, Appl. Phys. Lett. 106, 052405 (2015).
10:48AM A18.00013 Spin Transport in Ferromagnetic and Antiferromagnetic Insulators. SHAN-SHAN SU, GEN YIN, YIZHOU LIU, Department of Electrical and Computer Engineering, University of California, Riverside; JIADONG ZANG, Department of Physics, University of New Hampshire; YAFIS BARLAS, Department of Physics and Astronomy, University of California, Riverside; ROGER LAKE, Department of Electrical and Computer Engineering, University of California, Riverside - Recently, experiments of spin pumping have been done for system with antiferromagnetic oxides (AFMOs) as a spacer between YIG and Pt [1-3]. Observation of spin transport through the AFMO and the enhancement of spin pumping signal in the system due to the insertion of AFMO has been reported [1,2]. In this research, we model the spin transport in Pt/YIG/Pt and Pt/YIG/AFMO/Pt heterostructures using the Landau–Lifshitz–Gilbert equations coupled with the non-equilibrium Green's function equations. We show that a pure spin current generated at the first Rashba SOC node is carried by magnon through YIG, which can be converted back to spin pumping signal at the second electrode. The spin dynamical details at the heterostructure can determine the transport efficiency. The effect of different magnetization orientations and finite temperatures will be addressed. [1] C. Hahn et al., EPL 108, 57005 (2014) [2] H. Wang et al., Phys. Rev. Lett. 113, 097202 (2014) [3] H. Wang et al., Phys. Rev. B 91, 220419 (2015)

This work was supported by the SHINES under Award SC0012670.

Monday, March 14, 2016 8:00AM - 11:00AM

Session A19 GMAG DMP: Manganites and Cobaltites

8:00AM A19.00001 Investigating short-range magnetism in strongly correlated materials via magnetic pair distribution function analysis and ab initio theory. BENJAMIN FRANDSEN, Columbia University; KATHERINE PAGE, Oak Ridge National Laboratory; MICHELA BRUNELLI, European Synchrotron Radiation Facility; JULIE STAUNTON, University of Warwick; SIMON BILLINGE, Columbia University - Short-range magnetic correlations are known to exist in a variety of strongly correlated electron systems, but our understanding of the role they play is challenged by the difficulty of experimentally probing such correlations. Magnetic pair distribution function (mPDF) analysis is a newly developed neutron total scattering method that can reveal short-range magnetic correlations directly in real space, and may therefore help ameliorate this difficulty. We present temperature-dependent mPDF measurements of the short-range magnetic correlations in the paramagnetic phase of antiferromagnetic MnO, an archetype strongly correlated transition-metal oxide. We observe significant correlations on a ~1 nm length scale that differ substantially from the low-temperature long-range-ordered spin arrangement. With no free parameters, ab initio calculations using the self-interaction-corrected local spin density approximation of density functional theory quantitatively reproduce the magnetic correlations to a high degree of accuracy. These results yield valuable insight into the magnetic exchange in MnO and showcase the utility of the mPDF technique for studying magnetic properties of strongly correlated electron systems.

8:12AM A19.00002 Magnetic Order in the Mixed-Spin Triangular Lattice Antiferromagnet Na₉MnO₂. ROBIN CHISNELL, DAN PARSHALL, NIST Center for Neutron Research, XIN LI, Harvard; AMBER LARSON, University of Maryland; TAKEHIITO SUZUKI, JOSEPH CHECKELSKY, MIT; EFRAIN RODRIGUEZ, University of Maryland; JEFFREY LYNN, NIST Center for Neutron Research - Na₉MnO₂ (TM = transition metal) materials consist of alternating layers of Na and TM ions with the TM ions arranged on a geometrically frustrated triangular lattice. Na can be easily and reversibly removed from these materials, making them of interest for application in rechargeable batteries and allowing for exploration of their rich phase diagrams as a function of Na concentration. Na ordering is an important factor in ground state selection, and is driven by electrostatic interactions in many Na₉TM₂O₅ systems. The TM = Mn series differs in that Na ordering is driven by a cooperative Jahn-Teller effect, due to the coexistence of Jahn-Teller active Mn¹⁺ and inactive Mn⁰⁺ ions. This effect also results in an ordered arrangement of the Mn¹⁺ and Mn⁰⁺ ions, and thus of spin-2 and spin-3/2 moments. For x = 5/6, we have recently shown the coexistence of charge and magnetic stripe orderings [1]. Here, we present the results of neutron diffraction measurements performed on single crystal samples of Na₉MnO₂ and discuss the details of the magnetic structure in the magnetically ordered phase.


8:24AM A19.00003 Spin polarized scanning tunneling microscopy of bilayer manganite La₂−2xSr₁−x₂Mn₂₋₇ single crystals.¹ XINZHOU TAN, ALEX DE LOZANNE, JIANSHI ZHOU, JOHN GOOSENOUGH, Univ of Texas, Austin - We employ spin-polarized scanning tunneling microscopy to investigate the (001) surface of bilayer manganite La₂−2xSr₁−x₂MnO₂ single crystals with x = 0.32 at various temperature and different magnetic fields. A spin reorientation transition (SRT) at this doping level starts around 70K, when the ferromagnetic spins change from out of plane to in plane configuration. Tracing the SRT while applying magnetic field along the c axis we are going to investigate the corresponding change from out of plane to in plane configuration. 

¹This work is supported by NSF DMR-1507874

8:36AM A19.00004 ABSTRACT WITHDRAWN


9:00AM A19.00006 Spin wave damping in colossal magnetoresistive La₀.₇Ca₀.₃MnO₃. JOEL HELTON, SUSUMU JONES, US Naval Academy; MATTHEW STONE, Oak Ridge National Laboratory; DMITRY SHULYATEV, National University of Science and Technology "MISIS", DANIEL PARSHALL, JEFFREY LYNN, NIST Center for Neutron Research - The hole-doped perovskite La₀.₇Ca₀.₃MnO₃ is best known for the colossal magnetoresistance displayed at a transition temperature of T=257 K. Previous studies have reported that the spin wave excitations in the ferromagnetic phase become anomalously damped near the Brillouin zone boundary, though a later work suggested that this was a measurement artifact due to an optical phonon branch. We have used the ARCS time-of-flight neutron spectrometer to investigate the spin wave excitations of La₀.₇Ca₀.₃MnO₃ at T=100 K and find a damping for spin waves at energies exceeding 20 meV that cannot be explained solely by proximity to the phonon branch. With additional measurements using the BT7 triple-axis neutron spectrometer, the spin wave damping is explored as a function of reduced wavevector, excitation energy, and temperature.
9:12AM A19.00007 Biquadratic and ring exchange interactions in orthorhombic perovskite manganites, NATALYA FEDOROVA, CLAUDE EDERER, NICOLA SPALDIN, Materials Theory, ETH Zurich, ANDREA SCARAMUCCI, Laboratory for Developments and Methods, Paul Scherrer Institute — We use ab initio electronic structure calculations within the GGA+U approximation to density functional theory (DFT) to determine the microscopic exchange interactions in the series of orthorhombic rare-earth manganites (o-RMnO$_3$). Our motivation is to construct a model Hamiltonian (excluding effects due to spin-orbit coupling), which can provide an accurate description of the magnetism in these materials. First we map the exchange couplings for several representatives of o-RMnO$_3$ series onto a Heisenberg Hamiltonian and find a clear deviation from the Heisenberg-like behavior. We demonstrate that this deviation can be explained only by the presence of relatively strong higher order exchange interactions (biquadratic and four-spin ring couplings) and show that they have the strongest effect in compounds, where nearest-neighbor exchange interactions are weakened due to the presence of large GdFeO$_3$-type distortion. Finally we discuss how these higher order terms determine magnetic ground states, influence magnetic excitations and define the multiferroic properties of o-RMnO$_3$.

9:24AM A19.00008 Role of Entropy and Structural Parameters in the Spin State Transition of LaCoO$_3$, BISMAYAN CHAKRABARTI, TURAN BIROL, KRISTJAN HAULE, Rutgers, The State University of New Jersey — The spin state transition in LaCoO$_3$ has eluded description for decades despite concerted theoretical and experimental effort. In this study, we approach this problem using fully charge consistent Density Functional Theory + Dynamical Mean Field Theory (DFT+DMFT). We show, from first principles, that LaCoO$_3$ cannot be described by a single, pure spin state at any temperature, but instead shows a gradual change in the population of higher spin multiples as temperature is increased. We explicitly elucidate the critical role of the lattice expansion and oxygen octahedral rotations in the spin state transition. We also show that the spin state transition and the metal-insulator transition in the compound occur at different temperatures. In addition, our results shed light on the importance of electronic entropy, which has so far been ignored in all first principles studies of this material.

9:36AM A19.00009 LaCoO$_3$ (LCO) - Dramatic changes in Magnetic Moment in fields to 500T$^1$, Y. LEE, B. N. HARMON, Ames Laboratory, U.S. DOE and Dept. of Physics and Astronomy, Iowa State University — LCO has attracted great attention over the years (>2000 publications) because of its unusual magnetic properties; although in its ground state at low temperatures it is non-magnetic. A recent experiment$^1$ in pulsed fields to 500T showed a moment of \(1.3_{\pm 1}\) above 140T, and above \(270T\) the magnetization reaches, reaching \(3.8_{\pm 1}\) by 500T. We have performed first principles DFT calculations for LCO in high fields. Our earlier calculations$^2$ explained the importance of a small rhombohedral distortion in the ground state that leads to a suppression of the 1.3$\pm 1$ moment for fields below \(140T\). By allowing fairly large atomic displacements in high fields, moments of \(4_{\pm 1}\) are predicted. [1] V. V. Platonov et al. Phys. Solid State 54, 279 (2012) [2] Y. Lee and B. N. Harmon et al. J. Appl. Phys. 113, 17E145 (2013)

$^1$This work was supported by the U.S. Department of Energy (DOE), Office of Science, Basic Energy Sciences, Materials Science and Engineering Division under contract No. DE-AC02-07CH11358.

9:48AM A19.00010 ABSTRACT WITHDRAWN —

10:00AM A19.00011 Interplay between frustration, magnetism and sodium vacancy ordering in in Na$_{0.84}$CoO$_2$, STANISLAW GALESKI, KURT MATTENBERGER, BERTRAM BATLOGG, Laboratory for Solid State Physics, ETH Zurich, Switzerland — We have performed an extensive survey of low temperature specific heat of Na$_{0.84}$CoO$_2$. Heat capacity measurements were performed with an AC steady state method using a membrane nanocalorimeter. Thanks to the 10-30 nanogram sample mass we were able to perform well controlled ultra-fast cooling (500K/s) form high temperatures to temperatures where the sodium ions become immobile. This allowed us to take snapshots of different high temperature sodium configurations, relate them to particular structural transitions and at the same time establish their influence on the low temperature magnetic order. Through correlation with XRD data we demonstrate that the least ordered sodium configuration increases the Tc of the 22K transition by 2K.

10:12AM A19.00012 Angle-resolved photoemission on the delafossite oxide metal PtCoO$_2$, VERONIKA SUNKO, University of St Andrews, PALLAVI KUSHWAHA, Max Planck Institute for Chemical Physics of Solids, P.J.W. MOLL, Laboratory for Solid State Physics, ETH Zurich, Switzerland, L. BAWDEN, J.M. RILEY, University of St Andrews, NABHANISHI NANDI, HELGE ROSNER, M.P. SCHMIDT, F. ARNOLD, E. HASSINGER, Max Planck Institute for Chemical Physics of Solids, T.K. KIM, M. HOESCH, Diamond Light Source, A.P. MACKENZIE, Max Planck Institute for Chemical Physics of Solids, P.D.C. KING, University of St Andrews — The delafossite structural series of oxides has recently attracted considerable attention because of its varied properties and unusual transport properties of the compounds in the series. Here we consider the Pt-based $d_1$ delafossite oxide PtCoO$_2$, the most conductive oxide known$^1$. From angle-resolved photoemission and density-functional theory, we show that the underlying Fermi surface is a single cylinder of nearly hexagonal cross-section, with very weak dispersion along $k_y$. Despite being predominantly composed of $d$-orbital character, the conduction band is remarkably steep, with an average effective mass of only 1.14$m_e$. Moreover, the sharp spectral features observed in photoemission remain well-defined with little additional broadening for over 500 meV below $E_F$, pointing to suppressed electron-electron scattering. Together, our findings establish PtCoO$_2$ as a model nearly-free electron system and an ideal testbed for elucidating the ultra-high conductivity in delafossite oxides. [1] Kushwaha P. et al., Sci. Adv. 1, 9 (2015)

10:24AM A19.00013 Theory for the Spin State and Spectroscopic Modes of Multiferroic CaBaCo$_4$O$_7$, RANDY FISHMAN, Oak Ridge National Laboratory, SANDOR BORDACS, ISTVAN KEZMARKI, VILMOS KOCSIS, Budapest University of Technology and Economics, URMAS NAGEL, TOOMAS ROOM, National Institute of Chemical Physics Department, Y. TAKAHASHI, Y. YAMAGATA, Y. TAGUCHI, Y. TAKAHASHI, RIKEN Center for Emergent Matter Science — With alternating Kagome and triangular lattices, the type I multiferroic CaBaCo$_4$O$_7$ is highly frustrated. Magnetic frustration produces a non-collinear, ferrimagnetic spin state with a net magnetic moment of about 1 $\mu_B$ along the $b$ axis below 60 K. Based on the the field dependence of the three observed spectroscopic modes between 0.8 and 2.7 THz and on the field dependence of the magnetization up to 14 T, we construct a microscopic model for this compound. Using the symmetry of the crystal, the model is constructed in terms of eight independent nearest-neighbor exchange interactions as well as both in-plane and easy-axis anisotropies. With three observed Co species (spins 1.45, 1.0, and 1.2), the magnetic unit cell contains 16 spins. Our results indicate that the easy-plane and hexagonal anisotropy in the triangular layers is far larger than the anisotropy in the kagome layers. The observed spin-induced polarization along the $c$ axis is produced by magnetostriiction. We also predict other spin-wave modes outside the window of the spectroscopic measurements.

$^1$Research Sponsored by the Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division
10:36AM A19.00014 Investigation of the magnetic properties in double perovskite R$_2$CoMnO$_6$ single crystals (R=rare earth: La to Lu)\textsuperscript{1}, M. K. KIM, J. Y. MOON, H. Y. CHOI, S. H. OH, N. LEE, Y. J. CHOI, Yonsei Univ, LABORATORY FOR INNOVATIVE FUNCTIONAL MATERIALS TEAM — We have successfully synthesized the series of the double-perovskite R$_2$CoMnO$_6$ (R=rare earth; La to Lu) single crystals and have investigated their magnetic properties. The ferromagnetic order of Co$^{3+}$/Mn$^{4+}$ spins emerges mainly along the c axis. Upon decreasing the size of rare earth ion, the magnetic transition temperature decreases linearly from 204 K for La$_2$CoMnO$_6$ to 48 K for Lu$_2$CoMnO$_6$, along with the enhancement of monoclinic distortion. The temperature and magnetic-field dependences of magnetization reveal the various magnetic characteristics such as the metamagnetic transition in R=Eu, the isotropic nature of rare earth moment in R=Gd, and the reversal of magnetic anisotropy in R=Tb and Dy. Our results offer comprehensive information for understanding the roles of mixed-valent magnetic ions and rare earth magnetic moments on the magnetic properties.

\textsuperscript{1}R2CoMnO6 single crystals, double-perovskite, magnetic anisotropy, rare earth

10:48AM A19.00015 Enhanced magnetic coercivity and maximum energy product in double-perovskite Y$_2$CoMnO$_6$ single crystals \textsuperscript{1}, HWAN YOUNG CHOI, S.H. OH, J.Y. MOON, M.K. KIM, D.G. OH, N. LEE, Y.J. CHOI, Yonsei university — We have investigated the influence of different annealing conditions on the magnetic properties on the single crystals of double-perovskite Y$_2$CoMnO$_6$. The ferromagnetic moment along the c-axis with the large magnetic coercivity and high squareness ratio was observed. Particularly, in the quenched specimen, the magnetic functionality has been greatly improved compared to that of the as-grown crystal. The magnetic coercivity and maximum energy product have been increased by $\sim$120\% and $\sim$50\%, respectively, by comprising substantial disorders and defects. Our result renders an efficient route to improve the magnetic functionality in mixed-valent magnets.

Monday, March 14, 2016 8:00AM - 10:36AM - Session A20 GMAG DMP FIAP: Spin Superfluidity and Dzyaloshinskii-Moriya Interaction 319 - Dario Arena, University of Southern Florida

8:00AM A20.00001 Spin superfluidity and long-range transport in thin-film ferromagnets \textsuperscript{1}, HANS SKARSVÅG, CECILIA HOLMQVIST, ARNE BRATAAS, Norwegian University of Science and Technology (NTNU) — In ferromagnets, magnons may condense into a single quantum state. Analogous to superconductors, this quantum state may support transport without dissipation. Recent works suggest that longitudinal spin transport through a thin-film ferromagnet is an example of spin superfluidity. Although intriguing, this tantalizing concept ignores long-range dipole interactions; here, we demonstrate that such interactions dramatically affect spin transport in single-film ferromagnets. “Spin superfluidity” only exists at length scales (a few hundred nanometers in yttrium iron garnet) somewhat larger than the exchange length. Over longer distances, dipolar interactions destroy spin superfluidity. Nevertheless, we predict the re-emergence of spin superfluidity in tri-layer ferromagnet–normal metal–ferromagnet films that are $\sim$ 1 $\mu$m in size. Such systems also exhibit other types of long-range spin transport in samples that are several micrometers in size.

\textsuperscript{1}H. Skarsvåg, C. Holmqvist and A. Brataas, arXiv:1506.06029

8:12AM A20.00002 Magnetization dynamics in exchange coupled antiferromagnet spin superfluids\textsuperscript{1}, YIZHOU LIU, Department of Electrical and Computer Engineering, Univ of California - Riverside, YAFIS BARLAS, Department of Physics and Astronomy, Univ of California - Riverside, GEN YIN, Department of Electrical and Computer Engineering, Univ of California - Riverside, JIA&DONG ZANG, Department of Physics and Material Science Program, University of New Hampshire, ROGER LAKE, Department of Electrical and Computer Engineering, Univ of California - Riverside — Antiferromagnets (AFMs) are commonly used as the exchange bias layer in magnetic recording and spintronic devices. Recently, several studies on the spin transfer torque and spin pumping in AFMs reveal much more interesting physics in AFMs. Properties of AFMs such as the ultrafast switching within picoseconds and spin superfluidity demonstrate the potential to build AFM based spintronic devices. Here, we study the magnetization dynamics in an exchange coupled AFM systems. Beginning from the Landau-Lifshitz-Gilbert equation, we derive a Josephson-like equation for the exchange coupled system. We investigate the detailed magnetization dynamics by employing spin injection and spin pumping theory. We also propose a geometry that could be used to measure this magnetization dynamics.

\textsuperscript{1}This work was supported as part of the Spins and Heat in Nanoscale Electronic Systems (SHINES) an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award SC0012670.

8:24AM A20.00003 Superfluidity of magnons in ferromagnetic films, CHEN SUN, Texas A&M University, THOMAS NATTERMANN, University of Cologne, VALÉRY POKROVSKÝ, Texas A&M University, Landau Institute for Theoretical Physics — The magnon Bose-Einstein condensation in Yttrium Iron Garnet films at room temperature was discovered by the Mnster experimental group (S.O. Demokritov) in 2006. Since the magnon condensate is coherent the natural question is whether the condensate is superfluid. Though the normal magnon density exceeds the condensate density in about 100 times, the velocity of the superfluid part is by 5-7 decimal orders larger than that of the normal part at the same field gradients. Thus, the spin current is dominated by the condensate, i.e. superfluid. A deeper obstacle is that the phase trapping is inconsistent with the free motion whose phase linearly depends on coordinate. The superfluidity can start only after submission of a finite (threshold) energy to the condensate by an external source. At energy close to threshold, the phase on long intervals of length remains close to the trapped values and changes by $\pi$ on a comparatively short intervals (phase solitons). The superfluid velocity remains almost zero between solitons and acquires finite value inside solitons. At large energy the superfluidity of magnons becomes close to a uniform flow.

8:36AM A20.00004 Two-Fluid Theory for Spin Superfluidity in Magnetic Insulators, BENEDETTA FLEBUS, Univ of Utrecht, SCOTT BENDER, YAROSLAV TSERKOVNYAK, UCLA, REMBERT DUINE, Univ of Utrecht, UU TEAM, UCLA TEAM — We investigate coupled spin and heat transport in easy-plane magnetic insulators. These materials display a continuous phase transition between normal and condensate states that is controlled by an external magnetic field. Using hydrodynamic equations supplemented by Gross-Pitaevski phenomenology and magnetoelectric circuit theory, we derive a two-fluid model to describe the dynamics of thermal and condensed magnons, and the appropriate boundary conditions in a hybrid normal-metal—magnetic-insulator—normal-metal heterostructure. We discuss how the emergent spin superfluidity can be experimentally probed via a spin Seebeck effect measurement.
8:48AM A20.00005 Magneto-optical Phase Transition in a Nanostructured Co/Pd Thin Film1. CHIDUBEM NWOKOYE, LAWRENCE BENNETT, EDWARD DELLA TORRE, ABID SIDDIQUE, MING ZHANG, MICHAEL WAGNER. Institute for Magnetic Research, Department of Electrical and Computer Engineering, The George Washington University, Washington, DC 20052, USA, FRANK NARDUCCI, Naval Air Systems Command, Avionics, Sensors and E*Warfare Department, Patuxent River, MD 20670, USA — Interest in the study of magnetism in nanostructures at low temperatures is growing. We report work that extends the magnetics experiments in [1] that studied Bose-Einstein Condensation (BEC) of magnons in confined nanostructures. We report experimental investigation of the magneto-optical properties, influenced by photon-magnon interactions, of a Co/Pd thin film below and above the magnon BEC temperature. Comparison of results from SQUID and MOKE experiments revealed a phase transition temperature in both magnetic and magneto-optical properties of the material that is attributed to the magnon BEC. Recent research in magnonics has provided a realization scheme for developing magnon BEC qubit gates for a quantum computing processor [2]. Future research work will explore this technology and find ways to apply quantum computing to address some computational challenges in communication systems. [1] Bennett L. H. and Della Torre, E. (2014) J. Mod. Phys. 5, 693. [2] Andrianov S. N. and Moiseev, S. A. (2014) Phys. Rev. A 90,042303.


9:12AM A20.00007 Extinction of phase transition and spin transport on diluted quantum two-dimensional antiferromagnet in Bose-Einstein condensation1. LEONARDO DOS SANTOS LIMA, Departamento de Fisica e Matematica, Centro Federal de Educao Tecnolgica de Minas Gerais — We study the two-dimensional Heisenberg antiferromagnetic model with ion single anisotropy in the square lattice in the presence of nonmagnetic impurities at \( T = 0 \) using the SU(3) Schwinger boson theory. In particular, we discuss the influence of site disorder on the quantum phase transition of this model at \( D_2 \), that separates the Néel phase, \( D < D_c \), which is gapless, from the disordered phase, gapped phase, \( D > D_c \). We find that the long-range order in \( D < D_c \) for the model without impurities is destroyed for a concentration of nonmagnetic impurities \( x \approx 0.15 \). We have studied also the spin transport of this model. In particular we discuss the influence of site disorder on the spin conductivity of the model and the influence of quantum phase transition on it. We find a large influence of the site dilution at the ac conductivity or continuum conductivity, and on the spin stiffness \( D_S \) that generates information about the dc conductivity. The point of extinction of \( D_c \) without does not generate any influence on the spin conductivity.

9:24AM A20.00008 Resonant x-ray magnetic diffraction of \( q = 0 \) antiferromagnetic order in \( \text{Cd}_3\text{Os}_2\text{O}_7 \) under high pressure. YEJUN FENG, Argonne National Lab, YISHU WANG, California Institute of Technology, A, PALMER, The University of Chicago, J.-G. YAN, M. MANDRUS, Univ. Tennessee and Oak Ridge National Lab, J.W. KIM, Argonne National Lab, T. F. RUSSELL, California Institute of Technology — The pyrochlore structured \( \text{Cd}_3\text{Os}_2\text{O}_7 \) manifests a continuous metal-insulator transition at ambient pressure. Associated with the rise of the insulating phase is the formation of an all-in/all-out type of spin arrangement for Os ions on each tetrahedron unit, resulting in antiferromagnetic order with a \( q = 0 \) wave vector. The nature of the insulating phase is not understood due to the interplay of different degrees of freedom with almost degenerate energy scales characteristic of 5d transition metal compounds. Here we probe directly the pressure evolution of the antiferromagnetism using resonant \( \text{x-ray} \) magnetic diffraction techniques. We track the antiferromagnetic state to 18 GPa at 4 K, gradually suppressing the strength of the magnetic order and locating the boundary of an apparent continuous quantum phase transition.

9:36AM A20.00009 Very large Rashba coupling by a staggered crystall field in the inversion-symmetric \( \text{BaNiS}_2 \) semi-metal1. ANDREA GAUZZI, DAVID SANTOS-COTTON, MICHELE CASULA, IMPMC-Sorbonne Universits, GABRIEL LANTZ, LPS-Universit Paris Sud, YANNICK KLEIN, IMPMC-Sorbonne Universits, EVANGELOS PAPALAZAROU, MARINO MARSI, LPS-Universit Paris Sud — By means of a single-crystal angular resolved photoemission spectroscopy study combined with first principles calculations, we give evidence of a giant Rashba coupling \( \alpha_R \approx 0.25 \text{ eV} \) leading to an energy splitting as large as \( \Delta_e \approx 150 \text{ meV} \) in a novel situation of an inversion-symmetric system - the \( \text{BaNiS}_2 \) semi-metal - composed of comparatively light elements. This finding is explained by a huge staggered crystal field \( 1.4 \text{ V/Å} \) associated with a peculiar non-symmetric square-pyramidal structure, which produces a local inversion asymmetry at the Ni site. We show that this very effective mechanism of Rashba coupling enables large changes of the electronic structure of solids without using either heavy elements or external fields.

1Partially funded by the Emergence program of the UPMC-Sorbonne Universities.

9:48AM A20.00010 Low-temperature magneto-thermal conductivity of the helimagnet \( \text{Cu}_4\text{OSe}_4 \)1. NARAYAN PRASAI, SUNXIANG HUANG, JOSHUA L. COHN, University of Miami, BENJAMIN TRUMP, GUY G. MARCUS, TYREL M. MQUESTEN, CHIA LING CHEN, Johns Hopkins University — We report measurements of thermal conductivity \( \kappa \) in the range of \( 0.6 \text{ K} \le T \le 200 \text{ K} \) for single crystals of the helimagnetic insulator \( \text{Cu}_4\text{OSe}_4 \). A maximum in \( \kappa \) near \( T \approx 8 \text{ K} \) with \( \kappa_{\text{max}} \approx 300 \text{ W/mK} \) implies a very high lattice quality for an oxide. The magneto-thermal conductivity at \( T \le 10 \text{ K} \) and influence of spin-reorientation transitions associated with low- \( T \) magnetic phases will be discussed for different orientations of the magnetic field relative to the crystallographic and heat flow directions.

1This material is based upon work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under grants No. DEFG02-12ER46888 (Univ. Miami) and No. DEFG02-08ER46544 (Johns Hopkins Univ.)
10:00AM A20.00011 Anisotropic RKKY and Dzyaloshinsky-Moriya interactions in a two-dimensional spin-polarized electron gas with Rashba and Dresselhaus spin-orbit coupling. MOHAMMAD MAHDI VALIZADEH, SASHI SATPATHY, University of Missouri - Columbia — Chiral order in magnetic structures is currently an area of considerable interest and leads to such structures as the skyrmion lattice. The chiral structures originate from the Dzyaloshinsky-Moriya (DM) interactions caused by broken symmetry and the presence of the spin-orbit interaction. We study the the indirect exchange interaction between two localized magnetic moments mediated by a spin-polarized 2DEG in the presence of both Rashba and Dresselhaus spin-orbit coupling. We find anisotropic RKKY and DM interactions, e.g., of the form $J_1(S_1zS_2z + S_1yS_2y) + J_2S_1zS_2z$, in the former case, in the presence of a non-zero spin polarization. The magnitude of the vector and tensor DM interactions are estimated and compared to recent experiments on magnetic thin films.

10:12AM A20.00012 Minimal Ingredients for Orbital Texture Switches at Dirac Points in Strong Spin-Orbit Coupled Materials. JUSTIN WAUGH, University of Colorado at Boulder, THOMAS NUMMY, University of Colorado at Boulder, STEPHEN PARHAM, DANIEL DESSAU, University of Colorado at Boulder — Recent angle resolved photoemission spectroscopy measurements on strong spin-orbit coupled materials have shown an in-plane orbital texture switch at their respective Dirac points. This feature has also been demonstrated in a few materials ($Bi_2Se_3$, $Bi_2Te_3$, and $BiTe$) even though such observations are not always straightforward. Here we present a minimal orbital-driven tight binding model to calculate the electron wave-function in a two-dimensional crystal lattice. We show that the orbital components of the wave-function demonstrate an orbital-texture switch in addition to the usual spin switch seen in spin polarized bands. This orbital texture switch is determined by the existence of three main properties: local or global inversion symmetry breaking, strong spin-orbit coupling, and non-local physics (the electrons are on a lattice). Using our model we demonstrate that the orbital texture switch is ubiquitous and to be expected in many real systems. The orbital hybridization of the bands is the key aspect for understanding the unique wave function properties of these materials, and this minimal model helps to establish the quantum perturbations that drive these hybridizations.

10:24AM A20.00013 A mechanism for orbital angular momentum and giant spin-splitting in solids and nanostructures. SEHOON OH, HYOUNG JOON CHOI, Department of Physics, IPAP, and Center for Computational Studies of Advanced Electronic Material Properties, Yonsei University, Seoul 03722, Korea — Giant spin-splitting (GSS) of electronic bands, which is several orders of magnitude greater than Rashba model, has been observed in various systems including noble-metal surfaces, thin film of transition-metal dichalcogenides, often accompanied by the orbital angular momentum (OAM). Here, we study structural and orbital conditions for emergence of a GSS by using tight-binding and first-principles calculations. We find that broken mirror symmetry of local atomic structure around an atom can produce non-zero OAM at the atom. This OAM results in a GSS if the atom is a high-atomic number element. We demonstrate these structural and orbital conditions in the cases of simple atomic chains, WS$_2$ monolayer, Au(111) surface, and bulk HgTe. Based on this mechanism of the spin-splitting, we suggest methods to control the GSS, which can be used in applications such as spintronic devices. This work was supported by NRF of KOREA (Grant No. 2011-0018306) and KISTI supercomputing center (Project No. KSC-2015-C3-039).

Monday, March 14, 2016 8:00AM - 11:00AM — Session A21 GMAG DMP: Magnetic Layers 320 - Mark Meisel, University of Florida

8:00AM A21.00001 Specific Heat Studies of a 2D S = Heisenberg Antiferromagnet. CHRISTOPHER LANDEE, FAN XIAO, Department of Physics, Clark University, CLARK WILKINSON, Department of Chemistry, Clark University, YAN LIU, Department of Physics, University of Colorado at Boulder. — We report specific heat measurements of a 2D S = 1/2 antiferromagnet (2D QHAF), $\text{Cu}(pz)_2(2$-$\text{OHpy})_2(ClO_4)_2$, where $pz$ = pyrazine and $2$-$\text{OHpy} = 2$-pyridone. The copper atoms and pyrazine molecules form distorted rectangular layers of pyrazine-bridged copper(II) ions with the pyridine molecules normal to the layers, providing exceptional spacing between layers [1]. The zero-field specific heat of this compound (1.8 - 35 K) is compared to the recent QMC simulations of the specific heat for the 2D QHAF. Under applied field, the temperature dependence of the specific heat varies smoothly, but no field-induced ordering is observed. This behavior differs from the field-induced ordering in the 2D QHAF Cu$_2$(pz)$_2$(ClO$_4$)$_2$ reported previously [2]. [1] V. Selmani, C. P. Landee, M. M. Turnbull, J. L. Wikaira, and F. Xiao. Inorg. Chem. 53, 1399-1401 (2010), doi: 10.1021/ji901075g [2] N. Tsyrulin, F. Xiao, A. P. Schneidewind, M. Rönnow, J. Gavilano, C. P. Landee, M. M. Turnbull, M. Kenzelmann. Phys. Rev. B, 81, 134409 (2010), doi: 10.1103/PhysRevB.81.134409.

8:12AM A21.00002 Thickness- and magnetic-field-driven suppression of antiferromagnetism in V$_3$S$_8$ single crystals. WILL HARDY, Applied Physics Graduate Program, Smalley-Curl Institute, Rice University, JIANGTAN YUAN, Department of Materials Science and NanoEngineering, Rice University, PANPAN ZHOU, Department of Physics and Astronomy, Rice University, JUN LOU, Department of Materials Science and NanoEngineering, Rice University, DOUGLAS NATELSON, Department of Physics and Astronomy, Rice University — The search for novel materials approaching the 2d limit can be expanded beyond the transition metal dichalcogenides (TMDs) to related compounds, widening the range of available physical phenomena and tuning parameters. V$_3$S$_8$, a metal with an antiferromagnetic (AFM) ground state below $\approx 32$ K, displays a prominent spin-flop transition at $\approx 4.2$ T. Here we study the AFM state in thin CVD-grown single crystals of V$_3$S$_8$, focusing on temperatures close to $T_{\text{Neff}}$, where the exact transition temperature depends on the crystal thickness. Magnetoresponse (MR) measurements performed just below $T_{\text{Neff}}$ reveal magnetic hysteresis, likely a result of a first-order magnetic field-driven breakdown of the AFM state. In thin crystals, on the order of 10 nm thick, monotonic MR measurements suggest that antiferromagnetism is suppressed as the thickness nears the 2d limit. This work demonstrates the possibility of growing single crystals of a relatively complicated magnetic system with thicknesses approaching one unit cell, thereby allowing the tuning of magnetic properties by a field-driven phase transition.

8:24AM A21.00003 Field induced phase transition in layered honeycomb spin system $\alpha$-RuCl$_3$ studied by thermal conductivity. IAN LEAHY, ALEX BORNSTEIN, University of Colorado, Boulder, CO 80309, KWANG-YONG CHOI, Chung-Ang University, Seoul, South Korea, MINHYEON LEE, University of Colorado, Boulder, CO 80309 — $\alpha$-RuCl$_3$, a quasi two-dimensional honeycomb lattice is known to be a candidate material to realize the Heisenberg-Kitaev spin model of a highly anisotropic bond-dependent exchange interaction. We investigate in-plane thermal conductivity ($\kappa$) as a function of temperature ($T$) and in-plane applied field ($H$). At $H = 0$, the onset of a strong increase in $\kappa$ marks the spontaneous long range ordering temperature, $T_c = 6.5K$, corresponding to zigzag antiferromagnetic ordering. A broad peak appearing below $T_c$ in $\kappa$ was used to study the magnetic interaction between spins in the honeycomb lattice. By fitting a model to the experimental data, $\kappa(T)$, we find the magnetic interactions between spins in the honeycomb lattice to be stronger than in the triangular lattice. The results presented here show that $\kappa(T)$ is highly sensitive to changes in the magnetic interactions between spins in the honeycomb lattice and can be used to study the magnetic interactions in $\alpha$-RuCl$_3$ in a field-driven phase transition.

1Work at the University of Colorado was supported by the US DOE Basic Energy Sciences under Award No. DE-SC0006888
Fingerprints of the field-induced Berezinskii-Kosterlitz-Thouless transition in quasi-two-dimensional quantum magnets

8:36AM A21.00004 Fingerprint of the field-induced Berezinskii-Kosterlitz-Thouless transition in quasi-two-dimensional quantum magnets

ALŽBETA ORENDÁČOVÁ, P.J. Šafárik University, Košice — The two-dimensional (2D) easy-plane (XY) model provides a prototypical description of 2D systems exhibiting topological excitations, which drive the Berezinskii-Kosterlitz-Thouless (BKT) transition that occurs in 2D superfluids, electron plasmas, Josephson junction arrays, ultracold atomic 2D Bose gasses, etc. The excitations in the 2D XY model are spin waves and vortices. In the BKT scenario, at low temperatures, all vortices (V) and antivortices (AV) are bound to V-AV pairs, and spin waves dominate in this quasi-long-range-ordered phase with an infinite correlation length, ξ, and an algebraic decay of correlations. At a critical temperature, T_{BKT}, the V-AV pairs start to unbind, driving the transition to a free vortex phase above T_{BKT}, characterized by an exponential divergence of ξ. Vortices remain stable also in quantum 2D anisotropic Heisenberg systems with a very weak XY anisotropy. The BKT scenario appears even in 2D isotropic Heisenberg magnets due to frustration or an external magnetic field. I will focus on quasi-2D spin 1/2 Heisenberg antiferromagnets with extremely weak spin anisotropy. These highly anisotropic layered Cu(II) organo-metallic insulators with relatively low saturation fields, about 6 T, enabled a comprehensive study in a wide range of magnetic fields and temperatures. A response of all compounds to the application of a magnetic field mimics 2D behavior with fingerprints of a field-induced Berezinskii-Kosterlitz-Thouless phase transition.

1Supported by the Templeton Foundation as part of the Durham Emergence Project.
10:12AM A21.00010 Time-Dependent Behavior in Arrays of Coupled Heisenberg Spin Chains
  , ROBERT KONIK, Brookhaven Natl Lab, ANDREW JAMES, London Centre for Nanoscience, J-S CAUX, Universiteit van Amsterdam — We employ matrix product state methods combined with data from exact solvability to study infinite arrays of coupled XXZ Heisenberg spin chains of finite length under a time dependent perturbation. We present results for both sudden changes (quantum quenches) as well as gradual changes in the interchain coupling. We benchmark our results and methods against perturbation theory as well as available equilibrium results on two dimensional Heisenberg models. We discuss these results in light of recent pump-probe resonant inelastic x-ray scattering experiments on the iridate compound Sr$_2$IrO$_4$.

10:24AM A21.00011 Excitations in the quantum paramagnetic phase of the quasi-one-dimensional Ising magnet CoNb$_2$O$_6$ in a transverse field: Geometric frustration and quantum renormalization effects1, IVELILSE CABRERA, Clarendon Laboratory, University of Oxford/NIST Center for Neutron Research , J. D. THOMPSON, R. COLDEA, D. PRABHAKARAN, Clarendon Laboratory, University of Oxford, R. I. BEWLEY, T. GUIDI, ISIS Facility, Rutherford Appleton Laboratory, J. A. RODRIGUEZ-RIVERA, NIST Center for Neutron Research, C. STOCK, NIST Center for Neutron Research/The University of Edinburgh — We report extensive single-crystal inelastic neutron scattering measurements of the magnetic excitations in the quasi 1D Ising ferromagnet CoNb$_2$O$_6$ in the quantum paramagnetic phase to characterize the effects of the finite interchain couplings. In this phase, we observe that excitations have a sharp, resolution-limited line shape at low energies and over most of the dispersion bandwidth, as expected for spin-flip quasiparticles. We map the full bandwidth along the strongly dispersive chain direction and resolve clear modifications of the dispersions in the plane normal to the chains, characteristic of frustrated interchain couplings in an antiferromagnetic Ising dimer triangular lattice. The dispersions can be well parametrized using a linear spin-wave model that includes interchain couplings and further neighbor exchanges. The observed dispersion bandwidth along the chain direction is smaller than that predicted by a linear spin-wave model using exchange values determined at zero field. We attribute this effect to quantum renormalization of the dispersion beyond the spin-wave approximation in fields slightly above the critical field, where quantum fluctuations are still significant.

1We acknowledge support from EPSRC Grant No. EP/H014934/1, the Oxford Clarendon Fund Scholarship and NSERC of Canada.

10:36AM A21.00012 Quantum Acoustic Magnetic Resonance Imaging and Spectroscopy: . . VIOLETA ZAMORANO, V. CELLI, B SHIVARAM, University of Virginia — We present a new modality to characterize single molecule and molecular magnets and propose that it can be used as a powerful spectroscopy and imaging tool. Heisenberg type Hamiltonians representing realistic molecules with appropriate crystal field terms are solved and the magnetic field dependence of the resulting quantum spin energy levels enumerated. The results through thermodynamic identities yield the bulk modulus which is shown to be sensitive to the crystal field parameters at low temperatures. Thus high field low temperature measurements of the sound velocity in molecular and single molecule magnets open the road to a completely new method of understanding such systems.

10:48AM A21.00013 Molecular quantum magnetism with strong spin-orbit coupling in inorganic solid Ba$_3$Yb$_5$Zn$_5$O$_{11}$ — SANG-YOUN PARK, SUNGDAE JI, JAE-HOON PARK, MPPC-CPM, Pohang Univ of Sci & Tech, SEUNGHWAN DO, KWANG-YONG CHOI, Dept. of Physics, Chung-Ang University, DONGJIN JANG, BURKHARD SCHMIDT, MANUEL BRANDO, Max Planck Institute for Chemical Physics of Solids, NICHOLAS BUTCH, NIST Center for Neutron Research — The molecular magnet, assembly of finite number of spins which are isolated from environment, is a model system to study the quantum information process such as the qubit or spintronic devices. In past decades, the molecular magnet has been mostly realized in organic material, however, it has difficulty synthesizing materials or controlling their properties, meanwhile tremendous endeavors to search inorganic molecular magnet are continuing. Here, we propose Ba$_3$Yb$_5$Zn$_5$O$_{11}$ as a candidate of inorganic molecular magnet. This material consists of an alternating 3D-array of small and large tetrahedron containing antiferromagnetically coupled four pseudospin-1/2 Yb ions, and magnetic properties are described by an isolated tetrahedron without long-range magnetic ordering. Inelastic neutron scattering measurement with external magnetic field reveals that extraordinarily huge Dzyaloshinsky-Miura (DM) interaction originating from strong spin-orbit coupling in Yb isospin is the key to explain energy level of tetrahedron in addition to Heisenberg exchange interaction and Zeeman effect. Magnetization measurement shows the Landau-Zener transition between avoided crossing levels caused by DM interaction.

Monday, March 14, 2016 11:15AM - 2:15PM  
Session B5 GMAG DMP: Frustrated Magnetism: Low Dimensional Magnets I 301 - Oleg Starykh, University of Utah

11:15AM B5.00001 Magnetic nanopantograph in the in SrCu$_2$(BO$_3$)$_2$ Shastry-Sutherland lattice , ANDRES SAUL, CINaM/CNRS — Magnetostriction experiments of the frustrated spin dimer compound SrCu$_2$(BO$_3$)$_2$ have shown that its macroscopic physical dimensions change with the applied magnetic field mimicking the complicated structures, with discreet jumps and plateaus, observed in the magnetization. Using Density Functional based methods we find that the driving force behind the magnetoelastic coupling is the Cu-O-Cu superexchange angle which, thanks to the orthogonal Cu$^{2+}$ dimers acting as pantographs, can shrink significantly (0.44%) with minute (0.01%) variations in the lattice parameters. Our calculations show that the consequence is a reduction of the order of ∼10% in the antiferromagnetic intra-dimer exchange integral $J$, sufficient to compensate the elastic energy loss in the deformation. This reduction should impact our reading of existing predictions of the magnetization versus field phase diagram and the effect of hydrostatic pressures on the ground state. Finally, our prediction of the dimer shrinking under applied magnetic field should appear as a modification of the optical Raman active modes compatible with the pantograph effect.

11:51AM B5.00002 Hysteretic magnetoresistance and unconventional anomalous Hall effect in the frustrated magnet TmB$_4$ , SAI SWAROOP SUNKU1, Div of Physics and Applied Physics, Nanyang Technological University, TAI KONG, Ames Laboratory and Dept of Physics and Astronomy, Iowa State University, TOSHIHITSU ITO, National Institute of Advanced Industrial Science and Technology (AIST), PAUL C. CANFIELD, Ames Laboratory and Dept of Physics and Astronomy, Iowa State University, B. SRIRAM SHASTRY, Physics Dept, University of California, Santa Cruz, PINAKI SENGUTPA, CHRISTOS PANAOGOPOULOS, Div of Physics and Applied Physics, Nanyang Technological University — We study TmB$_4$, a frustrated magnet on the Archimedean Shastry-Sutherland lattice, through magnetization and transport experiments. The lack of anisotropy in resistivity shows that TmB$_4$ is an electronically three-dimensional system. The magnetoresistance (MR) is hysteretic at low-temperature even though a corresponding hysteresis in magnetization is absent. The Hall resistivity shows unconventional anomalous Hall effect (AHE) and is linear above saturation despite a large MR. We suggest that both hysteretic MR and AHE arise from the formation of complex non-coplanar structures at magnetic domain walls.

1Current address: Department of Applied Physics and Applied Mathematics, Columbia University
12:03PM B5.00003 Spin-lattice coupling of $R_{1-x}Lu_B$_4 revealing anomalous weak ferromagnetism ($R$ = Sm, Gd, Tb, Dy, Ho) , B.Y. KANG, School of Materials Science and Engineering, Gwangju Institute of Science and Technology (GIST), Korea, SEONGSU LEE, Korea Atomic Energy Research Institute, Korea, SANG-YUN HWANG, SUNGDAEI JI, Max Planck POSTECH/Korea Research Institute, Korea, M.S. SONG, B.K. CHO, Gwangju Institute of Science and Technology (GIST), Korea — $R_B$ ($R$ = rare-earth elements) compounds exhibits antiferromagnetic ordering at low temperature and are classified as the Shashy-Sutherland lattice, which is a geometrically frustrated system. In previous study, it was reported that Y substitution in TbB$_4$ single crystals causes anomalous WF (weak ferromagnetism) even though Y$^{3+}$ is non-magnetic. The disturbance of a delicate equilibrium in a frustrated system can lead to new electronic and magnetic states. In this study, single crystals of $R_{1-x}Lu_B$_4 ($R$ = Sm, Gd, Tb, Dy, Ho), $(x=0, 0.8)$ were synthesized. WF is also observed. TbB$_4$ went through orthorhombic distortion below Neél temperature. To investigate the existence of orthorhombic distortion in TbLu$_3$B$_4$ $(x=0.1, 0.35)$, high resolution single crystal x-ray diffraction was performed at 5 K. It was confirmed that the distortion vanished with Lu substitution. Interestingly, lattice constant $a$ increases with decreasing temperature below the $T_C$. The strong correlation between spin-lattice coupling and WF will be discussed in detail.

12:15PM B5.00004 Neutron Diffraction on NaNi$_2$BiO$_6$: Complex Interactions on a Honeycomb Lattice$^1$, ALLEN SCHEIE, Johns Hopkins University, KATE ROSS, Colorado State University, ELIZABETH SEIBEL, Princeton University, JOSE RODRIGUEZ-RIVERA, NIST, COLLIN BROHOLM, Johns Hopkins University, ROBERT CAVA, Princeton University, INSTITUTE FOR QUANTUM MATTER COLLABORATION — Magnetic crystals with a honeycomb lattice can have a very high degree of frustration when next-nearest neighbor interactions are strong. Such complex interactions can lead to Kitaev model physics, including a proposed spin liquid phase. Using neutron scattering, we studied the magnetic properties of a new spin-1/2 honeycomb compound, NaNi$_2$BiO$_6$, which was known to have heat capacity peaks indicative of a phase transition at 5 K. The magnetic order indicates beyond nearest-neighbor exchange as well as significant inter-plane interaction, which allows for a study of rich and complex structure. In this talk I report the magnetic structure of the compound as found with neutron powder diffraction, and discuss the exchanges necessary to lead to such a complex order.

$^1$The work at IQM was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering, under Grant No. DEFG02-08ER46544.

12:27PM B5.00005 Field-induced dynamical properties of the XXZ model on a honeycomb lattice$^1$, PAVEL MAKSIMOV, ALEXANDER CHERNYSHEV, Univ of California - Irvine — We present a comprehensive 1/S study of the field-induced dynamical properties of the nearest-neighbor XXZ antiferromagnet on a honeycomb lattice using the formalism of the nonlinear spin-wave theory developed for this model. External magnetic field controls spin frustration in the system and induces non-collinearity of the spin structure, which is essential for the two-magnon decay processes. Our results include an intriguing field-evolution of the regions of the Brillouin zone where decays of spin excitations are prominent, a thorough analysis of the singularities in the magnon spectra due to coupling to the two-magnon continuum, the asymptotic behavior of the decay rates near high-symmetry points, and inelastic neutron-scattering spin-spin structure factor obtained in the leading 1/S order.

$^1$Supported by DOE

12:39PM B5.00006 Featureless Quantum Insulator on the Honeycomb Lattice$^1$, SHENCAN JIANG, Boston College, HYUNYONG LEE, PANJIN KIM, JUNG HOON HAN, Sungkyunkwan University, YING RAN, Boston College — We construct fully symmetric, gapped states without topological order on a spin-1/2’s honeycomb lattice at half-filling in terms of projected entangled pair states (PEPS) Four distinct classes differing by lattice quantum numbers are found by applying the systematic classification scheme introduced by two of the authors [S. Jiang and Y. Ran, arXiv:1505.03171 (2015)]. Lack of topological degeneracy or other conventional form of symmetry breaking, and the existence of the energy gap in both wave functions are checked by numerical calculation of the entanglement entropy and various correlation functions.

$^1$The Alfred P. Sloan fellowship and National Science Foundation under Grant No. DMR-1151440 and the NRF grant (No. 2013R1A2A1A01006430)

12:51PM B5.00007 Possible spin liquid behavior in Sc$_2$Ga$_4$Cu$_2$O$_7$, A.V. MAHAJAN, R. KUMAR, IIT Bombay, India, P. KHUNTIA, Ames Lab, Iowa State Univ, USA, D. SHEPTYAKOV, PSI, Switzerland, P.G. FREEMAN, H.M. RONNOW, EPFL, Switzerland, B. KOTESWARARAO, IIT Bombay, India, M. BAENITZ, MPICPFS, Germany, Y. FURUKAWA, Ames Lab, Iowa State Univ, USA, M. JEONG, EPFL, Switzerland — The title compound crystallizes in a hexagonal structure (space group P63/mmc) containing edge-shared triangular planes as also triangular bi-planes. Our work establishes that the single triangular layers mainly have $S = 0$ Ga$^{3+}$ (85% Ga, 15% Cu), while the bi-layers contain 43% Cu$^{2+}$ and 57% Ga$^{3+}$, as far as the cations are concerned. Our $\chi(T)$ data shows no spin-freezing or magnetic long-range order (LRO) down to 1.8 K. We infer an effective moment of 1.7 $\mu_B$ and a $\theta_{SW}$ of about -50 K, suggesting AF interactions. In our specific heat data, no anomalies were found down to 0.35 K, in the field range 0-140 kOe. The magnetic specific heat has a nearly $T^2$ power-law behavior at low- $T$ (for $H > 90$ kOe). The $^{71}$Ga nuclear magnetic resonance (NMR) shift $K(T)$ displays a broad maximum at $T ~ 50$ K. The $^{71}$Ga spin lattice relaxation rate 1/$T_1$ displays a $T^{3/2}$ power-law increase from 0.1 K to 2 K, then remains nearly unchanged up to 10 K, and increases thereafter. Once again, down to 100 mK there is no indication of LRO which is usually manifested as an anomaly in the $T$-dependence of $K$ and 1/$T_1$. Our data suggest the formation of a quantum spin liquid in the $S = 1/2$ system Sc$_2$Ga$_4$Cu$_2$O$_7$.

1:03PM B5.00008 Phase diagram of weakly coupled Heisenberg spin chains subject to a uniform Dzyaloshinskii-Moriya interaction$^1$, WEN JIN, OLEG STARYKH, University of Utah — Motivated by recent experiments on spin chain materials $K_x$Cu$_2$SO$_4Cl$_2$ and $K_x$Cu$_2$SO$_4Br$_2$, we theoretically investigate the problem of weakly coupled spin chains (chain exchange $J$) subject to a staggered between chains, but uniform within a given chain, Dzyaloshinskii-Moriya interaction (DMI) of magnitude $D$. In the experimentally relevant limit $J' < D < J$ of strong DMI the spins on the neighboring chains are forced to rotate in opposite directions, effectively resulting in a cancelation of the interchain interaction between components of spins in the plane normal to the vector D. This has the effect of promoting two-dimensional collinear spin density wave (SDW) state, which preserves U(1) symmetry of rotations about the D-axis. We also investigate response of this interesting system to an external magnetic field $h$ and obtain the $h-D$ phase diagrams for the two important configurations, $h \parallel D$ and $h \perp D$. The transitions between various SDW-like phases are found to be of either a commensurate-incommensurate or a spin-flop kind.

$^1$Supported by NSF DMR-1507054
We have demonstrated that the propagation of magnons with large momentum is nonreciprocal in a noncentrosymmetric ferromagnet. In noncentrosymmetric materials, the relativistic effect extensively modifies the energy band of magnons as well as that of electrons. With use of microfabricated microwave antennae, we have demonstrated that the propagation of magnons with large momentum is nonreciprocal in a noncentrosymmetric ferromagnet. This result may pave a new path to designing magnonic device based on the relativistic band engineering.

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Supported by the ARC Centre for Engineered Quantum Systems.

**1:15PM B5.00009 Spin Liquid in the Triangular Lattice Heisenberg Model**: JAN MCCULLOCH, SEYED SAADATMAND, University of Queensland — We report the results of a large-scale numerical study of the spin-1/2 Heisenberg model on the triangular lattice, with nearest- and next-nearest neighbor interactions. Using SU(2)-invariant iDMRG for infinite cylinders, we focus on the YC12 structure (with a circumference of 12 sites), and obtain 4 candidate groundstates, corresponding to even/odd spinon sectors, each with linear and projective representations of the cylinder geometry. The momentum-resolved entanglement spectrum reveals the structure of the low-lying spinon excitations. Contrary to some recent works, we find no evidence for chiral symmetry breaking.

**1:27PM B5.00010 Anisotropic thermal conductivity of proton fluctuation-induced quantum spin liquid \( \kappa_{\text{H}_2\text{-Cat-EDT-TTF}} \)**, MASAAKI SHIMOZAWA, YOSHITAKE SUZUKI, KAORI SUGII, AKIRA UEDA, SHOGO YAMADA, YUSUKE IMAI, KIYOSHI TORIZUKA, YOSHIYA UWATOKO, HATSUMI MORI, MINORU YAMASHITA, ISSP, University of Tokyo — We report the thermal transport properties of a quantum spin liquid candidate \( \kappa_{\text{H}_2\text{-Cat-EDT-TTF}} \) (H-CAT) with a two-dimensional nearly isotropic triangular lattice. Above 1.0 K, thermal conductivity of H-CAT is substantially smaller than that of a deuterated non-magnetic sample (D-CAT) despite no spin thermal conductivity in D-CAT. In the zero-temperature limit, a finite \( T \)-linear term of the thermal conductivity in H-CAT is clearly observed when the heat current is parallel to c-axis, while it is almost zero when the heat current is parallel to b-axis. These features would be attributed to anisotropic proton fluctuations present in H-CAT.

**1:39PM B5.00011 Theory of triplon dynamics in the quantum magnet BiCuPO_{6}**: YONG BAEK KIM, KYUSUNG HWANG, Department of Physics and Centre for Quantum Materials, University of Toronto, Toronto, Ontario M5S 1A7, Canada — We provide a theory of triplon dynamics in the valence bond solid ground state of the coupled spin-ladders modeled for BiCuPO_{6}. Utilizing the recent neutron scattering experimental data as guides and a theory of interacting triplons via the bond operator formulation, we determine a minimal spin Hamiltonian for this system. It is shown that the splitting of the low energy triplon modes and the peculiar magnetic field dependence of the triplon dispersions can be explained by including substantial Dzyaloshinskii-Moriya and symmetric anisotropic spin interactions. Taking into account the interactions between triplons and the decay of the triplons to the two-triplon continuum via anisotropic spin interactions, we provide a theoretical picture that can be used to understand the main features of the recent neutron scattering experimental data.

**1:51PM B5.00012 Multi-Magnon Bound States in J1-J2 Model on a Triangular Lattice**: RINA TAKASHIMA, Kyoto University, HIROAKI ISHIZUKA, LEON BALENTS, KITP, UCSB — Competing exchange interactions in spin systems often give rise to unusual magnetic behavior, such as spiral orders and nematic orders in spin chains. Also, on classical triangular Heisenberg models, recent studies found skyrmion lattice phases in an applied magnetic field. Motivated by these studies, we investigate the magnetic phase diagram of a quantum J1-J2 XXZ model on a triangular lattice. In order to study the quantum phases close to the saturation field, we calculate the low energy excitation spectrum near the saturation field, and find the instability toward condensation of multi-magnon bound states, namely, multipolar order. A similar behavior is confirmed in the exact diagonalization of finite size clusters. We also discuss the relationship between the obtained quantum phases and the skyrmion lattice phase which is found in the classical counterpart of our model.

**2:03PM B5.00013 The S=1/2 J1-J2 Heisenberg Model on the Triangular Lattice**: TSEZAR SEMAN, Northern Illinois University, Argonne National Laboratory, CHENG-CHIEN CHEN, Argonne National Laboratory, RAJIV SINGH, University of California, Davis, MICHEL VAN VEENENDAAL, Northern Illinois University, Argonne National Laboratory — We study the S=1/2 triangular-lattice Heisenberg model using large-scale exact diagonalization. As a function of the next-nearest-neighbor exchange J2, the model shows different long-range magnetically ordered states and a potential quantum spin liquid phase. We compute the spin gap and static structure factors in different regions of the phase diagram. The spin-wave and two-magnon Raman spectra are also explored accordingly.

Monday, March 14, 2016 11:15AM - 2:03PM

**Session B6 GMAG DMP FIAP: Dzyaloshinskii-Moriya Interaction**

11:15AM B6.00001 Proportionality of the interfacial Dzyaloshinskii-Moriya interaction and the Heisenberg exchange**: HANS NEMBACH, JUSTIN SHAW, National Institute of Standards and Technology, MATHIAS WEILER, Walther-Meissner Institut, EMILIE JU, TOM SILVA, National Institute of Standards and Technology — The Dzyaloshinskii-Moriya interaction (DMI) gives rise to chiral magnetic ordering and a shift of spin-wave frequencies, depending on their propagation direction. We employed Brillouin-Light-Scattering spectroscopy to measure this nonreciprocal frequency shift, which allowed us to directly determine the magnitude of the DMI in a series of Ni_{80}Fe_{20}(t)/Pt thin film bilayers where the thickness t ranged from 1 to 13 nm. It has also been predicted by theory that the DMI is proportional to the Heisenberg exchange for bulk magnetic oxides and metallic spin-glasses. We tested this prediction for our metallic system by independently determining the Heisenberg exchange via fitting the Bloch T^{3/2}-law to the temperature dependence of the magnetization obtained from SQUID magnetometry. We find that the Ni_{80}Fe_{20} thickness dependence of the DMI and the Heisenberg exchange are identical, which is consistent with the notion that both effects share the same underlying physics. This result will lead us to a deeper understanding of the DMI and related spin-orbital effects.

11:27AM B6.00002 Nonreciprocal magnon propagation in a noncentrosymmetric ferromagnet LiFeO_{2}**, YUSUKE IGUCHI, SOICHIRO UEUMURA, KAZUNORI UENO, YOSHINORI ONOSE, Department of Basic Science, University of Tokyo — In noncentrosymmetric materials, the relativistic effect extensively modifies the energy band of magnons as well as that of electrons. With use of microfabricated microwave antennae, we have demonstrated that the propagation of magnons with large momentum is nonreciprocal in a noncentrosymmetric ferromagnet LiFeO_{2}. The nonreciprocity is clearly explained by the effect of asymmetric magnon band originating from the relativistic Dzyaloshinskii-Moriya interaction. This result may pave a new path to designing magnonic device based on the relativistic band engineering.

**Supported by the ARC Centre for Engineered Quantum Systems.**
11:39AM B6.00003 A Dzyaloshinskii-Moriya Anisotropy in nanomagnets with in-plane magnetization[1]. M. CUBUKCU, J. Sampaio, Unite Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Universite Paris-Saclay, Palaiseau, France, A. V. KHVALKOVSKIY, D. APALKOV, Samsung Electronics, Semiconductor RD Center (Grandis), San Jose, USA, V. CROS, N. REYREN, Unite Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Universite Paris-Saclay, Palaiseau, France — The Dzyaloshinskii-Moriya interaction (DMI) is known to be a direct manifestation of spin-orbit coupling in systems with broken inversion symmetry. We present a new anisotropy for in-plane-magnetized nanomagnets which is due to the interfacial DMI. This new anisotropy depends on the shape of the magnet, and is perpendicular to the demagnetization shape anisotropy [1]. The DMI anisotropy term that we introduce here results from the DMI energy reduction due to an out-of-plane tilt of the spins at the edges that are oriented perpendicular to the magnetization. For large enough DMI, the reduction of the DMI and anisotropy energies takes over the demagnetization energy cost when magnetization lies along the minor axis of a structure. Our experimental, numerical and analytical results demonstrate this prediction in magnets of elongated shape for small enough volume (and thus quasi-uniform magnetization). Our results also provide the first experimental evidence of the interfacial DMI-induced tilt of the spins at the borders. [1] M. Cubukcu et al., arXiv:1508.02961 (2015).

11:51AM B6.00004 First principles study of the effective Hamiltonian for Dzyaloshinskii-Moriya interaction, TAKASHI CORETSUNE, TORU KIKUCHI, RYOTARO ARITA, GEN TATARA, RIKEN CEMS — We propose a new formalism to calculate the Dzyaloshinskii-Moriya (DM) interaction by deriving an effective Hamiltonian for a spin gauge field. By treating the spin gauge field perturbatively, we obtain a physically intuitive result that the spin current density is related to the DM interaction. Using first-principles calculations, we confirm that our approach agrees well with the results using the energies of helical spin structures. We also discuss the relation between band structures and DM interaction for the B20 chiral magnets.

12:03PM B6.00005 Torque, spin and energy Hall currents in magnets with Dzyaloshinskii-Moriya interactions, VLADIMIR ZYUZIN, ALEXEY KOVALEV, University of Nebraska — Within a linear response theory, we study nonequilibrium magnonic torques as well as spin and energy Hall currents generated by thermal gradients in ferromagnetic and anti-ferromagnetic systems. We predict a contribution related to Berry curvature which arises in multiband systems with topologically non-trivial magnon bands. We identify symmetries that need to be broken in order to have non-vanishing nonequilibrium magnonic torques. As an example, we study kagome lattice of spins with various symmetries of Dzyaloshinskii-Moriya interactions.

12:15PM B6.00006 Magnon Chirality Hall Effect in Antiferromagnet[1]. RAN CHENG, NIKHIL SIVADAS, Carnegie Mellon University, SATOSHI OKAMOTO, Oak Ridge National Laboratory, DI XIAO, Carnegie Mellon University, CARNEGIE MELLON UNIVERSITY TEAM, OAK RIDGE NATIONAL LABORATORY COLLABORATION — In a collinear antiferromagnet with easy-axis anisotropy, symmetry dictates that the spin wave modes must be doubly degenerate with opposite chirality. We show that in the presence of the Dzyaloshinskii-Moriya interaction, there exist a magnon chirality Hall effect, where magnons with opposite chirality flow to opposite transverse edges when an in-plane temperature gradient is applied. Possible material candidates to realize this effect is also discussed.

12:27PM B6.00007 Soliton-like magnetic domain wall motion induced by the interfacial Dzyaloshinskii-Moriya interaction, TERUO ONO, Kyoto University — Topological defects such as magnetic solitons, vortices, Bloch lines, and skyrmions start to play an important role in modern magnetism due to their extraordinary stability which can be haled as future memory devices. Recently, novel type of antisymmetric exchange interaction, namely the Dzyaloshinskii-Moriya interaction (DMI), has been uncovered and found to influence on the formation of topological defects. Exploring how the DMI affects the dynamics of topological defects is therefore an important task. Here we investigate the dynamics of the magnetic domain wall (DW) under a DMI by developing a time-of-flight measurement scheme which allows us to measure the DW velocity for magnetic fields up to 0.3T. For a weak DMI, the trend of DW velocity follows the Walker’s model which predicts that the velocity of DW increases with field up to a threshold (Walker field) and decreases abruptly. On the other hand, for a strong DMI, velocity breakdown is completely suppressed and the DW keeps its maximum velocity even far above the Walker field. Such a distinct trend of the DW velocity, which has never been predicted, can be explained in terms of magnetic soliton, of which topology can be protected by the DMI. Importantly, such a soliton-like DW motion is only observed in two dimensional systems, implying that the vertical Bloch lines (VBLs) creating inside of the magnetic domain-wall play a crucial role. This work was partly supported by JSPS KAKENHI Grant Numbers 15H05702, 26687030, 26687034, 26103002, 254251, Collaborative Research Program of the Institute for Chemical Research, Kyoto University, and R & D Project for ICT Key Technology of MEXT from the Japan Society for the Promotion of Science (JSPS).

1:03PM B6.00008 Magnetoelectric effects in the spin 1/2 XX chain with three spin interactions and Dzyaloshinskii-Moriya interaction[1], P DURGANANDINI, Department of Physics, SP Pune University, Pune - 411007, India — We consider the spin 1/2 XX chain with three spin interactions of the XZX+YXY and XZY-YZX types in an external magnetic field and with Dzyaloshinskii-Moriya (D-M) interaction. Interpreting the D-M interaction as a local electric polarization, we study the magnetoelectric effects in the system by using the exact solution of the problem. We obtain the ground state phase diagram by calculating the electric polarization, magnetization and isentropes. There are various regimes of magnetic and electric polarization depending on the relative strengths of the three spin interaction as well as that of the external fields. For a certain range of three spin interaction strengths, the system shows the existence of finite magnetization and electric polarization even in the absence of any external fields. The external electric and magnetic fields modify the ground state phases and can be used to tune the various regimes. We also calculate the entropy and analyze the electrocaloric and magnetocaloric effects. We show that the electrocaloric and magnetocaloric effects can be used to obtain information about the magnetoelectric effects in the system.

[1] This work was supported by the Samsung Global MRAM Innovation Program.

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Large anomalous Hall effect in a non-collinear antiferromagnet Mn$_2$Sn at room temperature.  

Recent development in theoretical and experimental studies have provided a framework for understanding the anomalous Hall effect using Berry-phase concepts, and this perspective has led to predictions that, under certain conditions, a large anomalous Hall effect may appear in spin liquids and antiferromagnets. This talk will present experimental results showing that the antiferromagnet Mn$_2$Sn, which has a non-collinear 120-degree spin order, exhibits a large anomalous Hall effect. The magnitude of the Hall conductivity is $\sim 20 \Omega^{-1}\text{ cm}^{-1}$ at room temperature and $>100 \Omega^{-1}\text{ cm}^{-1}$ at low temperatures. We found that a main component of the Hall signal, which is nearly independent of a magnetic field and magnetization, can change the sign with the reversal of a small applied field, corresponding to the rotation of the staggered moments of the non-collinear antiferromagnetic spin order which carries a very small net moment of a few of $\mu_B$. 

1. N. Nagaosa et al., Rev. Mod. Phys. 82, 1539 (2010).  

Nanoscale and proximity effects on low-dimensional helical magnetic structures.  

Leonid Sandratskii, J. Fischer, S. Park, S. Ouazi, D. Sander, J. Kirschner, Max Planck Inst Microstructure — We combine symmetry arguments, first-principles calculations and spin-resolved STS measurements to study a 2D helical magnet of some nm extension in proximity to ferromagnetic Co and vacuum regions. Considering the prototypical helical 2D system, an Fe bilayer with intrinsic helical spin structure (1), we report a non-uniform distortion of the spin helix which depends on the lateral extension of the bilayer and on the proximity to either Co or vacuum. The proximity effect manifests itself in different modifications of the magnetic and electronic structures of Fe in vicinity of the interfaces with Co and vacuum. These nanoscale and proximity effects have not been discussed before. We demonstrate that, in contrast to an ideal helix of infinite length, the lack of symmetry of the nm-long distorted Fe spin helix, induces an energy dependence of the direction of the electronic magnetization which is revealed in the measured energy dependence of the spin-asymmetry of the differential tunneling conductance. (1) Phark, S. H.; Fischer, J. A.; Corbetta, M.; Sander, D.; Nakamura, K. & Kirschner. Reduced-dimensionality-induced helimagnetism in iron nanoislands Nat Commun 5 (2014) 5183.

Emergence of magnetic order in ultra-thin pyrochlore iridate films.  

Suraj Cheema, Claudy Serrao, Julia Mundy, Shreyas Patankar, Robert Birgeneau, Joseph Orenstein, Sayeed Salahuddin, Rama-Mamorothy Ramesh, Univ of California - Berkeley — We report on thickness-dependent magnetotransport in (111) - oriented Pb$_{2}$Ir$_{2}$O$_{7-\delta}$ (Pb227) epitaxial thin films. For thicknesses greater than 4 nm, the magnetoresistance (MR) of metallic Pb227 is positive, linear and non-saturated up to 14 T. Meanwhile at 4 nm, the conduction turns nonmetallic and the MR becomes negative and asymmetric upon field-cooling; such traits are reminiscent of all-in-all-out (AIAO) magnetic order in the insulating pyrochlore iridates. Hysteretic low-field MR dips and trained-untrained resistivity bifurcations suggest the presence of magnetic conducting domain walls within the chiral AIO spin structure. Beyond just AIO order, angular-dependent MR indicates a magnetic phase space hosting 2-in-2-out (2I2O) spin ice order. Such anomalous magnetotransport calls for re-evaluation of the pyrochlore iridate phase diagram, as epitaxially strained Pb227 exhibits traits reminiscent of both the insulating magnetic and metallic spin-liquid members. Furthermore, these results open avenues for realizing topological phase predicitons in (111) - oriented pyrochlore slabs of kagome-triangular iridate heterostructures.

Modulated magnetic ground state and complex phase diagram in the chiral helimagnet Cr$_{1/3}$NbS$_2$.  

Em Clements, R Das, Univ. of South Florida, L Li, Univ. of Pennsylvania, P Lampen-Kelley, Univ. of Tennessee, Oak Ridge National Lab, Mh Phan, Univ. of South Florida, Veerle Keppens, Univ. of Tennessee, D Mandrus, Univ. of Tennessee, Oak Ridge National Lab, H Srikanth, Univ. of South Florida — The chiral helimagnetic ground state of noncentrosymmetric Cr$_{1/3}$NbS$_2$ originates from competition between coexisting symmetric ferromagnetic (FM) exchange and the antisymmetric Dzyaloshinskii-Moriya (DM) interaction. Previously, it has been shown via Lorentz microscopy that a field induced chiral soliton lattice (SL) exists followed by an incommensurate-commensurate metamagnetic transition to a FM state. The high magnetic conducting domain walls within the chiral AIO spin structure. Beyond just AIO order, angular-dependent MR indicates a magnetic phase space hosting 2-in-2-out (2I2O) spin ice order. Such anomalous magnetotransport calls for re-evaluation of the pyrochlore iridate phase diagram, as epitaxially strained Pb227 exhibits traits reminiscent of both the insulating magnetic and metallic spin-liquid members. Furthermore, these results open avenues for realizing topological phase predictions in (111) - oriented pyrochlore slabs of kagome-triangular iridate heterostructures.

Quantized Conductance in InSb nanowires at zero magnetic field.  

KamMhuber, Maja Cassiday, Hao Zhang, Ønder Gül, Fei Pei, Michael De Moor, Delft University of Technology, Kenji Watanabe, Takashi Taniguchi, National Institute for Materials Science, Japan, Diana Car, Erik Bakkers, Eindhoven University of Technology, Leo Kouwenhoven, Delft University of Technology — We present measurements of InSb nanowires in the ballistic transport regime. In 1D materials such as nanowires, electron scattering has an increased chance of back-reflection, obscuring the observation of quantized conductance at low magnetic fields. By improving the contacts to the nanowire as well as its dielectric environment backscattering events are minimized and conductance quantization is observable at zero magnetic field with high device yield. We study the evolution of individual sub-bands in an external magnetic field, observing a degeneracy between the 2nd and 3rd sub-band when the magnetic field is orientated perpendicular to the nanowire axis.

Monday, March 14, 2016 11:15AM - 2:15PM — Session B18 GMAG DCMP FIAP: Spin-orbit and Superconductivity: Majorana Modes 317 - Alex Matos-Abiague, University at Buffalo

Quantized Conductance in InSb nanowires at zero magnetic field.  

KamMhuber, Maja Cassiday, Hao Zhang, Ønder Gül, Fei Pei, Michael De Moor, Delft University of Technology, Kenji Watanabe, Takashi Taniguchi, National Institute for Materials Science, Japan, Diana Car, Erik Bakkers, Eindhoven University of Technology, Leo Kouwenhoven, Delft University of Technology — We present measurements of InSb nanowires in the ballistic transport regime. In 1D materials such as nanowires, electron scattering has an increased chance of back-reflection, obscuring the observation of quantized conductance at low magnetic fields. By improving the contacts to the nanowire as well as its dielectric environment backscattering events are minimized and conductance quantization is observable at zero magnetic field with high device yield. We study the evolution of individual sub-bands in an external magnetic field, observing a degeneracy between the 2nd and 3rd sub-band when the magnetic field is orientated perpendicular to the nanowire axis.
11:27AM B18.00002 Majorana fermions in charge carrier hole quantum wires\(^1\), JINCHENG LIANG, YULI LYANDA-GELLER, Purdue Univ — In order to realize Majorana fermions in a hybrid semiconductor-superconductor structure, spin helical order is needed, which prevents fermion doubling. A natural proposal for Majorana fermion setting is to utilize charge carrier hole systems, which have strong spin orbit couplings that can result in a spin helix. In this work, we demonstrate that transformation of heavy holes into light holes and vice versa upon reflection from the heterostructure boundaries crucially affects Luttinger hole spectrum in low dimensions, and most importantly, spin-orbit interactions are dominated by several terms linear in the hole momentum. We show that the criterion for realizing proximity-induced topologically non-trivial superconducting phase and zero Majorana modes in a hole wire is similar to that for electrons, but an extra constraint should be satisfied. Due to their stronger spin-orbit coupling, the hole systems can be promising settings to study Majorana fermions experimentally.

\(^1\)This research was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0010544.

11:39AM B18.00003 Majorana modes in InSb nanowires (II): resolving the topological phase diagram, HAO ZHANG, ÖNDER GÜL, MICHEL DE MOOR, FOKKO DE VRIES, JASPER VAN VEEN, DAVID VAN VOERKOM, KUN ZUO, VINCENT MOUŘÍK, MAJA CASSIDY, ATTILA GÉRSEDI, Delft Univ. of Tech., DIANA CAR, Eindhoven Univ. of Tech, ERIK BAKKERS, Delft Univ. of Tech, Eindhoven Univ. of Tech, SRIJIT GOSWAMI, Delft Univ. of Tech, KENJI WATANABE, TAKASHI TANIGUCHI, Advanced Materials Laboratory, National Institute for Materials Science, Japan, LEO KOUVENHOVEN, Delft Univ. of Tech — Majorana modes in hybrid superconductor-semiconductor nanowires can be probed via tunneling spectroscopy which shows a zero bias peak (ZBP) in differential conductance. Majorana modes are formed when the Zeeman energy is larger than the chemical potential and the superconducting gap. This Majorana condition outlines the topologically non-trivial phase and predicts a particular dependence of ZBPs on the gate voltage and the external magnetic field. In this talk we show that the magnitude of the superconducting gap can be tuned by gate voltage and vice versa, consistent with these Majorana predictions. Supported by measurements in different external magnetic field orientations, these observations pave the way for exploring the topological phase diagram of spin-orbit coupled semiconductor nanowires with induced superconductivity.


12:03PM B18.00005 Investigation of semiconductor nanowires with shadow-evaporated epitaxial superconducting shells, JOHN WATSON, MAJA CASSIDY, JAKOB KAMMHUBER, MICHEL DE MOOR, LEO KOUVENHOVEN, Delft Technical University, PETER KROGSTRUP, MINGTANG DENG, THOMAS JESPERSEN, JESPER NYGARD, CHARLES MARCUS, University of Copenhagen — We report progress on epitaxially grown InAs/Al core/shell nanowire heterostructures by molecular beam epitaxy with junctions in the Al shells formed in-situ by a crossed wire shadowing method during growth. Such wires allow the creation of superconductor-normal-superconductor (SNS) junctions with high quality superconductor-semiconductor interfaces without introducing damage in the junction by etching. The Al shadowing is accomplished by a two-step growth process in which the nanowire growth direction is changed resulting in crossed networks of nanowires which shadow one another from the Al flux. We observe hard superconducting gaps and supercurrents in excess of 50 nA with in-plane critical fields above 1 T. We compare our results with shadowed devices to previous data from SNS junctions with wet-etched shells. Our experiments indicate that this crossed wire shadowing technique provides an interesting route to investigating induced superconductivity in semiconductor nanowires.

12:15PM B18.00006 Wireless Majorana Fermions: From Magnetic Tunability to Braiding\(^1\), GEOFFREY FATIN, ALEX MATOS-ABIAUGE, BENEDIKT SCHARF, IGOR ZUTIC, University at Buffalo - SUNY — We propose a versatile platform to investigate the existence of zero-energy Majorana fermions (MFs) and their non-Abelian statistics through braiding. This implementation combines a two-dimensional electron gas formed in a semiconductor quantum well grown on the surface of an s-wave superconductor, with a nearby array of magnetic tunnel junctions (MTJs). The underlying magnetic textures produced by MTJs provide highly-controllable topological phase transitions to confine and transport MFs in two dimensions, overcoming the requirement for a network of wires.

\(^1\)This work has been supported by ONR Grant N000141310754 and U.S. DOE BES Award DE-SC0004890.

12:27PM B18.00007 Spin-Orbit Coupling in Hybrid Semiconductor Structures: From Majorana Fermions to Topological Insulators, BENEDIKT SCHARF, State Univ of NY - Buffalo — Hybrid semiconductor structures with strong spin-orbit coupling are responsible for many fascinating phenomena. Topological states in systems of reduced dimensionality, in particular, offer many intriguing possibilities, both for fundamental research as well as for potential applications. In this talk, we describe the importance of the interplay of spin-orbit coupling (SOC) and the sample geometry in realizing exotic Majorana fermions (MFs) in quantum dots and rings and discuss several schemes to detect MFs in two dimensions.

1. An effective SOC from the magnetic textures produced by magnetic tunnel junctions could enable a versatile control of MFs and their adiabatic exchange.
2. We show that in 2D topological insulators (TIs), such as inverted HgTe/CdTe QWs, helical quantum spin Hall (QSH) states persist even at finite magnetic fields below a critical magnetic field above which only quantum Hall (QH) states can be found.
3. We propose magneto-optical absorption measurements to probe the magnetic-field induced transition between the QSH and QH regimes.
4. This measurement scheme is robust against perturbations such as additional SOC due to bulk or structure-inversion asymmetry.
5. Finally, tunnel junctions based on the surfaces of 3D TIs are presented. These junctions can exhibit giant tunneling anomalous Hall (TAH) currents and negative differential TAH conductance, which makes them an attractive and versatile system for spintronic applications.

\(^3\)B. Scharf et al., PRB 86, 075418 (2012).

B. L. Fatin et al., arXiv:1510.08182.
B. Scharf et al., PRB 91, 235433 (2015).
B. Scharf et al, preprint.
1:03PM B18.00008 Wavefunction oscillations and fermion parity oscillations in disordered Majorana wires
SURA JEGDE, SMITHA VISHWESVARA, Univ of Illinois - Urbana — We study aspects of decay and oscillations of Majorana wavefunctions in one-dimensional topological superconducting chains, by employing Majorana transfer matrix technique. The phase transition separating the trival phase and the topological phase associated with the Majorana end modes can be traced to the cancellation of the two parts (superconducting and normal) of the Lyapunov exponent of the transfer matrix. We find that the Majorana oscillations and related fermion parity flips can be completely determined by an underlying non-superconducting tight-binding model. Using this observation we pinpoint the behavior of Majorana mode oscillations within the topological phase diagram. For a disordered wire, Majorana oscillations are completely washed out, leading to a second localization length for the Majorana modes. The remnant oscillations are however manifested and completely randomized by disorder effects. As a result, the associated fermion parity flips depend heavily on the average of the disorder distribution and the number of lattice sites of the chain. We show that the transfer matrix technique offers a simple way of understanding the known log-normal distribution of mid-gap Majorana states.

1:15PM B18.00009 Interfacial spin-orbit fields in ferromagnet/normal metal (FN) and ferromagnet/superconductor (FS) systems
PETRA HOEGL, University of Regensburg, ALEX MATOS-ABIAGUE, IGOR ZUTIC, University at Buffalo - SUNY, JAROSLAV FABIAN, University of Regensburg — Breaking of space-inversion symmetry at interfaces induces spin-orbit fields as an emergent phenomenon. Interfacial spin-orbit fields are believed to enable a wealth of new phenomena, not existent or fragile in the bulk, such as the tunneling anisotropic magnetoresistance (TAMR), interfacial spin-orbit torques, Skyrmions, or possible realization of topological superconductors. We theoretically investigate spin-polarized transport in FN and FS junctions in the presence of Rashba and Dresselhaus interfacial spin-orbit fields. The interplay of magnetism and spin-orbit fields leads to a marked magnetoanisotropy of the conductances. Remarkably, the anisotropy in FS systems—magnetoanisotropic Andreev reflection (MAAR)—is giant compared to TAMR, its normal-state counterpart in FN junctions [1]. We further report on the dependence of spin-flip probability currents on characteristic system parameters [2].

1:27PM B18.00010 An exactly solvable model for a strongly spin-orbit-coupled nanowire quantum dot
RUI LI, Beijing Computational Science Research Center, LIAN-AO WU, University of the Basque Country, XUEDONG HU, University at Buffalo, SUNY, J.Q. YOU, Beijing Computational Science Research Center — In the presence of spin-orbit coupling, quantum models for semiconductor materials are generally not exactly solvable. As a result, understanding of the strong spin-orbit coupling effects in these systems remains incomplete. Here we develop a method to solve exactly the one-dimensional hard-wall quantum dot problem for a single electron in the presence of a strong spin-orbit coupling and a finite magnetic field. This method allows us to obtain the exact eigenenergies and eigenstates for the single electron. With the help of this solution, we demonstrate unique effects from the strong spin-orbit coupling in a semiconductor quantum dot, in particular the anisotropy of the electron g-factor and its tunability.

1:39PM B18.00011 Charge instability in double quantum dots in Ge/Si core/shell nanowires
AZARIN ZARASSI, ZHAOEN SU, University of Pittsburgh, JENS SCHWENDERLING, RWTH Aachen University, SERGEY M. FROLOV, University of Pittsburgh, MORA HOCEVAR, Institute Nel CNRS, BINH-MINH NGUYEN, HRL Labs, JINKYONG YOO, Los Alamos National Laboratory, SHADI A. DAYE, University of California San Diego — Controlling dephasing times of charge qubits is of great challenge in the studies of spin qubit. Reported long spin coherence time and predicted strong spin-orbit interaction of holes in Ge/Si core/shell nanowires, as well as their weak coupling to very few nuclear spins of these group IV semiconductors, persuade electrical spin control. We have established Pauli spin blockade in gate-tunable quantum dots formed in these nanowires. The g-factor has been measured and evidence of spin-orbit interaction has been observed in the presence of magnetic field. However, electrical control of spins requires considerable stability in the double dot configuration, and imperfectly these dots suffer from poor stability. We report on gate fabrication modifications on Ge/Si core/shell nanowires, as well as measurement techniques to suppress the charge instabilities and ease the way to study spin-orbit coupling and resolve electric dipole spin resonance.

1:51PM B18.00012 Electrically driven hole spin resonance in MOSFET nanowires
DHARMRAJ KOTEKAR PATIL, ROY MAURAND, ANDREA CORNA, XAVIER JEHL, CEA-INAC and Universit Grenoble Alpes, 17 Rue des Martyrs, 38054 Grenoble, France, ALEXEI ORLOV, Department of Electrical Engineering, University of Notre Dame, Notre Dame, IN 46566, USA, ROMAIN LAIVILLE, SYLVAIN BARRAUD, LOUIS HUTIN, CEA-LETI and Universit Grenoble Alpes, 17 Rue des Martyrs, 38054 Grenoble, France, MARC SANQUER, SILVANO DE FRANCESCHI, CEA-INAC and Universit Grenoble Alpes, 17 Rue des Martyrs, 38054 Grenoble, France — Hole spins in silicon represent a promising direction for solid-state quantum computation, possibly combining fast qubits with limited hyperfine interaction yielding long coherence times. Here we report on hole double quantum dots defined in dual-gate, p-type silicon nanowire MOSFETs. Devices are fabricated on 300-mm silicon-on-insulator wafers using an industry-standard CMOS platform. We show that a microwave signal applied to one gate of the transistor can induce hole spin resonance leading to an enhanced electrical current through the device. The origin of the observed spin resonance is discussed. From the power dependence of the spin resonance signal we deduce Rabi frequencies as high as ~100 MHz. Our experiments suggest hole quantum dots in silicon as promising candidates for electrically controlled spin qubits.

2:03PM B18.00013 Spin transistor based on pure nonlocal Andreev reflection in EuO-graphene/superconductor/EuO-graphene nanostructure
YEE SIN ANG, LAY KEE ANG, Singapore University of Technology and Design, CHAO ZHANG, University of Wollongong, ZHONGSHUI MA, Peking University — In graphene-magnetic-insulator hybrid structure such as graphene-Europium-oxide, proximity induced exchange interaction opens up a spin-dependent bandgap and spin splitting in the Dirac band. We show that such band topology allows pure crossed Andreev reflection to be generated exclusively without the parasitic local Andreev reflection and elastic cotunnelling over a wide range of bias and Fermi levels. We model the charge transport in an EuO-graphene/superconductor/EuO-graphene three-terminal device and found that the pure non-local conductance exhibits rapid on/off switching characteristic with a minimal subthreshold swing of ~20 mV. Non-local conductance oscillation is observed when the Fermi level in the superconducting lead is varied. The oscillatory behavior is directly related to the quasiparticle propagation in the superconducting lead and hence can be used as a tool to probe the subgap quasiparticle mode in superconducting graphene. The non-local current is 100% spin-polarized and is highly tunable in our proposed device. This opens up the possibility of highly tunable graphene-based spin transistor that operates purely in the non-local transport regime.

Monday, March 14, 2016 11:15AM - 2:15PM — Session B19 GMAG DMP: Magnetic Devices and Production Level Scaling
11:15AM B19.00001 Development of 22 T VSM System using Novel Improvements in HTS Conductor

JEREMY GOOD, DARKO BRACANOVIC, Cryogenic Ltd — Current research has identified a need for greater magnetising fields during vibrating sample magnetometer (VSM) measurements, and offers the means to implement a VSM system with 22 T superconducting magnet, a unique system and the highest field combined with a VSM anywhere in the world. Recent developments in HTS conductors have allowed greater reliability than previous coils made from YBCO and BISCO and thus facilitate the consistent achievement of higher magnetising fields at the sample with operation at 4.2 K rather than 2.2 K. Cryogenic Ltd wind HTS coils in both solenoids and pancake forms with an emphasis on solenoids, since they have been found to give a more reliable performance with less thermal transfer to the surrounding liquid helium. The 22 T VSM system has been developed using 2G YBCO coated and BSSCO tape which exhibit critical currents up to 5 times greater than those seen in YBCO and BISCO at 4.2 K.

11:27AM B19.00002 Write operation in MRAM with voltage controlled magnetic anisotropy

KAMARAM MUNIRA, SUMEET PANDEY, GURTEJ SANDHU, Micron Technology, Inc. — In non-volatile Magnetic RAM, information is saved in the bistable configuration of the free layer in a magnetic tunnel junction (MTJ). New information can be written to the free layer through magnetic induction (Toggle MRAM) or manipulation of magnetization using electric currents (Spin Transfer Torque MRAM or STT-MRAM). Both of the writing methods suffer from a shortcoming in terms of energy efficiency. This limitation on energy performance is brought about by the need for driving relatively large electrical charge currents through the devices for switching. In STT-MRAM, the nonzero voltage drop across the resistive MTJ leads to significant power dissipation. An energy efficient way to write may be with the assistance of resistance controlled digital magnetic anisotropy (VCMA), where voltage applied across the MTJ creates an electric field that modulates the interfacial anisotropy between the insulator and free layer. However, VCMA cannot switch the free layer completely by 180 degree rotation. It can lower the barrier between the two stable configurations or at best, cancel the barrier, allowing 90 degree rotation. A second mechanism, spin torque or magnetic field, is needed to direct the final switching destination.


YUNPENG CHEN, University of Delaware, XIN FAN, University of Denver, YUNSONG XIE, University of Delaware, JEFFREY WILSON, RAINEE SIMONS, Electron and Opto-Electronic Devices Branch, NASA Glenn Research Center, SUI-TAT CHUI, JOHN XIAO, University of Delaware — Magnetic resonance is a critical property of magnetic materials for the applications in microwave devices and novel spintronics devices. The resonance frequency is commonly controlled with an external magnetic field generated by an energy-inefficient and bulky electromagnet. The search for tuning the resonance frequency without electromagnets has attracted tremendous attention. The voltage control of resonance frequency has been demonstrated in multiferroic heterostructures through magnetoelastic effect. However, the frequency tunable range is limited. We propose a paradigm to tune the magnetic resonance frequency by recognizing the huge interlayer exchange field and the existence of the high-frequency modes in coupled oscillators. We demonstrate the optical mode in exchange coupled magnetic layers which occurred at much higher frequencies than coherent ferromagnetic resonance. We further demonstrated a large resonance frequency tunable range from 11GHz to 21 GHz in a spin valve device by in-situ manipulating of the exchange interaction. The technique developed here is far more efficient than the conventional methods of using electromagnets and multiferroics. This new scheme will have an immediate impact on applications based on magnetic resonance.

11:51AM B19.00004 Amplification effect of low-field magnetoresistance in silicon dual p + n junctions

DEZHENG YANG, TAO WANG, MINGSU SI, FANGCONG WANG, Key Laboratory for Magnetism and Magnetic Materials of Ministry of Education, Lanzhou University, Lanzhou 730000, China, SHURING ZHOU, Department of Physics, Tongji University, Shanghai 200092, China, DEZHENG XUE, Key Laboratory of Thin Film and Nanomaterials of Ministry of Education, Lanzhou University, Lanzhou 730000, China — Recent magnetic tunnel junctions with large magnetoresistance are identified as promising feature for the development of magnetoelectronics. However, to manipulate the magnetoresistance require the magnetic field of several Tesla. In this work, we provide an amplification effect of low-field magnetoresistance based on an elementary electronic building block: dual p + n junction. Analogous to the electrical amplification effect of transistors n − p junction, where the coupling current between n and n + p junctions is tuned by base current, in a silicon p + n − p + n device we demonstrate that the coupling strength of n − p and n + n − p junctions can be tuned by magnetic field. Owing to the amplification effect of magnetic-field-manipulated coupling, at a small magnetic field from 0 to 0.1 T the device is directly switched from conducting state ‘on’ (10000 ohms) to blocking state ‘off’ (5 megohm), yielding an magnetoresistance of 50,000 per cent and magnetic field sensitivity as high as 50 per cent Oe. Such a combination of magnetoresistance and high sensitivity not only makes the semiconductor device available in the magnetic field sensing industry, but also permits a new kind of magnetic-field-manipulated semiconductor electronics.

12:03PM B19.00005 Towards Atomic-Scale Data Storage in Topologically Protected Spin Structures

RALPH SKOMSKI, BALA BALAMURUGAN, PRIYANKA MANCHANDA, University of Nebraska, GEORGE C HADJIPANAYIS, University of Delaware, D J SELLMYER, University of Nebraska — Model calculations are used to investigate prospects for atomic-scale data storage in topologically protected spin structures. The approach relies exclusively on exchange interactions, as contrasted to storage based on spin-orbit coupling. The latter category includes magnetocrystalline anisotropy, as in present-day ultrahigh-density recording media, and skyrmions involving Dzyaloshinski-Moriya (DM) interactions. Since spin-orbit coupling is a higher-order relativistic correction to the leading electrostatic terms, including exchange, the corresponding bit sizes are limited with large magnetoresistance are identified as promising feature for the development of magnetoelectronics. However, to manipulate the magnetoresistance require the magnetic field of several Tesla. In this work, we provide an amplification effect of low-field magnetoresistance based on an elementary electronic building block: dual p + n junction. Analogous to the electrical amplification effect of transistors n − p junction, where the coupling current between n and n + p junctions is tuned by base current, in a silicon p + n − p + n device we demonstrate that the coupling strength of n − p and n + n − p junctions can be tuned by magnetic field. Owing to the amplification effect of magnetic-field-manipulated coupling, at a small magnetic field from 0 to 0.1 T the device is directly switched from conducting state ‘on’ (10000 ohms) to blocking state ‘off’ (5 megohm), yielding an magnetoresistance of 50,000 per cent and magnetic field sensitivity as high as 50 per cent Oe. Such a combination of magnetoresistance and high sensitivity not only makes the semiconductor device available in the magnetic field sensing industry, but also permits a new kind of magnetic-field-manipulated semiconductor electronics.

12:15PM B19.00006 Stability of single skyrmionic bits

OLENA VEDMEDENKO, JULIAN HAGEMEISTER, NIKLAS ROMMING, KIRSTEN VON BERGMANN, ROLÁND WIESENDANGER, University of Hamburg — The switching between topologically distinct skyrmionic and ferromagnetic states has been proposed as a bit operation for information storage. While long lifetimes of the bits are required for data storage devices, the lifetimes of skyrmions have not been addressed so far. Here we show by means of atomistic Monte Carlo simulations that the field-dependent mean lifetimes of the skyrmionic and ferromagnetic states have a high asymmetry with respect to the critical magnetic field, at which these lifetimes are identical. According to our calculations, the main reason for the enhanced stability of skyrmions is a different field dependence of skyrmionic and ferromagnetic activation energies and a lower attempt frequency of skyrmions rather than the height of energy barriers. We use this knowledge to propose a procedure for the determination of effective parameter values and the quantification of the Monte Carlo timescale from the comparison of theoretical and experimental data. [1] Nature Comms. 6, 8455 (2015)

[1] Financial support from the DFG in the framework of the SFB668 is acknowledged.

Reconfigurable magnetic logic combined with non-volatile memory in silicon. ZHAOCHU LOU, XIAOZHONG ZHANG, Tsinghua Univ — Silicon-based complementary metal-oxide-semiconductor (CMOS) transistors have achieved great success and become the mainstream of integrated logic circuits. However, the traditional pathway to enhance computational performance and decrease cost by continuous miniaturization is approaching its fundamental limits. The recent emergence of magnetic logic devices, especially magnetic-field-based semiconductor logic devices, promises to surpass the development limits of CMOS logic and arouses profound attentions. Based on our Si based magnetoresistance (MR) device [1], we proposed a Si based reconfigurable magnetic logic device by coupling nonlinear transport effect and Hall effect in Si [2], which could do all four basic Boolean logic operations including AND, OR, NOR and NAND combined with non-volatile memory. Further, we developed a Si based current mode logic magnetic devices, which allowed direct communication between different logic devices by current-induced magnetization switch effect without external intermediate magnetic-electric converters. This may result in a memory-logic integrated system leading to a non von Neumann computer. [1] CH Wan, et al, Nature 477, 304, (2011). [2] ZC Luo et al. Adv. Funct. Mater. 25, 158, (2015).

Toward spin-based Magneto Logic Gate in Graphene. HUA WEN, Dept of Physics and Astronomy, and Univ. of California, Riverside, HANAN DERY, Dept. of Electrical and Computer Engineering, University of Rochester, WALID AMAMOU, Dept. of Physics and Astronomy, University of California, Riverside, TIANCONG ZHU, Dept. of Physics, The Ohio State University, ZHISEHNG LIN, Dept. of Physics and Astronomy, University of California, Riverside, JING SHI, Dept. of Physics, University at Buffalo, State University of New York, ILYA KRIVOROTOV, Dept. of Physics and Astronomy, University of California, Irvine, LU SHAM, Dept. of Physics, University of California, San Diego, ROLAND KAWAKAMI, Dept. of Physics, The Ohio State University — Graphene has emerged as a leading candidate for spintronics applications due to its long spin diffusion length at room temperature. A universal magnetologic gate (MLG) based on spin transport in graphene has been recently proposed as the building block of a logic circuit which could replace the current CMOS technology. This MLG has five ferromagnetic electrodes contacting a graphene channel and can be considered as two three-terminal XOR logic gates. Here we demonstrate this XOR logic gate operation in such a device. This was achieved by systematically tuning the injection current bias to balance the spin polarization efficiency of the two inputs, and offset voltage in the detection circuit to obtain binary outputs. The output is a current which corresponds to different logic states: zero current is logic ‘0’, and nonzero current is logic ‘1’. We find improved performance could be achieved by reducing device size and optimizing the contacts.

Low Drift in Resistance of Plasma Oxidized, Cobalt Confined AlOx Tunnel Barriers. Z. S. BARCIKOWSKI, Y. HONG, J. M. POMEROY, National Institute of Standards and Technology — Co/AlOx/Co tunnel junctions show <15% drift in resistance measured over the first three months. This long term stability is achieved using plasma oxidation and sandwiching the AlOx tunnel barrier between cobalt layers. Plasma oxidation of aluminum, when compared to thermal oxidation, has been shown to produce a more homogeneous and stoichiometric oxide. The confinement of the oxide between Co layers, which have higher oxide enthalpies of formation, is thought to provide a barrier against oxygen diffusion. Junction resistance and current-voltage (I-V) measurements are taken over a period of approximately 9 months. Barrier width (s) and asymmetric barrier heights (ϕ1, ϕ2) are extracted using Simmons/Chow transport model. Bottom barrier height (ϕ2) and barrier width (s) show near constant values in contrast to a rise in top barrier height (ϕ1) in time.

A Study of Morphology and Magnetic Properties of Doped Barium Ferrite Films Formed by Aerosol Deposition. SCOOTER JOHNSON, Naval Research Laboratory, CHRISTOPHER GONZALEZ, California State University Long Beach, ZACHARY ROBINSON, College at Brockport SUNY, DAVID ELSWORTH, MINGZHONG WU, Colorado State University — Aerosol deposition is a room-temperature thick film deposition technique that produces polycrystalline films that have >95% of theoretical density and are up to several hundred microns thick. In addition to depositing films at room temperature another distinct advantage of aerosol deposition is that the ability to produce films with the same resulting stoichiometry as the starting material. For this work, we deposited a proprietary doped barium ferrite (BaFe12O19) film from powder produced by Temex Ceramics. This material is designed for microwave absorption near 18 GHz via ferromagnetic resonance. We compare the structural and magnetic properties of the as-deposited film, bulk material, and starting powder. For this purpose, we employed scanning electron microscopy, x-ray photoemission spectroscopy, x-ray diffraction, vibrating sample magnetometry, and broad-band ferromagnetic resonance characterization techniques.

Large-area patterned substrates for superparamagnetic microbeads. MINAE OUK, GEOFFREY S.D. BEACH, Massachusetts Inst of Tech-MIT — Superparamagnetic microbeads (SBs) have been used to capture and manipulate biological entities in a fluid environment. Chip-based magnetic actuation provides a means to transport SBs in lab-on-a-chip technologies. This is accomplished using the stray field from patterned magnetic microstructures [1], or domain walls in magnetic nanowires [2]. Recently many studies have focused on the submicron-size antidot array of magnetic materials because non-magnetic holes affect the micromagnetic properties. Here, we use photolithographic patterning to create periodic anti-dot arrays in Co thin films, show the transport of SBs across large distance by a rotating field. We describe the dynamics of bead motion, highlighting the key factors to control bead transport. We show there is a critical threshold for both in-plane and out-of-plane components that must be exceeded for bead motion to occur. The threshold values are different depending on direction, which allows for directionally-anisotropic transport across the chip surface. Hence the periodic micromagnetically-patterned substrates can be used to digitally separate magnetic beads and augment microfluidic actuation for long distance transport.[1]B. Yellin, et al., Lab Chip, 7, 1681 (2007) [2]E. Rapoport and G. S. D. Beach, APL 100, 082401 (2012)
1:39PM B19.00013 Measurement of Nanoparticle Magnetic Hyperthermia Using Fluorescent Microthermal Imaging, XIAOWAN ZHENG, EDWARD VAN KEUREN, Georgetown University — Nanoparticle magnetic hyperthermia uses the application of an AC magnetic field to ferromagnetic nanoparticles to elevate the temperature of cancer cells. The principle of hyperthermia as a true cell-specific therapy is that tumor cells are more sensitive to high temperature, so it is of great importance to control the locality and magnitude of the temperature differences. One technique to measure temperature variations on microscopic length scales is fluorescent microthermal imaging (FMI). Since it is the local temperature that is measured in FMI, effects such as heating due to nearby field coils can be accounted for. A dye, the rare earth chelate europium thienyltrifluoroacetate (Eu:TTA), with a strong temperature-dependent fluorescence emission has been incorporated into magnetic nanoparticles dispersed in a polymer film. FMI experiments were carried out on these samples under an applied high frequency magnetic field. Preliminary results show that FMI is a promising technique for characterizing the local generation of heat in nanoparticle magnetic hyperthermia.

1:51PM B19.00014 Optimization of magnetic refrigerators by tuning the heat transfer medium and operating conditions, MOHAMMADREZA GHAHREMANI, AMIR ASLANI, LAWRENCE BENNETT, EDWARD DELLA TORRE, George Washington University — A new reciprocating Active Magnetic Regenerator (AMR) experimental device has been designed, built and tested to evaluate the effect of the system’s parameters on a reciprocating Active Magnetic Regenerator (AMR) near room temperature. Gadolinium turnings were used as the refrigerant, silicon oil as the heat transfer medium, and a magnetic field of 1.3 T was cycled. This study focuses on the methodology of single stage AMR operation conditions to get a higher temperature span near room temperature. Herein, the main objective is not to report the absolute maximum attainable temperature span seen in an AMR system, but rather to find the system’s optimal operating conditions to reach that maximum span. The results of this work show that there is an optimal operating frequency, heat transfer fluid flow rate, flow distribution, and displaced volume ratio in an AMR system. It is expected that such optimization and the results provided herein will permit the future design and development of more efficient room-temperature magnetic refrigeration systems.


11:15AM B21.00001 Decoherence mechanisms in Mn3 single-molecule magnet\(^1\), C ABEYWARDANA, Department of Chemistry, University of Southern California, Los Angeles CA 90089, USA, A. M. MOWSON, G. CHRISTOU, Department of Chemistry, University of Florida, Gainesville FL 32611, USA, TATIANA EGERS, Department of Physics, University of South Florida, Tampa, FL, ALEX LEARY, MICHAEL MCMENY, Materials Science and Engineering, Carnegie-Mellon University, Pittsburgh, PA, IVAN SKORVANEK, Institute of Experimental Physics, Slovak Academy of Sciences, Kosice, Slovakia, HARIRHAN SRIKANTH, MANH-HUONG PHAN, Department of Physics, University of South Florida, Tampa, FL — The Magnetoimpedance (MI) effect in 2 mm wide (Fe\(_x\)Co\(_{1-x}\))\(_{1.5}\), Bi\(_1\)Nb\(_0\)Si\(_1\)Co\(_1\), rapidly quenched ribbons with varying glass former content (x = 0 and x = 4) has been studied in the frequency range of 1-1000 MHz. Two measurement techniques were used: auto-balancing bridge method in the frequency range of 1-110 MHz and transmission line technique for 20-1000 MHz. The impact of DC Joule heating treatments of varying current amplitude and annealing time on the MI effect of the amorphous ribbons was examined by evaluating the field and frequency dependence on the resistive and reactive components of the MI. To interpret the MI behavior, the domain structure of the ribbons in their as-quenched state and after heating treatment was imaged by magneto-optical Kerr effect microscopy. A significant improvement in the MI response from the as-quenched state was found for both compositions of ribbon with a 3 hour-500 mA Joule anneal treatment. The improvement is attributed to the development of a low anisotropy domain structure longitudinally and at an oblique angle between the longitudinal and transverse directions for the 0% and 4% Nb content, respectively.

\(^1\)This work is supported by the National Science Foundation (DMR-1508661) and the Searle scholars program.

11:27AM B21.00002 Controlling electronic access to the spin excitations of a single molecule in a tunnel junction, CYRUS F. HIRJIBEHEDIN, BEN WARNER, FADI EL HALLAK, HENNING PRUESER, AFOLABI AJIBADE, TOBIAS G. GILL, ANDREW J. FISHER, UCL, MATS PERSSON, U. Florida and Chalmers University of Technology — Spintronic phenomena can be utilized to create new devices with applications in data storage and sensing. Scaling these down to the single molecule level requires controlling the properties of the current-carrying orbitals to enable access to spin states through phenomena such as inelastic electron tunneling. Here we show that the spin properties of a tunnel junction containing a single molecule can be controlled by their coupling to the local environment. For tunneling through iron phthalocyanine (FePc) on an insulating copper nitride (Cu\(_2\)N) monolayer above Cu(001), we find that spin transitions may be strongly excited depending on the binding site of the central Fe atom. Different interactions between the Fe and the underlying Cu or N atoms shift the Fe d-orbitals with respect to the Fermi energy, and control the relative strength of the spin excitations, an effect that can described in a simple co-tunneling model. This work demonstrates the importance of the atomic-scale environment in the development of single molecule spintronic devices.

11:39AM B21.00003 Inelastic Neutron Scattering and Magnetisation Investigation of an Exchange-Coupled Dy\(_2\) SMM\(^2\), MICHAEL L. BAKER, City College of New York, CUNY and New York University, QING ZHANG, MYRTAM P. SARANGHI, City College of New York, CUNY, ANDREW D. KENT, YIZHANG CHEN, New York University, NICHOLAS BUTCH, NIST, EU FEMIO M. PINEDA, ERIC MCNINSE, University of Manchester — The strong spin orbit coupling and weak crystal field energies of single exchange-coupled rare earth SMMs makes the precise evaluation of their magnetic properties nontrivial. Here we report a detailed magnetic characterization of the single molecule magnetic hqH\(_2\)Dy\(_2\)(hq)(NO\(_3\))\(_2\)MeOH. Inelastic neutron scattering is used to obtain direct access to several low energy crystal field excitations. The INS results display several features that are not found in earlier FIR absorption experiments [1], while other features found in the latter are absent. Based on the effective point charge model, numerical calculations are currently underway to resolve these apparent discrepancies using complementary magnetisation measurements to resolve the exchange between Dy ions. [1] E. M. Pineda et al. Nat. Commun. 5, 5243 (2014).

\(^2\)Work supported by ARO W911NF-13-1-025 (CCNY) and NSF-DMR-1309202 (NYU)
12:27PM B21.0005 Evaluation of the exchange interaction and crystal fields in a prototype Dy₃ SMM, QING ZHANG, MYRIAM SARACHIK, City College of New York, CUNY, MICHAEL BAKER, Stanford University, YIZHANG CHEN, ANDREW KENT, New York University, EUFEMIO PINEDA, ERIC MCIINNES, The University of Manchester — In order to gain an understanding of the INS and magnetization data obtained for Dy₃, the simplest member of a newly synthesized family of dysprosium-based molecular magnets [1], we report on calculations of the magnetic behavior of a Dy₂ cluster with the formula [hq4]Dy₂(h₄)₂(NO₃)₅MEOH. The molecular complex contains one high symmetry Dy(III) ion and one low symmetry Dy(III) ion. Our calculations suggest that exchange coupling between the two ions controls the behavior of the magnetization at low temperature, while the crystal field of the low symmetry Dy(III) ion controls the behavior at higher temperature. A point charge electrostatic model, based on crystallographic coordinates, provides a starting point for the determination of the crystal field [2]. Parameters in these calculations are adjusted to provide best fits to inelastic neutron scattering data (INS) and low temperature magnetometry [3]: the INS measurements access crystal field energies and low temperature magnetization probes the Dy-Dy exchange interaction. [1] E. M. Pineda, et al. Nat. Commun. 5, 5243 (2014). [2] J. B. Baldov, et al. J. Comput. Chem. 34 (22), 1961-1967, 2013. [3] N. F. Chilton, et al. J. Comput. Chem. 34, 1164-1175 (2013).

12:39PM B21.0007 The first single atom magnet, FABIO DONATI, STEFANO RUSPONI, CHRISTIAN WÄCKERLIN, APARAJITA SINGHA, ROMANA BALTIC, KATHARINA DILLER, FRANÇOIS PATTHEY, EDGAR FERNANDES, HARALD BRUNE, Ecole Polytechnique Fédérale de Lausanne, JAN DREISER, Paul Scherrer Institute, ZELJKO SLJIVANCANIN, Vinča Institute of Nuclear Sciences, KURT KUMMER, European Synchrotron Radiation Facility, SEBASTIAN STEPANOW, LUCA PERSICHETTI, CORNELIU NISTOR, PIETRO GAMBARDELLA, ETH Zürich — The prime feature of a magnet is to retain a significant fraction of its saturation magnetization in the absence of an external magnetic field. Realizing magnetic remanence in a single atom would allow storing and processing information in the smallest unit of matter. Here we show that individual rare-earth atoms on ultrathin insulating layers grown on non-magnetic metal substrates exhibit magnetic remanence and, therefore, are the first magnets formed by a single surface adsorbed atom. These magnets have a magnetic lifetime of 1500 s and a coercive field of 3.7 T at 10 K. In addition, their hysteresis loop remains open up to 30 K. This extraordinary stability is achieved by a suitable combination of magnetic ground state and adsorption site symmetry, and by decoupling the 4f spin from the underlying metal by a tunnel barrier.

12:51PM B21.0007 Giant exchange interaction in mixed lanthanides, NAOKA IWAHARA, VEACHESLAV VIERU, LIVIU UNGUR, LIVIU CHIBOTARU, Theory of Nanomaterials Group, Katholieke Universiteit Leuven — Combining strong magnetic anisotropy with strong exchange interaction is a long standing goal of quantum magnetism. Anisotropy and anisotropy, usually display a weak exchange coupling, amounting to only few wavenumbers. Recently, an isostuctural series of mixed Ln-Ln complexes with R the Nd³⁺ radical have been reported, in which the exchange splitting is estimated to reach hundreds wavenumbers [1,2]. Here we apply a new methodology allowing to establish on the basis of DFT and ab initio calculations the microscopic mechanism governing the unusual exchange interaction in these compounds [3].

1:03PM B21.0008 Visualizing Improved Spin Coupling in Large Magnetic Molecules, JUDITH DONKER, Institute for Molecules and Materials, Radboud University Nijmegen, JAN-PHILIPP BROSCINSKI, BASTIAN FELDSCHER, THORSTEN GLASER, Faculty of Chemistry, University of Bielefeld, ALEXANDER AKO KHAJETOORIANS, DANIEL WEGNER, Institute for Molecules and Materials, Radboud University Nijmegen — In an attempt to combine a high spin ground state and a large magnetic anisotropy in one molecule, triplesalalen-based complexes promising building blocks for a new generation of single molecule magnets (SMMs). The spin coupling in these molecules is based on the spin polarization effect, which requires a delocalized aromatic π-system in the central carbon ring of the complex. Unfortunately, chemical analysis indicates that this ring can change its configuration to 6-radiadene, therefore causing a loss of aromaticity and weakening the magnetic coupling. We have employed a combination of scanning tunneling microscopy (STM) and spectroscopy (STS) to investigate single Cu₃-triplesalalen and Cu₄-triplesalalen molecules, the latter being designed to show an enhanced interaction of the spin coupling. The large molecules were deposited in situ using the unconventional techniques pulse injection and rapid heating. A thorough structural and spectral analysis allows us to discuss the electronic properties of the two complexes, with a special focus on the state of the central carbon ring. We find that even small changes in the ligand structure have a drastic influence on the intramolecular spin coupling, which opens the way for an improved rational design of future SMMs.

1:15PM B21.0009 Exchange coupling and anisotropy effects on the low temperature temperature dynamics in rare-earth dioxygen complexes, ASMA AMJAD, GIORDANO PONETI, SILVIA SOTTINI, ANDREA DEI, LORENZO SORACE, INSTM, Universit di Firenze — The prelude of relevant magnetic coupling in f-element based complexes is actively pursued to improve the single-molecule magnetic features. However, a quantitative analysis of magnetic properties of exchange-coupled anisotropic rare-earth based complexes is often difficult due to their small size and the strong magnetic coupling. In this study, we investigated the properties of complexes containing different ligands with comparable molecular structures and ligand field strengths. A span of low-temperature magnetic and EPR study of homologous LnNi²+Semiquinonate (LnSQ) and LnNi²+Tropolonate (LnTrp) complexes, where Ln = Dy, Tb is investigated. Single-crystal EPR revealed that the direct exchange coupling in DySQ resulted in a highly anisotropic pseudo-triplet state. An out-of-phase susceptibility signal was observed for TbTrp only in the presence of an external magnetic field. Furthermore, the dynamics revealed slow relaxation of magnetization in the DySQ at low temperature which upon comparative study with the dynamics of the related DyTrp revealed a not so simple dependence on the crystal field effects of the coordination sphere of the lanthanide.
1:27PM B21.00010 Anomalous power dependence in the zero-field resonance for the molecular nanomagnet Cr_{2}Mn_{4}.
C.A. COLLETT, Department of Physics, Amherst College, Amherst, MA, USA. G.A. TIMCO, R.E.P. WINPENNY, School of Chemistry, The University of Manchester, UK. J.R. FRIEDMANN, Department of Physics, Amherst College, Amherst, MA, USA — We report electron-spin resonance studies of the paramagnetic ring \([\text{Cr}_{2}\text{Mn}_{4}]\) with a large zero-field ground-state tunnel splitting of \(\sim 4\) GHz. We perform parallel-mode electron-spin-resonance (ESR) spectroscopy with loop-gap resonators (LGRs) with resonance frequencies of \(4-6\) GHz. A crystal of Cr_{2}Mn_{4} is placed on the loop of the LGR with the sample's easy axis parallel to the field. We observe an ESR peak at zero dc field. With increasing radiation power, a pronounced dip develops in the center of the resonance peak, indicating a decoupling of the sample from the resonator with increased power. The onset of this decoupling depends on both the temperature and the applied power, with greater power required to observe the dip at higher temperatures. By using the radiation, we can rule out that the dip is related to sample heating or saturation of the resonance. Power, temperature, and frequency dependence of the decoupling will be presented, and possible explanations will be discussed.

1:39PM B21.00011 Time-resolved Measurements of Spontaneous Magnetic Deflagration of Mn_{12}BuAc\(^{1}\). YIZHANG CHEN, A. D. KENT, New York Univ NYU, QING ZHANG, M. P. SARACHIK, City College of New York CUNY, M. L. BAKER, City College of New York and New York University NYU, D. A. GARANIN, Lehman College of CUNY, NAJAH MHENES, CHRISTOS LAMPROPOULOS, University of North Florida — Magnetic deflagration in molecular magnets has been triggered by heat pulses [1,2] and acoustic waves [3,4]. In this work we report spontaneous magnetic deflagration (i.e. deflagration that occurs without an external trigger) in the axially symmetric single molecule magnetic Racah\(^{2}\) BuAc. Magnetic hysteresis measurements show steps due to resonant quantum tunneling (RQT) below 1K, confirming the spin-Hamiltonian parameters for this material and previous results. Deflagration speeds measured with a newly constructed higher bandwidth (2MHz) setup will be presented as a function of transverse and longitudinal fields \(H_{\perp} \otimes H_{\parallel}\) both on and off resonance. A large increase in front velocity near RQT steps is observed in experiments with swept transverse fields and will be discussed in light of models of deflagration.

\(^{1}\)Work supported by NSF-DMR-1309202 (NYU); ARO W911NF-13-1-0125 (CCNY); DMR-1161571(Lehman); Cottrell College Science Award (UNF).

1:51PM B21.00012 ELECTRO-NUCLEAR CLOCK TRANSITIONS IN A Ho(III) MOLECULAR NANOMAGNET\(^{1}\). DORSA KOMIJANI, M. SHIDDIQ, Department of Physics, Florida State University (NHMFL), FL, Y. DUAN, A. GAITA-ARINO, E. CORONADO, Instituto de Ciencia Molecular (ICMol), Universitat de Valencia, Spain, S. HILL, Department of Physics, Florida State University (NHMFL), FL — One of the challenges in the field of quantum information processing involves protecting qubits against decoherence. The primary source of decoherence in spin qubits at low temperatures is the dipolar interaction, which can be minimized using so-called clock transitions [1]. Here, we report pulsed EPR studies of the Holmium Polyoxometalate, \([\text{Na}_{3}]_{\text{Ho}_{2}}\text{Y}_{1-x}\cdot\text{W}_{x}\text{O}_{3}\text{O}_{8}\text{Cl}_{2}\text{O}_{3}\text{H}_{2}\text{O}\text{H}_{2}\text{O}]\), where we observe electro-nuclear clock transitions that involve coupled dynamics of the electron and nuclear spins \((\Delta m_{J}=\pm 8\text{ and }\Delta m_{I}=\pm 1)\). These transitions are formally forbidden in EPR. However, the symmetry of this molecule generates admixtures of the ground doublet \((m_{J}=\pm 4)\) through second order perturbation, and application of a transverse magnetic field mixes \(m_{J}\) and \(m_{I}\) ± 1 states, allowing such transitions to occur in the vicinity of avoided level crossings. Pulsed EPR measurements on an \(x=0.1\) sample, were carried out at a temperature of \(5\) K at X-band. These experiments suggest an enhancement in the coherence time at these electro-nuclear clock transitions which is significant for applications in hybrid magnetic qubits, where manipulation of the nuclear spin is controlled by EPR pulses. [1] G. Wólfowicz, et al., Nature Nanotechnology 8, 561 (2013).

\(^{1}\)This work was supported by NSF (DMR-1309463) and AFSOR.

2:03PM B21.00013 A Crystal Field Approach to Orbitally Degenerate SMMs: Beyond the Spin-Only Hamiltonian\(^{1}\). LAKSHMI BHASKARAN, Department of Physics and NHMFL, Florida State University, Tallahassee, USA, KATIE MARRIOTT, MARK MURRIE, WestCHEM, School of Chemistry, University of Glasgow, Glasgow, UK, STEPHEN HILL, Department of Physics and NHMFL, Florida State University, Tallahassee, USA — Single-Molecule Magnets (SMMs) with large magnetization reversal barriers are promising candidates for high density information storage. Recently, a large uniaxial magnetic anisotropy was observed for a mononuclear trigonal bipyramidal (TPB) \([\text{Ni}(\text{Cl}(\text{Me-abco})_{3})]^{2+}\) SMM [1]. High-field EPR studies analyzed on the basis of a spin-only Hamiltonian give \(D>400\) cm\(^{-1}\), which is close to the spin-orbit coupling parameter \(\lambda = 668\) cm\(^{-1}\) for Ni\(^{II}\), suggesting an orbitally degenerate ground state. The spin-only description is ineffective in this limit, necessitating the development of a model that includes the orbital, resulting in a phenomenon that takes into account a full description of crystal field, electron-electron repulsion and spin-orbit coupling effects on the ground state of a Ni\(^{II}\) ion in a TBP coordination geometry. The model is in good agreement with the high-field EPR experiments, validating its use for spectroscopic studies of orbitally degenerate molecular nanomagnets. [1] K. E. Marriott et al., Chem Sci (published Online)

\(^{1}\)This work was supported by the NSF (DMR-1309463).

Monday, March 14, 2016 2:30PM - 5:30PM — Session C3 GMAG: Antiferromagnetic Spintronics Ballroom III - Axel Hoffmann, Argonne Natl Lab

2:30PM C3.00001 Electrical switching of an antiferromagnet\(^{1}\). TOMAS JUNGWIRTH, Institute of Physics, Academy of Sciences of the Czech Republic and University of Nottingham UK — Louis Néel pointed out in his Nobel lecture that while abundant and interesting from theoretical viewpoint, antiferromagnets did not seem to have any applications. Indeed, the alternating directions of magnetic moments on individual atoms and the resulting zero net magnetization make antiferromagnets hard to control by tools common in ferromagnets. Strong coupling would be achieved if the externally generated field had a sign alternating on the scale of a lattice constant at which moments alternate in AFMs. However, generating such a field has been regarded unfeasible, hindering the research and applications of these abundant magnetic materials. We have recently predicted that relativistic quantum mechanics may offer staggered current induced fields with the sign alternating within the magnetic unit cell which can facilitate a reversible switching of an antiferromagnet by applying electrical currents with comparable efficiency to ferromagnets. Among suitable materials is a high Néel temperature antiferromagnet, tetragonal-phase CuMnAs, which we have recently synthesized in the form of single-crystal epilayers structurally compatible with common semiconductors. We demonstrate electrical writing and read-out, combined with the insensitivity to magnetic field perturbations, in a proof-of-concept antiferromagnetic memory device. References: [1] J. Zélevny, et al., Phys. Rev. Lett. 113, 157201 (2014). [2] P. Wadley, et al., Nat. Commun. 4, 2322 (2013). [3] P. Wadley et al. http://arxiv.org/abs/1503.03765. [4] T. Jungwirth, X. Marti, P. Wadley, J. Wunderlich, http://arxiv.org/abs/1508.05296.

\(^{1}\)We acknowledge support from European Research Council Advanced Grant no. 268066.
3:06PM C3.00002 Interconnections between magnetic state and transport currents in antiferromagnetic Sr$_2$IrO$_4$ , MAXIM TSOI, The University of Texas at Austin — Interconnections between magnetic state and transport currents in ferromagnetic (F) heterostructures are the basis for spintronic applications, e.g. tunneling magnetoresistance and spin-transfer torque phenomena provide a means to read and write information in magnetic memory devices like STT-RAM. Similar interconnections were proposed [1] to occur in systems where F-components are replaced with antiferromagnets (AFM). We demonstrated experimentally the existence of such interconnections in antiferromagnetic Mott insulator Sr$_2$IrO$_4$: first, we found [2] a very large anisotropic magnetoresistance (AMR) which can be used to monitor (read) the magnetic state of AFM; second, we demonstrated [3] the feasibility of reversible resistive switching driven by high-density currents/high electric fields which can be used for writing in AFM memory applications. These results support the feasibility of AFM spintronic where antiferromagnets are used in place of ferromagnets. This work was supported in part by C-SPIN, one of six centers of STARnet, a Semiconductor Research Corporation program, sponsored by MARCO and DARPA, and by NSF grants DMR-1207577, DMR-1265162 and DMR-1122603. [1] A. S. Núñez et al., Phys. Rev. B 73, 214426 (2006); [2] C. Wang et al., Phys. Rev. X 4, 041034 (2014); [3] C. Wang et al, PRB 92, 115136 (2015).

3:42PM C3.00003 Spin-Hall effects in metallic antiferromagnets.1, WEI ZHANG, Argonne National Laboratory — Materials possessing new parameters for efficient and tunable spin Hall effects are being explored, among which antiferromagnets have become one of the most promising candidates. Two distinct properties of antiferromagnets are the microscopic spin magnetic moment ordering and the intrinsic anisotropy. Thus the natural question arises whether these two unique features of antiferromagnets can become new degrees of freedom for tuning their spin Hall effects. We performed experimental studies using spin pumping and inverse spin Hall detection on prototypical CuAu-I-type metallic antiferromagnets, PtMn, IrMn, PdMn, and FeMn, in which we observed increasing spin Hall effects for the alloys with heavier elements included. In particular, PtMn shows a large spin Hall effect that is comparable to Pt. We also demonstrated that the spin transfer torques from the antiferromagnets are large enough to excite ferromagnetic resonance of an adjacent ferromagnetic layer. We conclude that the sign and magnitude of the spin Hall effects in these antiferromagnets are determined by the atomic spin-orbit coupling of the heavy elements (e.g. Pt and Ir) as well as the large spin magnetic moments of Mn. In addition, by using epitaxial growth, we investigated the influence of the different crystalline and magnetic orientations on the anisotropic spin Hall effects of these antiferromagnets. Most of the experimental results were further corroborated by first-principles calculations, which determine the intrinsic spin Hall Effect contribution and suggest pronounced anisotropies. Thus metallic antiferromagnets may become an active component for manipulating spin dependent transport properties in spintronic concept.1

1Work at Argonne were supported by the U.S. DOE, OM, Materials Sciences and Engineering Division. Work at Center for Nanoscale Materials was supported by DOE, OS-BES (DE-AC02-06CH11357). Work at Julich was supported by SPP 1538 Programme of the DFG.


3 This work was done in collaboration with: M. Benjamin Jungfleisch, Frank Freimuth, Joseph N. Sklenar, Wanjun Jiang, John E. Pearson, Yurii Mokrousov, John B. Ketterson, and Axel Hoffmann


1This research is supported by the U.S. DOE through Grants DE-FG02-03ER46054 and DE-SC0001304, by the NSF MRSEC program through Grant No. 1420451 and by the Army Research Office through Grant W911NF0910147.

4:54PM C3.00005 Mechanism of spin current transfer through antiferromagnetic dielectrics, VASYL TYBERKEVYCH, Oakland University — The mechanisms of spin current (SC) transfer are well-studied in both metallic systems, where SC is carried mostly by spin-polarized electrons, and in ferromagnetic (FM) dielectrics, where propagating spin waves (magnons) are responsible for the spin transfer. The possibility of SC transfer through antiferromagnetic dielectrics (AFMD) is much less investigated, although recent experimental studies by H. Wang et al. [H. Wang et al., Phys. Rev. Lett. 113, 097202 (2014)] demonstrated high extrinsic efficiency of SC transfer in tri-layer FM-AFMD-Platinum (YIG-NIO-Pt) systems measured by the inverse spin Hall effect (ISHE). Perhaps the most unexpected result of these studies was that, with the increase of the thickness of the AFMD layer, the ISHE voltage, first, increased, and, then, exponentially decayed with the characteristic decay length of $\lambda \sim 10$ nm. Moreover, the excitation frequency of SC signal adhered to the ferromagnetic resonance (FMR) frequency of the YIG layer, rather low compared to the frequencies of the antiferromagnetic resonance in the AFMD, which rules out the eigenmodes of the AFMD layer as potential carriers of the spin current. Here we propose a possible mechanism of SC transfer through the AFMD with a biaxial anisotropy, which explains all previous experimental findings and opens a new way of manipulating spin currents using anisotropic AFMD materials. We show, that spin current can be carried by evanescent AFMD modes non-resonantly excited at the FM-AFMD interface. The decay length of the evanescent modes is defined by the AFMD anisotropy and determines the SC penetration depth into the AFMD. Furthermore, the anisotropy of the AFMD leads to the coupling between the spin subsystem and the crystal lattice of the AFMD, which makes possible exchange of angular momentum between these subsystems. We demonstrate that, under certain realistic conditions, the angular momentum flows from the lattice to the spin subsystem, in which case the AFMD layer acts as a spin current amplifier. The enhancement or the suppression of the spin current by the AFMD lattice depends on the phase shift between the two evanescent AFMD modes and, thus, can be controlled by the method of excitation.

Monday, March 14, 2016 2:30PM - 5:18PM – Session C5 GMAG DMP: Frustrated Magnetism: Theory 301 - Gang Chen, Fudan University

2:30PM C5.00001 Functional renormalization group - a new approach to frustrated quantum magnetism , JOHANNES REUTHER, Freie Universitaet Berlin — The experimental and theoretical investigation of quantum spin systems has become one of the central disciplines of contemporary condensed matter physics. From an experimental viewpoint, the field has been significantly fueled by the recent synthesis of novel strongly correlated materials with exotic magnetic or quantum paramagnetic ground states. From a theoretical perspective, however, the numerical treatment of realistic models for quantum magnetism in two and three spatial dimensions still constitutes a serious challenge. This particularly applies to frustrated systems, which complicate the employment of established methods. This talk intends to propagate the pseudofermion functional renormalization group (PFFRG) as a novel approach to determine large size ground state correlations of a wide class of spin Hamiltonians. Using a diagrammatic pseudofermion representation for quantum spin models, the PFFRG performs systematic summations in all two-particle fermionic interaction channels, capturing the correct balance between classical magnetic ordering and quantum fluctuations. Numerical results for various frustrated spin models on different 2D and 3D lattices are reviewed, and benchmarked against other methods if available.
3:06PM C5.00002 Filling constraints for spin-orbit coupled insulators in symmorphic and nonsymmorphic crystals. HARUKI WATANABE, Massachusetts Institute of Technology, HOI CHUN PO, ASHVIN VISHWANATH, UC Berkeley, MICHAEL ZALATEL, Station Q — We determine conditions on the filling of electrons in a crystalline lattice to obtain the equivalent of a band insulator - a gapped insulator with neither symmetry breaking nor fractionalized excitations. We allow for strong interactions, which precludes a free particle description. Previous approaches that extend the Lieb-Schultz-Mattis argument invoked spin conservation in an essential way, and cannot be applied to the physically interesting case of spin-orbit coupled systems. Here we introduce two approaches, the first an entanglement based scheme, while the second studies the system on an appropriate flat Bieberbach manifold to obtain the filling conditions for all 230 space groups. These approaches only assume time reversal rather than spin rotation invariance. The results depend crucially on whether the crystal symmetry is symmorphic. Our results clarify when one may infer the existence of an exotic ground state based on the absence of order, and we point out applications to experimentally realized materials. Extensions to new situations involving purely spin models are also mentioned.

3:18PM C5.00003 Quantum Dimer Model: Phase Diagrams. GARRY GOLDSSTEIN, Cambridge University, CLAUDIO CHAMON, Boston university, CLAUDIO CASTELNOVO, Cambridge University — We present new theoretical analysis of the Quantum Dimer Model. We study dimer models on square, cubic and triangular lattices and we reproduce their phase diagrams (which were previously known only numerically). We show that there are several types of dimer liquids and solids. We present preliminary analysis of several other models including doped dimers and planar spin ice, and some results on the Kagome and hexagonal lattices.

3:30PM C5.00004 Characterizing excitations statistics in fractionalized phases through spectral functions. SIDDHARDH C. MORAMPUDI, FRANK POLLMANN, Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, ARI M. TURNER, Johns Hopkins University, Baltimore, USA — Characterizing topologically ordered phases of matter involves identifying the statistics of their emergent anyonic excitations. We show that the exchange statistics of excitations show characteristic signatures in experimentally relevant spectral functions. Drawing motivation from models of gapped quantum spin liquids and fractional Chern insulators which possess fractionalized anyonic excitations, we consider a model with gapped two particle and three particle abelian anyonic excitations. We show that the low energy part of spectral functions can show a robust behaviour from which the statistics of the excitations can be obtained.

3:42PM C5.00005 From Möbius aromaticity to gapped spin liquids. CHENG-CHIEN CHEN, Argonne National Laboratory, LUKAS MUECHELER, TITUS NEUPERT, Princeton University, JOSEPH MACIEJKO, University of Alberta, ROBERTO CAR, Princeton University — Motivated by the concept of Möbius aromatics in organic chemistry, the Hubbard model on ring-shaped molecules has been shown previously to support a fragile Mott insulator (FMI) ground state, which is distinct from a conventional insulator through its nontrivial transformation properties under point-group symmetry operations. In this talk, we discuss two-dimensional lattices of weakly-coupled FMI molecules belonging to multi-dimensional irreducible representations of the molecular point group. The low-energy effective Hamiltonians map onto quantum compass models with broken spin SU(2) symmetry. On the triangular lattice, the ground state develops long-range magnetism, which corresponds to a charge-ordered state of the molecules. On the honeycomb lattice, interestingly, we find a non-degenerate gapped spin-liquid ground state that preserves all spatial symmetries but transforms nontrivially under point-group operations. Our microscopic model therefore realizes an intrinsically interacting fermionic symmetry protected topological (SPT) phase.

3:54PM C5.00006 Tetrahedral Spin Crystal to a Chiral Spin Liquid: Frustration-induced quantum melting. ARUN PARAMEKANTI, CIARAN HICKEY, University of Toronto, LUKASZ CINCIO, Perimeter Institute, ZLATKO PAPIC, University of Leeds — Motivated by the recent interest in interacting topological phases, we study the Haldane-Hubbard model which is shown to host a Mott insulating state with chiral tetrahedral magnetic texture. Frustration-induced melting of this spin crystal leads to a chiral spin liquid. We discuss the properties of these phases, and the Chern-Simons-Higgs theory of the intervening exotic quantum critical point.

4:06PM C5.00007 Symmetric tensor networks and practical simulation algorithms to sharply identify classes of quantum phases distinguishable by short-range physics. YING RAN, SHENHAN JIANG, Boston College — Phases of matter are sharply defined in the thermodynamic limit. One major challenge of accurately simulating quantum phase diagrams of interacting quantum systems is due to the fact that numerical simulations usually deal with the energy density, a local property of quantum wavefunctions, while identifying different quantum phases generally rely on long-range physics. In this paper we construct generic fully symmetric quantum wavefunctions under certain assumptions using a type of tensor networks, which are very powerful practical simulation algorithms based on them. We find that quantum phases can be organized into crude classes distinguished by short-range physics, which is related to the fractionalization of both on-site symmetries and space-group symmetries. Consequently, our simulation algorithms, which are useful to study strong-range physics as well, are expected to be able to sharply determine crude classes in interacting quantum systems efficiently. Examples of these crude classes are demonstrated in half-integer quantum spin systems on the kagome lattice. Limitations and generalizations of our results are discussed.

4:18PM C5.00008 Numerical studies of AKLT valence bond solids in one, two and three dimensions. KEOLA WIERSCHEM, KEVIN BEACH, The University of Mississippi — The fixed-point valence bond solids of Affleck, Kennedy, Lieb and Tasaki (the so-called AKLT states) have become archetypes of symmetry protected topological order. These states are constructed by first placing $M$ valence bonds on each pair of neighboring lattice points, and then symmetrizing the $M$ resulting spin-1/2 degrees of freedom at each lattice site into a combined spin-$S$ degree of freedom with $2S = M z$ (where $\text{MW}$ is the multiplicity of the AKLT state and $z$ is the lattice coordination number). Using Monte Carlo sampling of the AKLT wavefunctions in the loop gas framework, we directly calculate correlation functions and energy gap estimators for these states in one, two and three dimensions. We also study the behavior of the so-called strange correlator, which has been proposed as a measure of symmetry protected topological order.

4:30PM C5.00009 Theory of supersymmetry "protected" topological phases of isostatic lattices and highly frustrated magnets. MICHAEL LAWLER, Binghamton University — I generalize the theory of phonon topological band structures of isostatic lattices to highly frustrated antiferromagnets. I achieve this with a discovery of a many-body supersymmetry (SUSY) in the phonon problem of balls and springs which also applies to geometrically frustrated magnets. The Witten index of the SUSY model, when restricted to the single body problem of isostatic lattices to highly frustrated antiferromagnets. The analogous supersymmetry of the magnon problem turns out to be particularly useful for highly frustrated magnets with the kagome family of antiferromagnets an analog of topological isostatic lattices. Thus, a solid state realization of the theory of phonon topological band structure may be found in highly frustrated magnets. However, our results show that this topology is protected not
Frustration can induce novel phenomena in the transport properties of itinerant magnets. The "amount of frustration" is typically quantified by the $T_{C}/T_C$ ratio. A large value of this ratio corresponds to a broad temperature regime $T_{C} < T < T_C$, where the spins are in spin liquid state, i.e., the magnetic structure factor is not flat, as in the gas ($T > \Theta_{CW}$) state and it does not contain Bragg peaks, as in the ordered or "solid" state at $T_{C}$. We demonstrate that when interaction between magnetic moments is mediated by the conduction electrons, the electronic resistivity increases upon lowering temperature, due to enhanced scattering rate for $k \leq 2k_F$. To illustrate this phenomenon we consider a triangular Kondo lattice model with classical local moments. By using both analytical and numerical methods, we unambiguously demonstrate that the electronic resistivity grows upon lowering temperature inside the spin liquid regime. This growth necessarily leads to a resistivity minimum when electron-electron and electron-phonon scattering are included. We note that the origin of this resistivity minimum is radically different from the well-known minimum induced by the Kondo effect.

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5:06PM C5.00012 Lifting mean field degeneracies in anisotropic spin systems

3DM, ANANDAKUMAR SARELLA, F. I. KAYA, K. E. AIDALA, Mt Holyoke Coll — Ferromagnetic nanostructures can exhibit intriguing magnetic states, such as the metastable 360 domain wall (DW), in which two 180 DWs combine to form a nearly flux closed state in sufficiently thin structures. These composite structures have potential to maximize storage densities due to their minimal stray fields. We study a straightforward method to nucleate 360 DWs in nanorings, nanowires, using in-plane circular fields, as if from a current carrying wire passing through the substrate in close proximity to the nanostructures. Our simulations, using OOMMF, predict that the vortex state of a ring with appropriate geometry will reverse from CW to CCW through an intermediate phase consisting of pairs of 360 DWs. We examine the dependence of the switching field and intermediate states on geometric properties such as the diameter, thickness, and width of the ring. Using the local circular field, we can also nucleate 360 DWs in nanowires, pinning the location of the DWs at notches spaced as close as 100 nm apart, suggesting high density storage. We are currently studying these structures experimentally using AFM/MFM. We generate the circular field by passing current through AFM tip and image the resulting magnetic states with MFM.

Simulations were run on the Odyssey cluster, Research Computing Group at Harvard.

2:42PM C6.00002 Quantitative X-Ray Magnetic Microscopy: from parallel stripe domains to buried topological defects

NOMMF, predict that the vortex state of a ring with appropriate geometry will reverse from CW to CCW through an intermediate phase consisting of pairs of 360 DWs. We examine the dependence of the switching field and intermediate states on geometric properties such as the diameter, thickness, and width of the ring. Using the local circular field, we can also nucleate 360 DWs in nanowires, pinning the location of the DWs at notches spaced as close as 100 nm apart, suggesting high density storage. We are currently studying these structures experimentally using AFM/MFM. We generate the circular field by passing current through AFM tip and image the resulting magnetic states with MFM.

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Work supported by Spanish grant FIS2013- 45469
2:54PM C6.00003 Soft x-ray ptychography studies of nanoscale magnetic and structural correlations in thin SmCo5 films. P. FISCHER, MSD LBNL Berkeley CA 94720, X. SHI, ALS LBNL Berkeley, CA 94720, V. NEU, D. ELEFANT, IFW Dresden Germany, J.C.T. LEE, D.A. SHAPIRO, M. FARMAID, T. TYLISZCZAK, W. SHIU, S. MARCHESINI, S. ROY, S.D. KEVAN, ALS LBNL Berkeley CA 94720 — Soft x-ray ptychographic imaging was applied to probe an amorphous 50 nm thin SmCo5 film prepared by off-axis pulsed laser deposition and exhibiting a strong perpendicular magnetic anisotropy. Amplitude and phase contrast images, retrieved at photon energies near the cobalt L3 resonance, were used to identify and characterize magnetic and structural features with a spatial resolution of about 10 nm. Aside from the common magnetic labyrinth domain pattern, nanoscale structural inclusions were identified that are primarily located in close proximity to the magnetic domain walls. X-ray absorption spectroscopy suggests that these inclusions are nanocrystalline Sm2Co17 phases with nominally in-plane magnetic anisotropy. Our results indicate that x-ray ptychographic imaging enables fruitful studies of magnetic and structural correlations at length scales relevant to emerging magnetic and spintronic devices.

2:54PM C6.00004 Asymmetric and Stochastic Behavior in Magnetic Vortices Studied by Soft X-ray Microscopy. MI-YOUNG IM, LBNL — Asymmetry and stochasticity in spin processes are not only long-standing fundamental issues but also highly relevant to technological applications of nanomagnetic structures to memory and storage nanodevices. Those nontrivial phenomena have been studied by direct imaging of spin structures in magnetic vortices utilizing magnetic transmission soft x-ray microscopy (BL6.1.2 at ALS). Magnetic vortices have attracted enormous scientific interests due to their fascinating spin structures consisting of circularity rotating clockwise ($c = +1$) or counter-clockwise ($c = -1$) and polarity pointing either up ($p = +1$) or down ($p = -1$). We observed a symmetry breaking in the formation process of vortex structures in circular permalloy ($Ni_{81}Fe_{20}$) disks. The generation rates of two different vortex groups with the signature of $c = +1$ and $p = -1$ are completely asymmetric. The asymmetric nature was interpreted to be triggered by intrinsic Dzyaloshinskii-Moriya interaction (DMI) arising from the spin-orbit coupling due to the lack of inversion symmetry near the disk surface and extrinsic factors such as roughness and defects. We also investigated the stochastic behavior of vortex creation in the arrays of asymmetric disks. The stochasticity was found to be very sensitive to the geometry of disk arrays, particularly interdisk distance. The experimentally observed phenomenon couldn’t be explained by thermal fluctuation effect, which has been considered as a main reason for the stochastic behavior in spin processes. We demonstrated for the first time that the ultrafast dynamics at the early stage of vortex creation, which has a character of classical chaos significantly affects the stochastic nature observed at the steady state in asymmetric disks. This work provided the new perspective of dynamics as a critical factor contributing to the stochasticity in spin processes and also the possibility for the control of the intrinsic stochastic nature by optimizing the design of asymmetric disk arrays.

2:54PM C6.00005 Ultrafast Soft X-ray Microscopy: Pushing the Limits of Time Resolution and Magnetic Sensitivity. HENDRIK OHLDAG, SLAC — Natl Accelerator Lab — Understanding magnetic ultrafast timescales is crucial for the development of new magnetic devices. Samples of interest are often thin film magnetic multilayers with thicknesses in the range of a few atomic layers. This fact alone presents a sensitivity challenge in STXM microscopy, which is more suited toward studying thicker samples. In addition the relevant time scale is of the order of 10 ps, which is below the typical x-ray pulse length of 50-100 ps. The SSRL STXM is equipped with a single photon counting electronics that effectively allows using a double lock-in detection at 476MHz (the x-ray pulse frequency) and 1.28MHz (the synchrotron revelation frequency) to provide the required sensitivity. In the first year of operation the SSRL STXM was the only soft x-ray microscope in the world that could acquire time resolved images of standing as well as traveling spin waves in a thin magnetic film in real space as well as detect the real time spin accumulation in non magnetic Copper once a spin polarized current is injected into this material. The total magnetic moment is comparable to that of a single nanocube of magnetic Fe buried under a micron of non-magnetic material.

3:06PM C6.00006 ABSTRACT WITHDRAWN —

4:06PM C6.00007 Magnetothermology of hybrid colloids measured by spin coating and classical rheometry. RAHEEMA MUHAMMAD ASLAM, University of Navarra, Spain, KESHWAD SHAHRIVAR, JUAN DE VICENTE LVAREZ-MANZANEDA, University of Granada, Spain, WENCESLAO GONZALEZ-VIAS, University of Navarra, Spain — Hybrid colloids composed of micron-sized ferromagnetic and diamagnetic particles constitute a promising category of magnetothermological fluids with enhanced field-induced apparent yield stress. However, the physical mechanism explaining this stress enhancement is currently lacking. For the first time, we measure and compare the magnetic field-dependent viscosity of hybrid diluted colloids using spin-coating [1] and magnetothermometry [2]. In the former technique, a magnetic field is applied during the spin coating of the colloidal suspension involving evaporation of the solvent. The viscosity of the colloidal suspension at applied field can be derived from the surface coverage of the dry spin-coated deposits and from the viscosity of the colloid at zero field. In the latter, its viscosity is measured with a torsional parallel plate magnetorheometer under uniaxial magnetic fields aligned in the gradient direction of a steady shearing flow. The experimental results under different conditions and the effect of each component on the magnetothermological properties of the resulting colloid will be discussed. [1] M. Pichiumani et al., Soft Matter, 2013, 9, 3220-3229 [2] Juan de Vicente et al., Soft Matter, 2011, 7, 3701-3710

This work is partly supported by the Spanish MINECO (FIS201454101-P).

4:18PM C6.00008 Accuracy of MRI-based Magnetic Susceptibility Measurements. STEPHEN RUSSEK, HANNAH ERDEVIG, KATHRYN KEENAN, KARL STUPIC, NIST - Boulder — Magnetic Resonance Imaging (MRI) is increasingly used to map brain structure and function. MRI-based susceptometry is shown to be as or more accurate than standard magnetometry and susceptometry techniques.

This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, by Leading Foreign Research Institute Recruitment Program through the NRF.

3:06PM C6.00004 Asymmetric and Stochastic Behavior in Magnetic Vortices Studied by Soft X-ray Microscopy

1Supported by the Director of the Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DEAC02-05CH11231.

3:42PM C6.00005 Ultrasensitive Scanning Transmission X-ray Microscopy: Pushing the Limits of Time Resolution and Magnetic Sensitivity

1Supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231, by Leading Foreign Research Institute Recruitment Program through the NRF.
4:30PM C6.00009 Neutron interferometry with cold stage1, TAIYSI MINEEVA, Institute for Quantum Computing, M ARIF, M.G. HUBER, National Institute of Standards and Technology, C.B. SHAHI, Tulane University, C.W. CLARK, Joint Quantum Institute, D.G. CORY, J. NSOFINI, D. SARENAC, D.A. PUSHIN, Institute for Quantum Computing — Neutron interferometry (NI) is amongst the most precise methods for characterizing neutron interactions by measuring the relative difference between two neutron paths, one of which contains a sample-of-interest. Because neutrons carry magnetic moment and are deeply penetrating, they are excellent probes to investigate properties of magnetic materials. The advantage of NI is its unique sensitivity which allows to directly measure magnetic and structural transitions in materials. Up to now NI has been sparingly used in material research due to its sensitivity to environmental noise. However, recent successes in implementing Quantum Error Correction principles lead to an improved NI design making it robust against mechanical vibrations. Following these advances, a new user facility at the National Institute for Standards and Technology was built to study condensed matter applications, biology and quantum physics. Incorporating cold sample stage inside NI is the first of its kind experiment which can be carried out on large range of temperatures down to 4K. Upon successful realization, it will open new frontiers to characterize magnetic domains, phase transitions and spin properties in a variety of materials such as, for example, iron-based superconductors and spintronic materials.

1Supported in part by CERC, CIFAR, NSERC and CREATE.

4:42PM C6.00010 Relaxometry imaging of superparamagnetic magnetite nanoparticles at ambient conditions, AMIT FINKLER, DOMINIK SCHMID-LORCH, THOMAS HÄBERLE, 3. Physikalisches Institut, Universität Stuttgart, FRIEDEMANN REINHARD, Technische Universität München, ANDREA ZAPPE, 3. Physikalisches Institut, Universität Stuttgart, MICHAEL SLOTA, 1. Physikalisches Institut, Universität Stuttgart, LAPO BOGANI, Department of Materials, University of Oxford, JÖRG WRACHTRUP, 3. Physikalisches Institut, Universität Stuttgart — We present a novel technique to image superparamagnetic iron oxide nanoparticles via their fluctuating magnetic fields. The detection is based on the nitrogen-vacancy (NV) color center in diamond, which allows optically detected magnetic resonance (ODMR) measurements on its electron spin structure. In combination with an atomic-force-microscope, this atomic-sized color center maps ambient magnetic fields in a wide frequency range from DC up to several GHz [1], while retaining a high spatial resolution in the sub-nanometer range [2]. We demonstrate imaging of single 10 nm sized magnetite nanoparticles using this spin noise detection technique. By fitting simulations (Ornstein-Uhlenbeck process) to the data, we are able to infer additional information on such a particle and its dynamics, like the attempt frequency and the anisotropy constant [3]. This is of high interest to the proposed application of magnetite nanoparticles as an alternative MRI contrast agent or to the field of particle-aided tumor hyperthermia. [1] E. Schäfer-Nolte et al., Phys. Rev. Lett. 113, 217204 (2014) [2] P. Maletinsky et al., Nat. Nanotech. 7, 320 (2012) [3] D. Schmid-Lorch et al., Nano Lett. 15, 4942 (2015)

4:54PM C6.00011 Toward Hybrid Functional Systems integrating Nitrogen Vacancy Centers in Diamond and Model Ferrimagnets, HUILIANG ZHANG, FRANCESCO CASOLA, Harvard-Smithsonian Center for Astrophysics and Department of Physics, Harvard University, TOENO VAN DER SAR, MARC WARNER, Department of Physics, Harvard University, MEHMET ONBASLI, Department of Materials Science and Engineering, MIT, MIKE BUREK, MARKO LONCAR, School of Engineering and Applied Sciences, Harvard University, CAROLINE ROSS, Department of Materials Science and Engineering, MIT, RONALD WALSWORTH, Harvard-Smithsonian Center for Astrophysics and Department of Physics, Harvard University, AMIR YACOBY, Department of Physics, Harvard University — The development of a hybrid system integrating a low magnon damping ferromagnet with the single electron spin addressability of Nitrogen Vacancy (NV) centers in diamond has been recently proposed as a viable route for novel quantum information and enhanced magnetic field sensing experiments. We present our recent experimental efforts in the realization of devices with thin films of the model ferrimagnetic insulator Yttrium Iron Garnet (YIG). The crucial proximity between NVs and the YIG interface is realized by the selective transferring and positioning of diamond nanorods. Such a scheme has allowed NV-based ferromagnetic resonance and noise spectroscopy experiments of single, micrometer-scale, YIG patterns defined on a lattice matched substrate. We will discuss challenges and possibilities defined by the present results in the direction of the theoretically proposed experiments.

5:06PM C6.00012 Measurements of magnetic spin excitations in Permalloy microstructures using nitrogen-vacancy magnetometry, H.J. JASON LIU, SEUNGHA YOON1, ROBERT MCMICHAEL, Center for Nanoscale Science and Technology, National Institute of Standards and Technology — The magnetic properties of nitrogen-vacancy (NV) centers in diamond have enabled emerging applications in fields ranging from cell biology to quantum computing. An NV center is a lattice defect, which behaves like a spin-1 system. NV centers can be prepared in the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light. The Zeeman splitting of the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light. The Zeeman splitting of the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light. The Zeeman splitting of the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light. The Zeeman splitting of the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light. The Zeeman splitting of the m<sup>−</sup> state by excitation with green light, and the spin state can be detected by the center’s fluorescence of red light.

5:18PM C6.00013 Using NV-centers in diamond for optical magnetic sensing in superconductors1, N M NUSRAN, K R JOSHI, K CHO, R PROZOROV, Ames Laboratory and Iowa State University — Magnetic field–dependent fluorescence of nitrogen vacancy (NV) centers in diamond has recently emerged as a promising technology for nanoscale sensing including non-invasive sensitive magnetometry and mapping of the magnetic field distribution. In particular, NV-sensing can be used to study magnetic phenomena in superconductors. After detailed introduction of this novel magneto-sensing technique, we will present results of magnetic measurements on several superconductors, including Ba<sub>1−x</sub>K<sub>x</sub>Fe<sub>2</sub>As<sub>2</sub> and type-I materials. Details of the superconducting phase transition, the Meissner state, magnetic flux distribution upon field penetration, exit and trapping will be discussed.

1This work was supported by the U.S. Department of Energy, Office of Basic Energy Science, Materials Science and Engineering Division and was performed at the Ames Laboratory, Iowa State University under contract DE-AC02-07CH11358.

Monday, March 14, 2016 2:30PM - 5:18PM –
Session C18 GMAG DMP: Iridates I
317 - Deepak Singh, University of Missouri
2:30PM C18.00001 Topological and unconventional magnetic states in transition metal oxides
GREGORY FIEITE, University of Texas at Austin — In this talk I describe some recent work on unusual correlated phases that may be found in bulk transition metal oxides with strong spin-orbit coupling. I will focus on model Hamiltonian studies that are motivated by the pyrochlore iridates, though the correlated topological phases described may appear in a much broader class of materials. I will describe a variety of fractionalized topological phases protected by time-reversal and crystalline symmetries. The weak topological Mott insulator (WTMI), the TI* phase, and the topological crystalline Mott insulator (TCMI). If time permits, I will also discuss closely related heterostructures of pyrochlore iridates in a bilayer and trilayer film geometry. These quasi-two dimensional systems may exhibit a number of interesting topological and magnetic phases.

3:06PM C18.00002 Multipolar effects in Eu2Ir2O7
YILIN WANG, XI DAI, Institute of Physics, Chinese Academy of Sci (CAS) — We use the density functional theory plus the rotationally invariant Hartree-Fock mean-field method to study the magnetic properties of the pyrochlore iridate material Eu2Ir2O7 (5d ef), where the crystal field splitting Δs, spin-orbit coupling (SOC) λ and Coulomb interaction U of Ir atoms are all playing significant roles. We have constructed a 12g Wannier tight-binding Hamiltonian and calculated the U−λ phase diagram, from which we find a very stable all-in/all-out antiferromagnetic ground state for moderate SOC (0.2-0.5 eV). In this magnetic state, except for the dipole moments, we also find considerable multipolar moments (octupole) and large non-linear magnetic susceptibility. With strong enough SOC, the system reduces to a J_{eff} = \frac{3}{2} single band Hubbard model, and the ground state changes to another antiferromagnetic configuration without multipolar moments. Our results indicate that the coexisting multipolar order is crucial to stabilize the all-in/all-out state and contributes a lot to the non-linear magnetic susceptibility.

3:18PM C18.00003 Resonant X-ray scattering studies of magnetic order and excitations in pyrochlore iridates
DESMOND MCMORROW, London Center Nanotechnology — The rare-earth pyrochlore iridates (R2Ir2O7, R= rare earth) have been proposed to host a number of exotic electronic states as a consequence of the existence of strong spin-orbit coupling of the Ir^{4+} ion in the presence of significant electron correlations. Of crucial importance to understanding whether any of these states can be realized in practice is to determine the effective low-energy Hamiltonian describing the system. Here we report a comprehensive series of resonant X-ray experiments, both elastic (REXS) and inelastic (RIXS), which reveal the nature of the magnetic order and excitations in single crystals of Sm2Ir2O7 and Nd2Ir2O7.

3:54PM C18.00004 ABSTRACT WITHDRAWN —

4:06PM C18.00005 The interplay of ferromagnetic and antiferromagnetic exchanges in the the 3d-5d transition metal oxides Sr2BiIrO6 (B=Ni, Cu, Zn)
KATHARINA ROLFS, EKATERINA POMJAKUSHINA, SANDOR TOTH, VLADIMIR POMJAKUSHIN, KAZIMIERZ CONDER, Paul Scherrer Institute — In the field of strongly correlated electron systems significant attention has been drawn towards the study of compounds based on magnetic 4d and 5d transition metal (TM) oxides. The spin orbit coupling (SOC) within these systems becomes non-negligible compared to the crystal field energies and leads to new exotic ground states, such as the Mott insulating state in Sr2IrO4. In order to understand the influence of the SOC, we have used a first-principles electronic ground state to the focus also turned to mixed 3d-5d systems, which will give the possibility to disentangle SOC effects from common charge-spin-orbital physics, as it is present in pure 3d TMOs and could also introduce new properties. One group within these candidates is the group of Ir-based double perovskites A2BiIrO6 (B=3d TM). While in a large number of insulating 3d TMOs, the superexchange interactions between magnetic ions being nearest neighbour is adequate to determine the magnetic order, the SOC of 5d elements can change the exchange topology. This is possibly the case for Sr2Ir2O6, Sr2CuIrO6 and Sr2ZnIrO6. All compounds have high oxygen pressure compounds, which we successfully synthesised. The influence of the 3d metal on the magnetic properties will be discussed based on bulk magnetisation, transport measurements and neutron diffraction.

4:18PM C18.00006 Magnetic Orders Proximal to the Kitaev Limit in Frustrated Triangular Systems: Application to Ba3IrTi2O9
ANDREI CATUNEANU, Department of Physics and Center for Quantum Materials, University of Toronto, JEFFREY RAU, Department of Physics and Astronomy, University of Waterloo, HEUNG-SIK KIM, HAE-YOUNG KEE, Department of Physics and Center for Quantum Materials, University of Toronto — Frustrated transition metal compounds in which spin-orbit coupling (SOC) and electron correlation work together have attracted much attention recently. In the case of 5d transition metals, where SOC is large, J_{eff} = 1/2 bands near the Fermi level are thought to encompass the essential physics of the material, potentially leading to a concrete realization of exotic magnetic phases such as the Kitaev spin liquid. We derive a spin model on a triangular lattice based on J_{eff} = 1/2 pseudo-spins that interact via antiferromagnetic Heisenberg (J) and Kitaev (K) exchanges, and crucially, an anisotropic (T) exchange. Our classical analysis of the spin model reveals that, in addition to small regions of 120°, Z_2 / dual-Z_2 vortex crystal and nematic phases, the striped and ferromagnetic phases dominate the J-K-T phase diagram. We apply our model to the 5d transition metal compound, Ba3IrTi2O9, in which the Ir^{4+} ions form layered two-dimensional triangular lattices. By combining our ab-initio and classical analyses, we predict that Ba3IrTi2O9 has a striped ordered magnetic ground state.

4:30PM C18.00007 Spin-Orbit Induced Emergent Magnetic Phases in Iridium Based Oxides
INDRA DASGUPTA, Department of Solid State Physics, Indian Association for the Cultivation of Science, Jadavpur, Kolkata 700032 — We shall present our results on the electronic structure of 6H perovskite type quaternary iridates Ba3Ir2O9, in which Ir ions form structural dimers and non magnetic M provides a knob to tailor the valence of Ir. We shall first consider the d^{4.5} insulator Ba3Ir2O9 and explain the origin of the pressure induced magnetic transition to a spin-orbital liquid (SOL) state in this system. As a next example [2], we shall consider a pentavalent (d^{3}) 6H perovskite iridate Ba3ZnIrO9 and argue that the ground state of this system is a realization of novel SOL state. Our results reveal that such a system provides a very close realization of the elusive J=0 state where Ir local moments are generated due to the comparable energy scales of the singlet-triplet splitting driven by spin-orbit coupling (SOC) and the superexchange interaction mediated by strong intra-dimer hopping, however substantial frustrated interdimer exchange interactions induce quantum fluctuations favoring SOL phase at low enough temperature. [1] S.K. Panda, S. Bowal, Ying Li, S. Ganguly, Roser Valenti, L. Nordstrom, and I. Dasgupta Physical Review B (Rapid Communication), 2015 (Accepted for Publication), [2] A. Nag et. al. arXiv:1506.04312 [cond-mat.str-el]
4:42PM C18.00008 Orbital-selective singlet dimer formation and suppression of double exchange in 4d and 5d systems. SERGEY STRELTsov, Institute of Metal Physics, GANg CAO, University of Kentucky, DANIEL KHM0Ski, University of Cologne. One of the main mechanisms of ferromagnetic ordering in conducting materials is the double exchange (DE). It is usually supposed in DE model that the Hund’s coupling $J_H$ is much larger than electron hopping $t$; in this case one stabilizes the state with maximum spin per pair of ions, which finally leads to ferromagnetism in bulk systems. We show that in the dimerized 4d/5d transition metal oxides for which $J_H$ is reduced and $t$ is in contrast enhanced, another situation is possible, when formation of the spin-singlets on delocalized orbitals is more favorable. This leads to suppression of the DE and to a strong decrease of the total spin. The model calculations using the dynamical mean-field theory show that this effect survives even in the extended systems, not only for dimers. Such a situation is realized, e.g., in $\gamma$Y$\textsubscript{2}$$\text{MoO}_3$, CrO$_2$ under pressure and in many other 4d/5d based materials. Another mechanism, which may suppress DE and which is also typical for 4d/5d compounds is the spin-orbit coupling (SOC). We show on the example of Ba$_2$Al$_2$Ir$_2$O$_{11}$, that in this system it is the combination of molecular-orbital formation and SOC that strongly decreases magnetic moment on Ir.$^1$

$^1$Civil Research and Development Foundation via FSCX-14-61025-0

4:54PM C18.00009 Investigation of frustrated antiferromagnet on the honeycomb lattice with an applied field. SHENXIU LIU, Division of Applied Physics, Stanford University, HONGCHENG JIANG, TOM DEVEREAUX, Stanford Institute of Materials and Energy Sciences, SLAC. Quantum spin-1/2 honeycomb XY antiferromagnet, or the equivalent hard-core boson system, with both nearest-neighbor J1 and next-nearest-neighbor J2 interactions is a representative frustrated system possibly hosting new phases of matter. Recent theoretical studies suggest that this system may exhibit a series of incompressible states, which host fermionic elementary excitations rather than bosonic excitations, at small fixed filling factors or equivalent magnetic field strength. In this work, we will examine the theoretical prediction by directly studying the frustrated honeycomb J1-J2 XY model, using unbiased grand canonical density-matrix renormalization group technique. By searching for magnetization plateaus with an applied magnetic field, we will ultimately determine the presence of these incompressible states as well as their properties. For a more comprehensive study, different variants of this model, including the honeycomb J1-J2 Heisenberg antiferromagnet, will also be investigated.$^2$

$^2$this work is supported by the Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division, under Contract DE-AC02-76SF00515.

5:06PM C18.00010 Topological magnon bands in pyrochlore iridate thin films. PONTUS LAURELL, GREGORY A FITE, University of Texas at Austin. Thin films of pyrochlore iridates (A$_2$Ir$_2$O$_7$) have previously been studied using weak-coupling techniques such as DFT and DMFT. Here we approach the systems from the strong coupling limit. Since the pyrochlore iridates most likely reside in the difficult-to-access intermediate coupling regime, a strong coupling study should offer a complementary viewpoint to existing studies. We carry out a variational mean-field calculation of the magnetic ground state configurations. We show that the all-in/all-out state, known as the magnetic ground state, is generically present in the triangular-Kagome-triangular trilayers. This state can also be found in bilayer films, in specific parameter regimes. A linear spin-wave analysis of the magnetic excitations is also carried out. It shows that when the magnetic order is in (or close to) the all-in/all-out state, the lowest magnon band acquires a non-zero Chern number, leading to the prediction that pyrochlore iridate thin films can host the magnon Hall effect.

Monday, March 14, 2016 2:30PM - 5:30PM - Session C19 GMAG DMP: Epitaxial Engineering of Magnetic Oxide Thin Films 318 - Mark Huijbens, University of Twente

2:30PM C19.00001 Epitaxial Engineering of Domain Walls and Distortions in Ferrite Heterostructures. JULIA MUNDY, UC Berkeley. The defining feature of ferroics is the ability of an external stimulus—electric field, magnetic field, or stress—to move domain walls. These topological defects and their motion enables many useful attributes, e.g., memories that can be reversibly written between stable states as well as enhanced conductivity, permittivity, permeability, and piezoelectricity. Although methods are known to drastically increase their density, the placement of domain walls with atomic precision has until now evaded control. Here we engineer the location of domain walls with monolayer precision and exploit this ability to create a novel multiferroic in which ferroelectricity enhances magnetism at all relevant length scales. Starting with hexagonal LuFeO$_3$, a geometric ferroelectric with the greatest known planar ruffling, we introduce individual extra monolayers of FeO during growth to construct a formula-unit-thick sytactic layers of ferrimagnetic LuFeO$_3$ within the LuFeO$_3$ mosaic, i.e., (LuFeO$_3$)$_m$/[LuFeO$_3$]$_1$ superlattices. The severe ruffling imposed by the neighboring LuFeO$_3$ drives the ferrimagnetic LuFeO$_3$ into a simultaneously ferroelectric state and reduces the LuFeO$_3$ spin frustration. This increases the magnetic transition temperature significantly—to 281 K for the (LuFeO$_3$)$_m$/[LuFeO$_3$]$_1$ superlattice. Moreover, LuFeO$_3$ can form charged ferroelectric domain walls, which align to the LuFeO$_3$ bilayers with monolayer precision. Charge transfers to these domain walls to alleviate the otherwise electrostatically unstable polarization arrangement, further boosting the magnetic moment. Our results demonstrate the utility of combining ferroics at the atomic-layer level with attention to domain walls, geometric frustration and polarization doping to create multiferroics by design.

3:06PM C19.00002 Understanding the Interplay of Polar, Magnetic, and Electronic Order in Ferroic (LuFeO$_3$)$_m$/LuFeO$_3$ Superlattices. ALEJANDRO REBOLA, Cornell University, HENA DAS, Lawrence Berkeley National Laboratory. CRAIG FENNIE, Cornell University. Multiferroics are not only important from a technological point of view but also because of the rich and complex physics that results from the interplay between spin, charge and structural distortions. Hexagonal LuFeO$_3$ has recently been understood theoretically and experimentally, and shown to be an improper structural ferroelectric with a cofacial honeycomb lattice. The magnetic ground state configuration of LuFeO$_3$ is structurally homogeneous to LuFeO$_3$—both are characterized by a FeO$_6$ bipyramidal crystal field—unlike the latter it exhibits a much larger magnetic moment and it is still a matter of debate whether it is ferroelectric. The double Fe-layer in LuFeO$_3$ is thought to be charge ordered and highly frustrated, resulting in possible polar, non-polar or anti-polar charge arrangements. Here we first investigate the relation between different charge and magnetic orders and structural distortions in bulk LuFeO$_3$ by DFT and Monte Carlo calculations. Then we concentrate on a system that combines both mechanisms—a structural improper ferroelectric and a charge frustration that is controlled by a modulation of the FeO$_6$ bond lengths as $m$ in (LuFeO$_3$)$_m$/LuFeO$_3$.
3:30PM C19.00004 Ferroelectric-ferromagnetic coupling in hexagonal YMnO$_3$ film.\textsuperscript{1} SHAOBO CHENG, MENGLEI LI, SHIQIONG DENG, SHANYONG BAO, PEIZHE TANG, WENHUI DUAN, JING MA, CEWEN NANG, JING ZHU, Tonghua University — Simultaneously achieving ferroelectricity and ferromagnetism in a single phase material is an important research topic in recent decades. Here, we demonstrate that with the modulation of oxygen vacancies, the ferroelectric-ferromagnetic coupling can be realized in the typical hexagonal manganite: YMnO$_3$. The first-principal calculations are used to reveal the importance of oxygen vacancies on the alterations of magnetic behaviors for YMnO$_3$. In order to obtain net magnetic moments, the on-top oxygen polarization of MnO$_2$ clusters should be created, thus the initial 2D spin frustration structure of Mn ions will be broken. By growing YMnO$_3$ film on Al$_2$O$_3$ substrate, large in-plane compressive strain is induced, thus we can experimentally realize the on-top oxygen vacancies. With the help of SQUID and spherical aberration corrected TEM, the magnetic moments are experimentally measured and the correlations between the crystal structures and magnetic properties can be clearly understood. Our findings may pave a way for future applications of single phase multiferroic materials.

\textsuperscript{1}National 973 Project of China (2015CB654902, 2011CB606405) and Chinese National Natural Science Foundation (11374174, 51390471)

3:42PM C19.00005 An oxygen-deficiency modulated multiferroic: Cobalt-substituted pervoskite\textsuperscript{1} , JUAN MANUEL FLOREZ, Universidad Tecnica Federico Santa Maria; Massachusetts Inst. of Tech. — In this work, we use density functional theory to model recently demonstrated room temperature ferromagnetism and ferroelectricity in polycrystalline and single crystal Cobalt-substituted SrTiO$_3$ thin films (Sr(Ti$_{0.7}$Co$_{0.3}$O$_{3-d}$)), deposited at different oxygen pressures to change their oxygen vacancy concentration. The modeling indicates an origin for both magnetism and electric polarization in the interactions between oxygen vacancies and the B-site cations. The magnetization saturation increases with the oxygen deficiency as a result of valence spin states changes, which depend on whether the oxygen octahedral of the respective local B-site cations are complete or not. On the other hand, a finite electric polarization appears as a result of a non-centrosymmetric distribution of different resulting local charges and such a polarization increases when the oxygen vacancies increase. Increasing of both order parameters, magnetic and ferroelectric, are analyzed respect to all possible Co-sites and O-vacancies distributions, showing that these results suggest a class of multiferroic materials with properties controlled by their oxygen stoichiometry. Agreement and discrepancies between experiments and modeling are discussed.

\textsuperscript{1}M Florez and P Vargas thank Fondecyt 1130950 and 11130128, all authors thank the MISTI MIT-Chile, and CAR thanks the (S3TEC) and DoE under DE-SC0001299

3:54PM C19.00006 Transport and Raman signatures of electron-doped SmNiO$_3$ thin films . KOUSHIK RAMADOSS, School of Materials Engineering, Purdue University, West Lafayette, IN 47907, NIRAJAN MANDAL\textsuperscript{1}, Department of Physics, Purdue University, West Lafayette, IN 47907, YOU ZHOU, School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, YONG CHEN\textsuperscript{2}, Department of Physics, Purdue University, West Lafayette, IN 47907, SHIRAM RAMANATHAN, School of Materials Engineering, Purdue University, West Lafayette, IN 47907 — We report low temperature transport and Raman spectroscopy measurements of electron-doped SmNiO$_3$ (SNO) thin films. It has been shown that pristine SNO films can be doped with electrons using hydrogen. Our transport measurements indicate a Coulomb interaction dominated variable range hopping (VRH) for electron-doped samples whereas the pristine films show a Mott type VRH mechanism at low temperatures. The electron-doped samples display a strong localization which can be correlated with the high spin state of Ni$^{2+}$ ions. The spatial Raman map shows a remarkable shift of about 167 cm$^{-1}$ with electron doping thus serving as a spectroscopic tool to investigate hydrogen in our films. \textbf{References}


\textsuperscript{1}Birck Nanotechnology Center, Purdue University

\textsuperscript{2}School of Electrical and Computer Engineering, Purdue University

4:06PM C19.00007 Temperature dependent near field infrared microscopy of La$_{0.67}$Sr$_{0.33}$MnO$_3$ thin films\textsuperscript{1}, PENG XU, TJ HUFFMAN, MM QAZIBLASH, Department of Physics, College of William and Mary, INHAE KWAK, AMLAN BISWAS, Department of Physics, University of Florida — La$_{0.67}$Sr$_{0.33}$MnO$_3$ thin films are studied with apertureless, scattering-type near field microscopy at mid-infrared wavelength and varied temperatures. Spatial resolution of about 20 nm is achieved with our technique. The temperature-dependent resistivity shows a continuous second order phase transition between insulating and metallic phases. At most temperatures, near-field infrared microscopy reveals local persistent phase separation that is independent of temperature. It is possible that the local persistent phase separation is induced by strain inhomogeneity in the thin films. Remarkably, we also observe global time-dependent changes in the infrared near-field signal upon repeated scanning of the same microscopic area at a fixed temperature. This observation is consistent with time-dependent, fluctuating conductivity in the vicinity of a second order phase transition.

\textsuperscript{1}This work was supported by the National Science Foundation

4:18PM C19.00008 Step-induced magnetic phase separation in La$_{0.67}$Sr$_{0.33}$MnO$_3$/SrTiO$_3$ (100) thin films.\textsuperscript{1}, IN HAE KWAK, AMLAN BISWAS, University of Florida, Department of Physics — We investigated thickness dependent magnetic anisotropy in La$_{0.67}$Sr$_{0.33}$MnO$_3$/SrTiO$_3$ (100) (LSMO/STO) thin films using a combination of magnetic force microscopy (MFM) and magnetization measurements. Atomically smooth thin films of LSMO were grown on STO using pulsed laser deposition. The thin films showed step flow growth with unit cell step heights. MFM images of a 40 unit cell (u.c.)-thick film showed out-of-plane magnetic domain structure indicating bulk-like rhombohedral crystalline anisotropy. As the film thickness was decreased to 20 u.c., the MFM images showed signatures of step-induced uniaxial anisotropy. Hence, the magnetic domain structure shows that with the modulation of oxygen vacancies, a step-induced magnetic phase separation is realized in the thin films. Remarkably, we also observe global time-dependent changes in the infrared near-field signal upon repeated scanning of the same microscopic area at a fixed temperature. This observation is consistent with time-dependent, fluctuating conductivity in the vicinity of a second order phase transition.

\textsuperscript{1}Thank you for support from NSF-DMR 1410237

4:30PM C19.00009 Electronic and magnetic properties of quadruple manganite Ca$_{1-x}$Sr$_2$Mn$_2$O$_7$ films . AMANDA HUON, STEVEN MAY, Drexel University — We investigate the functional properties of epitaxial Ca$_{1-x}$Sr$_2$Mn$_2$O$_7$ films to better understand the underlying physical phenomenon in this perovskite system. We utilize oxide molecular beam epitaxy to fabricate Ca$_{1-x}$Sr$_2$Mn$_2$O$_7$ thin films. The epitaxial films were achieved through a two-step oxygen/ozone post-growth anneal. In parent x=0 films, we find bulk-like electronic and magnetic properties including an abrupt increase in resistivity at 425 K due to a nominal charge ordering transition and a net magnetization below 43 K likely arising from helical magnetic order. Finally, we will present on how tuning the Sr concentration alters the electronic and magnetic properties, providing a means to control the phase transition temperatures. The results highlight the scientific opportunities in heterostructures based on quadruple manganites.
4:42PM C19.00010 Observation of a huge polaron gyrotropic response near room temperature in manganite thin films. GERVASI HERRANZ, BLAI CASAL, RAFAEL CICHELERO, DAVID PESQUERA, MARIANO CAMPY, FLORENCIO SANCHEZ, JOSEP FONTCUBERTA, Instituto de Ciencia de Materiales de Barcelona ICMAB-CSIC, Campus UAB, 08193 Bellaterra, Spain, PABLO GARCIA FERNANDEZ, JAVIER JUNQUERA, Dept. Ciencias de la Tierra y Fs. de la Materia Condensada, U.de Cantabria, Av. de los Castros s/n, 39005 Santander, Spain — Magnetic materials induce rotation and ellipticity in the polarization of light. This phenomenon is exploited, e.g., to control the flux of light along optical fibers. In the pursuit for increased magneto-optic responses, strategies so far have been based on photonic or plasmonic effects. Here we uncover a novel physical mechanism by which the gyrotropic activity is hugely enhanced around the Curie temperature in optimally doped ferromagnetic manganites. This phenomenon is observed only for a narrow range of wavelengths and temperatures and is strongly dependent on the angle of incidence and polarization. We understand such an outstanding response as the result of the interplay between Jahn-Teller distortions and spin-orbit coupling in narrow-band manganites. The showcased material is La$_2$/3Sr$_2$/3MnO$_3$, for which the extraordinary gyrotropic response is seen near room temperature. This raises the possibility of optimizing the stoichiometric composition to drive the effect to higher temperatures. The observed phenomenon gives an added functionality — unseen previously in any manganite or other magnetic oxides— and puts a new perspective on the use of these materials for optical data storage and retrieval.

4:54PM C19.00011 The Manipulation of Electronic Phase Separation in Manganites. LIFENG YIN, State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai 200433, China — The Electronic Phase Separation (EPS) is a common phenomenon in strongly correlated systems where two or more electronic phases coexist owing to a delicate balance of competition between these phases. A model system is (La$_{1-x}$/Pr$_x$)$_3$MnO$_3$ (LPCMO), a colossal magnetoresistance (CMR) manganite that is known for its large-scale EPS. Since the transport and magnetic properties depend sensitively on EPS, it is crucial to manipulate the EPS domains, especially for the applications of CMR manganites in multifunctional electronic and spintronic devices. Through the broken symmetry induced edge states, we can control the nucleation and growth of ferromagnetic metallic domains, thus the spatial distribution of EPS domains in turn. When the Pr doping is chemically ordered, we found the size of EPS domains will be one order of magnitude smaller. Further, the EPS phenomenon can be fully destabilized by the spatial confinements when the sample size is smaller than 500nm. These findings could help to understand the origin of large-scale EPS in LPCMO.

5:06PM C19.00012 Enhanced magnetization in ultrathin manganite layers via structural “delta-doping” of octahedral rotations.1 EUN JU MOON, Drexel University, BRIAN J. KIRBY, National Institute of Standards and Technology, STEVEN J. MAY, Drexel University — The design of rotations and distortions of the corner-shared BO$_6$ octahedra has emerged as an exciting platform to control electronic or magnetic behavior in ABO$_3$ perovskite heterostructures. Recent work has shown that purely structural effects can be used to spatially confined magnetism in oxide heterostructures and point to the design of rotational gradients as routes to realize novel electronic or ferroic states in oxide superlattices [Nat. Comm. 5, 5710 (2014)]. Here, we demonstrate a structural “delta doping” approach for controlling magnetism in ultrathin layers within isovalent manganite superlattices. Polarized neutron reflectivity and temperature dependent magnetization measurements are used to correlate enhanced magnetization with local regions of suppressed octahedral rotations in the heterostructures.

1This work was supported by the U. S. Army Research Office under grant No. W911NF-15-1-0133.

5:18PM C19.00013 Ultrafast structural dynamics of LaVO$_3$ thin films grown by hybrid molecular beam epitaxy. MATTHEW BRAHLEK, JASON LAPANO, VLADIMIR STOICA, LEI ZHANG, HAI-TIAN ZHANG, HIROFUMI AKAMATSU, CRAIG EATON, VIVIAN KIM, JASON CHUNG, HAO CHEN, Iowa State University, IOKO KUO, LELAND, HAI-NI WEN, Argonne National Lab, ROMAN ENGEL-HERTBERG, Pennsylvania State University — LaVO$_3$, with a partially full d-shell is expected to be metallic, but due to electron-electron interactions a gap emerges and the ground state is a Mott insulator. Such effects are a strong function of the bonding geometry, and particularly the V-O-V bond angle. Controlling these structural effects on the ultrafast time scale can lead to control over the underlying electronic ground state. Here we report the ultrafast structural dynamics of 25 and 50 nm thick LaVO$_3$ thin films grown by the hybrid molecular beam epitaxy technique on SrTiO$_3$ when excited across the bandgap by 800 nm light. Using time-resolved x-ray diffraction on the 100 ps time scale at Sector 7 of the Advanced Photon Source, we directly measured the structural changes with atomic accuracy by monitoring integer Bragg diffraction peaks and find a large out-of-plane strain of 0.18% upon optical excitation; the recovery time is ~1 ns for the 25 nm film and ~2 ns for the 50 nm film, consistent with the thermal transport from the film to the substrate. Further, we will discuss the response of the oxygen octahedral rotation patterns indicated by changes of the half-order diffraction peaks. Understanding such ultrafast structural deformation is important for optimizing optical excitations to create new metastable phases starting from a Mott insulator. This work was supported by the Department of Energy under Grant DE-SC0012375, and DE-AC02-06CH11357.

Monday, March 14, 2016 2:30PM - 5:30PM — Session C21 GMAG DMP: Magnetic Chains and Kondo Effects

2:30PM C21.00001 Magnetic Behavior of quasi-1D-Ferromagnetic Fe Chains in Metallo-Organic Superlattices1 C. MONTON, Univ of Texas, San Antonio, A. C. BASARAN, I. VALMIANSKI, Univ California, San Diego, T. GREDIG, California State University, Long Beach, D. ALTBFIR, V. L. CARVALHO-SANTOS, Universidad de Santiago de Chile, IVAN K. SCHULLER, Univ California, San Diego — We report structural and magnetic properties of metallo-organic iron-phthalocyanine (FePc) / metal-free-phthalocyanine (H$_2$Pc) superlattices. H$_2$Pc is a weak diamagnetic molecule in which, instead of a metal ion, two hydrogen atoms occupy the center of the molecule. Due to molecular stacking, the divalent Fe(II) ion of FePc forms quasi one-dimensional (1D) chains. These Fe chains can be oriented either parallel or perpendicular to the substrate based on the choice of the substrate. These quasi-1D chains exhibit two magnetic regimes: ferromagnetic-like order below 5K, and nontraditional paramagnetic order (nonlinear behavior with decreasing saturation intensity with temperature) between 5 and 40 K. We have found that reducing the average Fe chains length from 70 to 7 Fe ions substantially increases the coercive field. We discuss the magnetic behavior of quasi-1D Fe chains as a function of the chains length and we correlate the observed magnetic behavior with structural information obtained from x-ray diffraction and Monte Carlo based micromagnetic simulations.

2Work supported by DEFG02-88ER45332, DMR 0847552, FONDECYT 1120356, FB0807, and FA9550-11-1-0347

2:42PM C21.00002 Spin Liquid Ground State in the Frustrated $J_1$-$J_2$ Zigzag Chain System BaTb$_2$O$_4$. A.A. ACZEL, Oak Ridge National Laboratory, L. LI, University of Tennessee, V.O. GARLEA, Oak Ridge National Laboratory, J.-Q. YAN, University of Tennessee and Oak Ridge National Laboratory, F. WEICKERT, V.S. ZAPF, R. MOVSHOVICH, M. JAIME, Los Alamos National Laboratory, P.J. BAKER, Rutherford Appleton Laboratory, V. KEPPENS, D. MANDRUS, University of Tennessee — We have investigated polycrystalline samples of the zigzag chain system BaTb$_2$O$_4$ with magnetic susceptibility, heat capacity, neutron powder diffraction, and muon spin relaxation ($\mu$SR). No magnetic transitions are observed in the bulk measurements, while neutron diffraction reveals the presence of low-temperature spin density wave (SDW), intrachain magnetic correlations between Tb$^{3+}$ ions. $\mu$SR indicates that these correlations are dynamic, as no signatures of static magnetism are detected by the technique down to 0.095 K. These combined findings provide strong evidence for a spin liquid ground state in BaTb$_2$O$_4$. 

1The pure resonance$\nu$
Study of magnetic and magnetocaloric properties of monoclinic and triclinic spin chain CO$_2$O$_6$.  

We have investigated magnetic and magnetocaloric properties of both monoclinic and triclinic phases of CO$_2$O$_6$ from magnetization and heat capacity measurements. Conventional and inverse magnetocaloric effects have been observed in both phases of CO$_2$O$_6$. For a field change from 0 to 7 T, maximum values of magnetic entropy change and adiabatic temperature change reach 11.8 J kg$^{-1}$ K$^{-1}$ and 9.5 K respectively for monoclinic CO$_2$O$_6$ while the corresponding values reach 12.1 J kg$^{-1}$ K$^{-1}$ and 13.1 K for triclinic CO$_2$O$_6$. Particularly for triclinic CO$_2$O$_6$, the magnetocaloric parameters are quite large in low or moderate field range. Apart from this, we have constructed magnetic phase diagram of monoclinic CO$_2$O$_6$ where field-induced complex magnetic phases appear below a certain critical temperature 6 K when external magnetic field is applied along crystallographic easy axis.

3:06PM C21.00004 Entanglement properties of the bond alternating Heisenberg chain with general integer spins , SHOHEI MIYAKOSHI, Chiba Univ, SATOSHI NISHIMOTO, IFW Dresden, TU Dresden, YUKINORI OTHA, Chiba Univ — Symmetry protected topological (SPT) phases are a gapped phase under a given symmetry. Unless any symmetries that protect the SPT phases are broken, the SPT phases can be distinguished from each other. Recently, it was pointed out that the entanglement spectrum of the many-body state characterizes SPT phases. In particular, the degeneracy of the entanglement spectrum reflects the corresponding symmetries and edge states of the system. Motivated by recent studies of the SPT phases, we study the bond-alternating Heisenberg model with general integer spins and clarify the entanglement properties of the ground state using the density matrix renormalization group method. In particular, this model has the intermediate phase at $S > 1$ due to the bond alternation. The entanglement properties of this phase in the case of $S > 2$ have not been studied sufficiently because of the numerical difficulties under an extremely small spin-gap situation. We studied the case of $S = 1.2.3$ using the antiperiodic boundary condition. Under the antiperiodic boundary condition, we found that the doubly degenerate spectra which characterize the intermediate phase can be observed in the entanglement spectrum. We will also discuss the effect of the single-ion uniaxial anisotropy.

3:18PM C21.00005 Finite temperature dynamics of spin-1/2 chains with symmetry breaking interactions\(^1\), SALVATORE R. MANMANA, ALEXANDER C. TIEGEL, THOMAS PRUSCHKE, Institute for Theoretical Physics, University of Goettingen, ANDREAS HONECKER, LPTM, Université de Cergy-Pontoise — I will discuss recent developments for flexible matrix product state (MPS) approaches to calculate finite-temperature spectral functions of low-dimensional strongly correlated quantum systems. The main focus will be on a Liouvillian formulation. The resulting algorithm does not specifically depend on the MPS formulation, but is applicable for any wave function based approach which can provide a purification of the density matrix, opening the way for further developments of numerical methods. Based on MPS results for various spin chains, in particular systems with Dzyaloshinskii-Moriya interactions caused by spin-orbit coupling and dimerized chains, I will discuss how symmetry breaking interactions change the nature of the finite-temperature dynamics of spin structure factor obtained in ESR and neutron scattering experiments.

\(^1\)We acknowledge funding by the Helmholtz Virtual Institute “New States of Matter and Their Excitations”.

3:30PM C21.00006 Magnetic Spin Relaxation Probed with Sweep Speed Dependent Coercivity\(^1\), THOMAS GREDIG, MATTHEW BYRNE, Department of Physics and Astronomy, California State University Long Beach — The magnetic spin relaxation of finite-length iron chains has been investigated in iron phthalocyanine thin films by means of sweep speed dependence on magnetic coercivity. The Fe(II) ions are embedded in a carbon matrix and molecules self-assemble during vacuum sublimation, so that the Fe(II) cores form well-separated chains of 1.3 nm and tunable chain lengths within the polycrystalline thin film. The average length of the chains is controlled through deposition variables and ranges from 30 nm to 300 nm. The coercivity strongly increases with chain length in this regime. This may be an interesting experimental realization of a low-dimensional finite-sized Ising model. The coercivity dependence on chain length and sweep speed is described with an Ising model based on Glauber dynamics.

\(^1\)Research support from NSF under grant DMR 0847552.

3:42PM C21.00007 Finite-temperature phase diagram of the frustrated spin chain $\beta$-TeVO$_4$, F. WEICKERT, ANDRAS C. TIEGEL, THOMAS PRUSCHKE, Institute for Theoretical Physics, University of Göttingen, H. BERGER, EPFL, Lausanne, Switzerland, H. ROSNER, MPI CPfS, Dresden, Germany, A. A. TSIRLIN, Augsburg University — For $\beta$-TeVO$_4$, the spin-1/2 model is still far from being understood, but our results will stimulate further research on this interesting model compound.

3:54PM C21.00008 Unusual features of magnetism in transition-metal-doped phthalocyanines C$_2$H$_{16}$N$_8$TM (TM = Mn, Fe, Co, Ni, Cu), ZHENGJUN WANG, MOHINDAR S. SEEHRA, Department of Physics and Astronomy, West Virginia University — Transition-metal-doped phthalocyanines (TMPc), semiconductors with potential optoelectronic applications [1], are planar molecules with the TM atom at the center bound to four N atoms and forming a linear chain along the monoclinic b-axis. Because of this symmetry, the ground states of TMPc often violate the Hund’s rules; e.g. the $S = 3/2$ state for $d^5$ Mn(II) in $\beta$-MnPc, $S = 1/2$ state for the $d^7$ Co(II) in $\beta$-CoPc, and $S = 0$ for Ni(II) in NiPc. The magnetic properties of TMPc are also affected by the stacking angle $\delta$ between the orientation of the molecular plane and the b-axis, $\delta$ being 45° for $\beta$-CoPc [2]. For TMPc, our M vs. T data fits well with the Bonner-Fisher model for $S = 1/2$ AFM Heisenberg linear chain [3] yielding the $g^{1/2}$-$g^{1/2}$ exchange constant $J_{ll} = -1.5$ K. For $\beta$-MnPc, a long-expected ferromagnetic with $T_C \approx 9$ K [4], our magnetic studies show it to be an Ising chain magnet with Arrenius magnetic relaxation governed by $J/k_B = 2.6$ K and the zero-field splitting $D/k_B = 8.3$ K. In $\beta$-MnPc, the absence of $\lambda$-type peak in specific heat and no peaks in ac susceptibilities near the quoted $T_C$ confirms the absence of long range order (LRO). Instead, we argue that LRO is absent in $\beta$-MnPc as D > J makes the spins in a chain parallel but canted with respect to spins in neighboring chains. [1] G. Mattioli et al, Phys. Rev. Lett. 101, 126805 (2008); [2] Z. Wang et al, IEEE Trans. Mag. 51, 2700104(2015); [3] J. Bonner & M. Fisher, Phys. Rev. 135, A640 (1964); [4] Y. Taguchi et al, J. Magn. Magn. Mater. 301, 1229 (2007).
4:06PM C21.00009 Heat transport in spin chains with weak spin-phonon coupling1. ALEXANDER CHERNYSHCHEV, University of California, Irvine. ALEXANDER ROZHKOVO, Institute for Theoretical and Applied Electrodynamics, Russian Academy of Sciences, Russia — We propose that the heat conductivity by 1D spin excitations in $S = 1/2$ Heisenberg spin chains can be quantitatively described within the bosonization framework, in which large-momentum scattering of spin excitations is due to optical phonons with the spin-phonon couplings that are well within the physical bounds. Our theory provides an excellent fit to the data from the systematic experimental thermal conductivity studies in the high-quality single-crystalline large-$J$ spin-chain cuprates that have recently become available. Our description of the spin-phonon scattering is also in accord with a physically intuitive picture of phonons playing the role of thermally-populated weak impurities for the fast spin excitations. Our approach stands out from previous considerations that require large coupling constants to explain the data and thus imply a spin-Peierls transition, absent in real materials.

1Supported by the DoE

4:18PM C21.00010 Spin dynamics in critical regime of the spin-1/2 XXZ chain. WANG YANG, JIANDA WU, CONGJUN WU, University of California San Diego — The spin-1/2 Heisenberg XXZ chain is one of the most well-studied quantum integrable models. Although its eigenstates and spectrum are solvable through Bethe ansatz, even understanding its zero temperature spin dynamics remains a challenge. In the axiostropic regime, by tuning longitudinal magnetic field, the system undergoes a quantum phase transition, entering into the critical regime. Recent experiments provided some evidences for understanding spin dynamics in the critical regime. Here we investigate the spin dynamics in this regime by form factor methods. Our results can be directly compared with experiments on relevant materials.

4:30PM C21.00011 First principles electron transport simulations in the Kondo regime, IVAN RUNGGER, National Physical Laboratory, MILOS RADONJC, WILHELM APPELT, LIVIU CHIONCEL, University of Augsburg, ANDREA DROGHETTI, Universidad del Pais Vasco — When magnetic atoms, molecules or thin films are brought into contact with metals the electron-electron interaction leads to the appearance of the correlated state at low temperatures. In this talk we will present results for the electronic structure and conductance in the Kondo regime of recent STM and break junction experiments for stable radical molecules which correspond to spin half molecular magnets. We will outline the methodological approach to evaluate the conductance of such systems from first principles, as implemented in the Smagol electron transport code. The method combines the density functional theory (DFT) with Anderson impurity solvers within the continuum time quantum Monte Carlo (CTQMC) and numerical renormalization group (NRG) approaches.

4:42PM C21.00012 Cobalt on silicene/ZrB$_2$: an intriguing Kondo system. TOBIAS GILL, BEN WARNER, HENNING PRUSER, UCL, UK. ANTOINE FLEURENCE, YUKIKO YAMADA-TAKAMURA, JAIST, Japan, CYRUS HIRJIBEHEIDIN, UCL, UK — Magnetic atoms placed upon metallic substrates have been used as prototypical systems for the investigation of the fundamentals of atomic-scale magnetism. Often these magnetic impurities undergo the Kondo effect, in which the magnetic moment of the impurity is collectively screened by a cloud of conduction electrons forming a many-body singlet ground state. Here we present results for individual Co adatoms on the silicene/ZrB$_2$ surface. Unlike on metallic surfaces, Co atoms exhibit a distinct energy-dependent change in the spatial distribution of their electronic states when imaged with scanning tunneling microscopy. At low biases around the Fermi level, the Co atoms exhibit a two-lobe structure that is oriented along one of three equivalent directions in the plane and that is revealed by scanning tunneling spectroscopy to result from a Kondo resonance centered upon each lobe. This spatially anisotropic Kondo resonance is reminiscent of the orbital states of magnetic atoms on semiconductor surfaces or of the spatially distributed Kondo resonances seen for magnetic molecules on metallic surfaces, and is a result of the interaction between a magnetic impurity and the unusual electronic structure of the silicene/ZrB$_2$ surface.

4:54PM C21.00013 ABSTRACT WITHDRAWN –

5:06PM C21.00014 Sub-molecular modulation of a 4f driven Kondo resonance by surface-induced asymmetry. BEN WARNER, FADI EL HALLAK, UCL, NICOLAE ATODIRESEI, Forschungszentrum Juelich, PHILIPP SEIBIT, HENNING PRUSER, UCL, VASILE CACIU, Forschungszentrum Juelich, MICHAEL WATERS, U. of Nottingham, ANDREW J. FISHER, UCL, STEFAN BLUGEL, Forschungszentrum Juelich, JORIS VAN SLAGEREN, U. of Stuttgart, CYRUS F. HIRJIBEHEIDIN, UCL — Coupling between a magnetic impurity and an external bath can give rise to many-body quantum phenomena, including Kondo and Hund’s Impurity states in metals, and Yu-Shiba-Rusinov states in superconductors. While advances have been made in probing the magnetic properties of d-shell impurities on surfaces, the confinement of f orbitals makes them much more difficult to access directly. Here we show that a 4f driven Kondo resonance can be modulated spatially by asymmetric coupling between a metallic surface and a molecule containing a 4f-like moment. Strong hybridisation of dysprosium double-decker phthalocyanine (DyPc$_2$) with Cu(001) induces Kondo screening of the central magnetic moment. Misalignment between the symmetry axes of the molecule and the surface induces asymmetry in the molecule’s electronic structure, spatially modulating electronic access to the magnetic moment through the Kondo resonance. This work demonstrates the important role that molecular ligands play in mediating electronic and magnetic coupling and in accessing many-body quantum states.

5:18PM C21.00015 Revealing the Atomic Site-Dependent g Factor within a Single Magnetic Molecule via the Extended Kondo Effect. SHIXUAN DU, Institute of Physics, Chinese Academy of Sciences — Control over charge and spin states at the single molecule level is crucial not only for a fundamental understanding of charge and spin interactions but also represents a prerequisite for development of molecular electronics and spintronics. In this talk, I will talk about the extended spin distribution in space beyond the central Mn ion, and onto the non-magnetic constituent atoms of the MnPc molecule. This extended spin distribution results in an extended Kondo effect, which can be explained by spin polarization induced by symmetry breaking of the molecular framework, as confirmed by DFT calculations. Measuring the evolution of the Kondo splitting with applied magnetic fields at different atomic sites, we find a spatial variation of the g-factor within a single molecule for the first time. The existence of atomic site-dependent g-factors can be attributed to specific molecular orbitals distributed over the entire molecule. This work not only open up a new opportunity for quantum information recording, but also provide a new route to explore the internal electronic and spin structure of complex molecules, hard to achieve otherwise. (L.W. Liu et al., Phys. Rev. Lett. 2015, 114, 126601. In collaboration with Liwei Liu, Kai Yang, Yuhang Jiang, Li Gao, Qi Liu, Boqun Song, Wende Xiao, Haitao Zhou, Hongjun Gao in CAS, Min Ouyang in MU, and A.H. Castro Neto in SNU.)

1Revealing the Atomic Site-Dependent g Factor within a Single Magnetic Molecule via the Extended Kondo Effect

Tuesday, March 15, 2016 8:00AM - 11:00AM – Session E3 gMAG, DCMP: A New Approach to the Kitaev Quantum Spin Liquid Ballroom III - Young-June Kim, Univ of Toronto
8:00AM E3.00001 Possible Observation of fractionalized excitations in a Relativistic Mott Insulator, KENNETH BURCH, Boston College — The combination of electronic correlation and spin-orbit coupling is thought to precipitate a variety of highly unusual electronic phases in solids, including topological and quantum spin liquid states. I will discuss our recent optical measurements that provide evidence for the relativistic Mott Insulating ground state of \( \alpha \)-RuCl\(_3\). Furthermore I will discuss the broad-continuum of scattering we observe, whose energy and temperature dependence suggest the presence of fractionalized excitations emerging from a quantum spin-liquid.

8:36AM E3.00002 Inelastic neutron scattering evidence for Kitaev quantum spin liquid physics in \( \alpha \)-RuCl\(_3\)\(^1\), STEPHEN NAGLER, Oak Ridge National Laboratory — The magnetic semiconductor \( \alpha \)-RuCl\(_3\) is composed of very weakly coupled honeycomb layers of edge-sharing RuCl\(_3\) octahedra. The Ru\(^{3+}\) ion has 5 \( d \) electrons in the low spin state, and the system is expected to have an effective \( J = \frac{1}{2} \) single ion ground state with an interacting spin Hamiltonian containing Kitaev-like terms. Inelastic neutron scattering \([1]\) on powders and single crystals has been used to determine the energy scale of the magnetic interactions and the overall form of the magnetic fluctuations. The results indicate that the Kitaev term is significant. Moreover, detailed measurements of the response show evidence for the fractionalized excitations that are characteristic of the Kitaev quantum spin liquid.

\[^1\] Research supported by the Scientific User Facilities Division, Basic Energy Sciences, US Department of Energy

9:12AM E3.00003 Magnetic and Crystal Structure of \( \alpha \)-RuCl\(_3\), JENNIFER SEARS, University of Toronto — The layered honeycomb material \( \alpha \)-RuCl\(_3\) has been proposed as a candidate material to show significant bond-dependent Kitaev type interactions \([1]\). This has prompted several recent studies of magnetism in this material that have found evidence for multiple magnetic transitions in the temperature range of 8-14 K \([2,3,4]\). We will present elastic neutron scattering measurements collected using a co-aligned array of \( \alpha \)-RuCl\(_3\) crystals, identifying zigzag magnetic order within the honeycomb planes with an ordering temperature of \( \sim 8 \) K \([2]\). It has been reported that the ordering temperature depends on the c-axis periodicity of the layered structure, with ordering temperatures of 8 and 14 K for three and two-layer periodicity respectively \([3]\). While the in-plane magnetic order has been identified, it is clear that a complete understanding of magnetic ordering and interactions will depend on the three dimensional structure of the crystal. Evidence of a structural transition at \( \sim 150 \) K has been reported \([4]\) and questions remain about the structural details, in particular the stacking of the honeycomb layers. We will present x-ray diffraction measurements investigating the low and high temperature structures and stacking disorder in \( \alpha \)-RuCl\(_3\). Finally, we will present inelastic neutron scattering measurements of magnetic excitations in this material.

Work done in collaboration with K. W. Plumb (Johns Hopkins University), J. P. Clancy, Young-June Kim (University of Toronto), J. Britten (McMaster University), Yu-Sheng Chen (Argonne National Laboratory), Y. Qiu, Y. Zhao, D. Parshall, and J. W. Lynn (NCCR).


9:48AM E3.00004 XY-like frustrated magnetic phase transitions in \( \alpha \)-RuCl\(_3\), HIDEKAZU TANAKA, Tokyo Institute of Technology — It is known that a honeycomb-lattice antiferromagnet with the nearest-neighbor exchange interaction undergoes a conventional magnetic ordering even for the spin-1/2 case. However, when a certain amount of second-neighbor exchange interaction or anisotropic exchange interaction exists, the honeycomb-lattice quantum magnet exhibits an unusual ground state. In the last decade, spin-1/2 quantum magnets on honeycomb lattices have been attracting considerable attention from the viewpoints of the frustrated \( J_1 - J_2 \) model and the Kitaev-Heisenberg model, both of which can exhibit the spin liquid state in some parameter range. \( \alpha \)-RuCl\(_3\) is a layered compound, in which magnetic Ru\(^{3+}\) ions with the 4\(d\) electronic state form a honeycomb lattice. We have investigated the magnetic properties of \( \alpha \)-RuCl\(_3\) via magnetization and specific heat measurements using single crystals. It was observed that \( \alpha \)-RuCl\(_3\) undergoes a structural phase transition at \( T_1 \approx 150 \) K accompanied by fairly large hysteresis. The magnetizations and magnetic susceptibilities are strongly anisotropic, which mainly arise from the anisotropic \( g \)-factors. These \( g \)-factors and the obtained entropy indicate that the effective spin of Ru\(^{3+}\) is one-half, which results from the low-spin state. Specific heat data show that magnetic ordering occurs in four steps at zero magnetic field. The magnetic phase diagram is obtained. The successive magnetic phase transitions can be ascribed to the competition among exchange interactions. We discuss the strongly anisotropic \( g \)-factors and deduce that the exchange interaction is strongly XY-like. Main results of this talk was published in Phys. Rev. B 91, 094422 (2015).

10:24AM E3.00005 Manifestations of Kitaev physics in thermodynamic properties of hexagonal iridates and \( \alpha \)-RuCl\(_3\)\(^1\), ALEXANDER TSIRILIN, Experimental Physics VI, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, Germany — Kitaev model is hard to achieve in real materials. Best candidates available so far are hexagonal iridates \( \text{Ir}_{1-x}\text{Ir}_x\text{O}_3 \) \((M = \text{Li} \text{ and Na})\) and the recently discovered \( \alpha \)-RuCl\(_3\) featuring hexagonal layers coupled by weak van der Waals bonding. I will review recent progress in crystal growth of these materials and compare their thermodynamic properties. Both hexagonal iridates and \( \alpha \)-RuCl\(_3\) feature highly anisotropic Curie-Weiss temperatures that not only differ in magnitude but also change sign depending on the direction of the applied magnetic field. Néel temperatures are largely suppressed compared to the energy scale of the Curie-Weiss temperatures. These experimental observations will be linked to features of the electronic structure and to structural peculiarities associated with deviations from the ideal hexagonal symmetry. I will also discuss how the different nature of ligand atoms affects electronic structure and magnetic superexchange.

\[^1\] This work has been done in collaboration with M. Majumder, M. Schmidt, M. Baenitz, F. Freund, and P. Gegenwart

Tuesday, March 15, 2016 8:00AM - 11:00AM – Session E5 GMAG DMP: Magnetic Thin Films and Multilayers 301 - Madhukar Reddy, Lam Research Corporation

8:00AM E5.00001 Spin-orbit coupling of 3d transition metal atoms on MgO/Ag, SHRUBA GAN-GOPADHYAY, University of California, Davis, BARBARA JONES, IBM Research Almaden — Spin-orbit coupling is normally predominant for high Z metal atoms, but we observe Fe and Co showing significant orbital moments on a MgO/Ag surface. DFT results show that on MgO/Ag both Co and Fe prefer O top binding sites. Calculation of orbital moments using DFT is always challenging, and we compare two DFT based protocols to calculate orbital moments. Our calculations show the magnitude of orbital moments strongly dependent on a number of factors including the number of Ag layers in our unit cell and the approximation we are using. Our results exhibit significant agreement with scanning tunneling microscopy (STM) and XMCD experiments. We show that Co retains its full atomic orbital moment on the O top site of MgO whereas the orbital moment for Fe is somewhat less than its atomic orbital moment.
8:12AM E5.00002 Enhancement of the Co magnetic moment in bcc Co$_{1-x}$Mn$_x$ on MgO$^1$. RYAN SNOW, HARSH BHATKAR, Montana State University, ALPNA N'DIAYE, ELKE ARENHOLZ, Lawrence Berkeley National Laboratories, YVES IDZERDA, Montana State University, MONTANA STATE UNIVERSITY TEAM, LAWRENCE BERKELEY NATIONAL LABORATORIES TEAM — Using X-ray absorption spectroscopy (XAS) and X-ray magnetic circular dichroism (MCD), we show that the elemental Co moment for MBE grown thin films of bcc Co$_{1-x}$Mn$_x$ grown on MgO(001) is enhanced by 40% to a maximum value of 2.1 $\mu_B$/atom at $x=0.24$. The net Mn moment is found to align parallel with Co for all concentrations and remains roughly constant until $x=0.3$, then drops steadily, up to $x=0.7$, where the total moment of the film abruptly collapses to zero. Using a low-concentration Mn moment of 3.0 $\mu_B$/atom, we have determined that the maximum moment of 2.3 $\mu_B$ is a result of the slope and is steeper on the high-Mn concentration side of the peak relative to the standard SP curve. This is in stark contrast to the fcc CoMn and hcp CoCr bulk behavior which shows only a rapid total moment reduction with Mn concentration.

$^1$This material is based upon work supported by the National Science Foundation under Grant ECCS-1542210. The Advanced Light Source is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Con

8:24AM E5.00003 Cap-Induced Magnetic Anisotropy in Ultra-thin Fe/MgO(001) Films$^1$. TOBIAS BROWN-HEFT, Materials Department, University of California Santa Barbara, MIHIR PENDHARKAR, Electrical and Computer Engineering Department, University of California Santa Barbara, ELIZABETH LEE, Engineering Department, Harvey Mudd College, Claremont, CA, CHRIS PALMSTROM, Electrical and Computer Engineering Department & Materials Department, University of California Santa Barbara — Magnetic anisotropy plays an important role in the design of spintronic devices. Perpendicular magnetic anisotropy (PMA) is preferred for magnetic tunnel junctions because the resulting energy barrier between magnetization states can be very high and this allows enhanced device scalability suitable for magnetic random access memory applications. Interface induced anisotropy is often used to control magnetic easy axes. For example, the Fe/MgO(001) system has been predicted to exhibit PMA in the ultrathin Fe limit. We have used in-situ magneto optic Kerr effect and ex-situ SQUID to study the changes in anisotropy constants between bare Fe/MgO(001) films and those capped with MgO, Pt, and Ta. In some cases in-plane anisotropy terms reverse sign after capping. We also observe transitions from superparamagnetic to ferromagnetic behavior induced by capping layers. Perpendicular anisotropy is observed for Pt/Fe/MgO(001) films after annealing to 300C. These effects are characterized and incorporated into a magnetic simulation that accurately reproduces the behavior of the films.

$^1$This work was supported in part by the Semiconductor Research Corporation programs (1) MSR-Intel, and (2) C-SPIN.

8:36AM E5.00004 Thickness quantization in a reorientation transition. DAVID VENUS, GEMING HE, HARRISON WINCH, RANDY BELANGER, McMaster University — The reorientation transition of an ultrathin film from perpendicular to in-plane magnetization is driven by a competition between shape and surface anisotropy. It is accompanied by a “stripe” domain structure that evolves as the reorientation progresses. Often, an n layer film has stable perpendicular magnetization and an n+1 layer film has stable in-plane magnetization. If the domain walls are not pinned, the long-range stripe domain pattern averages over this structure so that the transition occurs at a non-integer layer thickness. We report in situ experimental measurements of the magnetic susceptibility (via MOKE) of the reorientation transition in Fe/2 ML Ni/NI(110) films as a function of thickness as they are deposited at room temperature. In addition to a peak at the reorientation transition, we observe a strong precursor due to thickness quantization in atomic layers. This peak is described quantitatively by the response of small islands of thickness 3 layers with in-plane anisotropy in a sea of 2 layers Fe with perpendicular anisotropy. The fitted parameters give an estimate of the island size at which the response disappears. This size corresponds to a domain wall thickness, so that the islands become locally in-plane, demonstrating the self-consistency of the model.

8:48AM E5.00005 Spin and orbital magnetic moments of Fe and Co in Co/Fe and Fe/Co multilayers on Si from L$_{2,3}$ edge X-ray Magnetic Circular Dichroism Spectroscopy$^1$. KRISHNAMURTHY VEMURU, George Mason University, Fairfax, Virginia, RICHARD ROSENBERG, Advanced Photon Source, Argonne National Laboratory, Lemont, Illinois, GARY MANKEY , The University of Alabama, Tuscaloosa, Alabama — Nanostructured FeCo thin films are interesting for magnetic recording applications due to their high saturation magnetization, high Curie temperature and low magnetocrystalline anisotropy. It is desirable to know how the magnetism is modified by the nanostructure. We report Fe L$_{2,3}$ edge and Co L$_{2,3}$ edge x-ray magnetic circular dichroism (XMCD) investigations of element specific spin and orbital magnetism of Fe and Co in two multilayer samples: (S1) Si/SiO$_2$/[Co 0.8 nm/Fe 1.6 nm]$_{32}$/W (2nm) and (S2) Si/SiO$_2$/[Co 1.6 nm/Fe 0.8 nm]$_{32}$/W (2nm) thin films at room temperature. Sum rule analysis of XMCD at Fe L$_{2,3}$ edge in sample S1 shows that the orbital moment of Fe is strongly enhanced and the spin moment is strongly reduced as compared to the values found in bulk Fe. Details of sum rule analysis will be presented to compare and contrast spin magnetic moments and orbital magnetic moments of Fe and Co in the two multilayer samples.

$^1$This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

9:00AM E5.00006 Direct Mapping of Magnetic and Structural Profiles of Electric Field Moderated Oxygen Migration. DUSTIN A. GILBERT, ALEXANDER J. GRUTTER, BRIAN J. KIRBY, JULIE A. BORCHERS, BRIAN B. MARANVILLE, National Institute of Standards and Technology, ELKE ARENHOLZ, Lawrence Berkeley National Laboratory, KAI LIU, University of California, Davis — Recent studies on metal/oxide heterostructures have demonstrated control of interfacial magnetic anisotropy and saturation magnetization in ultrathin (5 ML) Co films through electric-field controlled oxygen migration. This approach presents a promising route to realize next-generation, ultralow power sensor and data-storage technologies. Here we demonstrate magnetoelectric coupling moderated by electrically-driven oxygen migration in much thicker alloy thin film can be continuously varied as a function of depth via a corresponding compositional gradient.$^1$ This work showed that the effective $T_C$ can be made to vary continuously over tens of nm. However, over a short enough distance, the system must become localized, with exchange coupling dominating the effects of the compositional gradient. Understanding this localization limit is important for potential applications, as it dictates the length-scale below which this technique stops being a viable engineering tool (at least for itinerant ferromagnets and their thermodynamic properties). To determine the localization limit in this class of system, we have fabricated a series of Co$_{1-x}$Cr$_x$ thin films, where $x$ varies sinusoidally between 0.28 (nominal $T_C \approx 250$ K) and 0.22 ($T_C > 300$ K), and have used polarized neutron reflectometry to study samples of differing oscillation wavelength. These measurements confirm the desired sinusoidal pattern was achieved, and reveal the temperature-dependence of the magnetic depth profile. Results will be presented in the context of mean-field simulations.$^1$  arXiv:1510.07535 [cond-mat.mtrl-sci].

9:12AM E5.00007 Magnetic localization limit in $T_C$ graded ferromagnetic thin films. BRIAN KIRBY, National Institute of Standards and Technology, LORENZO FALLARINO, PATRICIA RIEGO, MATTEO PANCALDI, ANDREAS BERGER, CIC nanoGune Consolider, CASEY MILLER, Rochester Institute of Technology — We have recently demonstrated that the effective Curie temperature ($T_C$) of a ferromagnetic alloy thin film can be continuously varied as a function of depth via a corresponding compositional gradient.$^1$ This work showed that the effective $T_C$ can be made to vary continuously over tens of nm. However, over a short enough distance, the system must become localized, with exchange coupling dominating the effects of the compositional gradient. Understanding this localization limit is important for potential applications, as it dictates the length-scale below which this technique stops being a viable engineering tool (at least for itinerant ferromagnets and their thermodynamic properties). To determine the localization limit in this class of system, we have fabricated a series of Co$_{1-x}$Cr$_x$ alloy films, where $x$ varies sinusoidally between 0.28 (nominal $T_C \approx 250$ K) and 0.22 ($T_C > 300$ K), and have used polarized neutron reflectometry to study samples of differing oscillation wavelength. These measurements confirm the desired sinusoidal pattern was achieved, and reveal the temperature-dependence of the magnetic depth profile. Results will be presented in the context of mean-field simulations.$^1$  arXiv:1510.07535 [cond-mat.mtrl-sci].
9:24AM E5.00008 Magnetic Irreversibility in VO$_2$/Ni Bilayers. JOSE DE LA VENTA, JOSH LAUZIER, LOGAN SUTTON, Colorado State Univ. — The temperature dependence of the coercivity and magnetization of VO$_2$/Ni bilayers was studied. VO$_2$ exhibits a well-known Structural Phase Transition (SPT) at 330-340 K, from a low temperature monoclinic (M) to a high temperature rutile (R) structure. The SPT of VO$_2$ induces an inverse magnetoelastic effect that strongly modifies the coercivity and magnetization of the Ni films. In addition, the growth conditions allow tuning of the magnetic properties. Ni films deposited on top of VO$_2$ (M) show an irreversible change in the coercivity after the first cycle through the high temperature phase, with a corresponding change in the surface morphology of VO$_2$. On the other hand, the Ni films grown on top of VO$_2$ (R) do not show this irreversibility. These results indicate that properties of magnetic films are strongly affected by the strain induced by materials that undergo SPT and that it is possible to control the magnetic properties by tuning the growth conditions.

9:36AM E5.00009 Layer Resolved Imaging of Magnetic Domain Motion in Epitaxial Heterostructures. SIOAN ZOHAR, YONGSEONG CHOI, Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439, USA, DAVID LOVE, RHODRI MANSELL, CRISPIN BARNES, Cavendish Laboratory, University of Cambridge, J J Thomson Avenue, CB3 0HE Cambridge, United Kingdom, DAVID KEAVNEY, RICHARD ROSENBERG, Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439, USA. — We use x-Ray Excited Luminescence Microscopy (XELM) to image the elemental and layer resolved magnetic domain structure of an epitaxial Fe/Cr wedge/Co heterostructure in the presence of large magnetic fields. The observed magnetic domains exhibit several unique behaviors that depend on the Cr thickness (tCr) modulated interlayer exchange coupling (IEC) strength. For Cr thickness tCr<1.5 nm and tCr>1.57 nm, strongly coupled parallel Co-Fc reversal and weakly coupled independent reversal are observed, respectively. The transition between these two reversal mechanisms for 0.34<tCr<1.5 nm is described by a combination of IEC guided domain wall motion and stationary zig zag domain walls. We observe domain walls nucleated at switching field minima are guided by IEC spatial gradients and collapse at switching field maxima.

9:48AM E5.0010 Magnetic profile of a graphene wrapped ferromagnetic surface. TIMOTHY CHARLTON, Science & Technology Facilities Council, DAVID LOVE, RAZAN ABOLJADAYEL, R. W. WEATHERUP, P. MONTEIRO, A. IONESCU, C. H. W BARNES, Cavendish Laboratory, Dept. of Physics, University of Cambridge. — Graphene has one of the highest electron mobilities at room temperature, making it ideal for next generation electronic devices. However, due to its small spin-orbit coupling it is not possible to manipulate spins directly in a pristine graphene monolayer. This may be overcome by proximity to a ferromagnet. Recent theoretical and experimental publications [1] indicate that on a Ni surface the graphene band structure is spin split. The authors used XMCD to measure the magnetic moment induced on the π electrons in graphene due to the proximity effect with Ni, obtaining a value between 0.05-0.10 μμμ per C atom. We have produced a uniform graphene layer grown by a CVD process directly on a Ni coated substrate (the catalyst). By varying key growth parameters (temperature & pressure) the interaction between graphene and the catalyst can be tuned to produce strong epitaxial alignment between graphene and Ni or a more weakly oriented rotated alignment. We will present results showing a magnetic enhancement at the ferromagnet- C interface extracted from recent polarized neutron reflectivity measurement on both epitaxial and rotated graphene wrapped ferromagnetic surfaces. [1] V. Karpan, et al., Phys. Rev. B 78, 195419 (2008), M. Weser, et al., Appl. Phys. Lett. 96, 012504 (2010)

10:00AM E5.00011 Self Exchange Bias and Bi-stable Magneto-Resistance States in Amorphous TbFeCo and TbSmFeCo Thin Films. CHUNG MA, XIAOPU LI, JIWEI LU, JOSEPH POON, Univ of Virginia, RYAN COMES, ARUN DEVARAJ, STEVEN SPURGEON, Pacific Northwest National Laboratory. — Amorphous ferromagnetic TbFeCo and TbSmFeCo thin films are found to exhibit strong perpendicular magnetic anisotropy. Self exchange bias effect and bi-stable magneto-resistance states are observed near compensation temperature by tuning the growth conditions. We also present results showing a magnetic enhancement at the ferromagnet- C interface extracted from recent polarized neutron reflectivity measurement on both epitaxial and rotated graphene wrapped ferromagnetic surfaces.

1The work was supported by the Defense Threat Reduction Agency grant and the U.S. Department of Energy.

10:12AM E5.00012 Angular dependence of exchange bias and magnetization reversal controlled by electric-field-induced competing anisotropies. YONGGANG ZHAO, AITIAN CHEN, PEISEN LI, Tsinghua University, XU ZHANG, Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, RENCI PENG, Tsinghua University, HAO-LIANG HUANG, University of Science and Technology of China, LVKUAN ZOU, XIAOLI ZHENG, Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, SEN ZHANG, College of National University of Defense Technology, PEIXIAN MIAO, Tsinghua University. — We study the angular dependence of exchange-field-controlled exchange bias and magnetization reversal in CoFeB/IrMn/Pb(B$_{12}$/3Nb$_{3}$/3)O$_{7}$/TiO$_{3}$ films. It is demonstrated that the ratio of the exchange-coupled unidirectional anisotropy and the uniaxial anisotropy of the FM layer, as well as their relative orientation can be dramatically and continuously tuned via electric fields. Simulations confirm that the electric-field-controlled exchange bias originates from the competition between the uniaxial anisotropy induced by the piezoelectric and the exchange-coupled unidirectional anisotropy. Moreover, electric-field-controlled magnetization reversal was realized at zero magnetic field.

10:24AM E5.00013 Rationale for contrasting phonon confinement and interface localization effect in FeAg and FeCr multilayers. SAMPYO HONG, TALAT RAHMAN, University of Central Florida. — We have performed density functional theory based calculations to investigate the propensity for formation of FeAg and FeCr multilayers. A perfect lattice match between Fe and Ag layers at the FeAg interface was obtained by modeling 45 rotated Ag(100) layers epitaxially on bcc Fe(100). In comparison, the FeCr interface was modeled by epitaxial layers of bcc Fe(100) and Cr(100). In FeAg, we find the signature peak of Fe bulk phonons (35 meV) to be substantially diminished and the low energy peaks to be remarkably enhanced, in qualitative agreement with experiment [1]. In contrast, the phonon density of state in the FeCr multilayers do not show any outstanding feature except a slight decrease in the 35 meV peak for the Fe layer at the interface, as compared to that of the middle Fe layer in excellent agreement with experiment [2]. The magnetic moment of the interfacial Fe atoms is larger than those Fe atoms in other layers, as a result of charge transfer from Fe to Ag at the interface. As compared to the middle layers, more spin-up and less spin-down states are occupied at the interface in such a way that Fe donates a large number of spin-down electrons to Ag but receives only a few spin-up electrons from the latter because of the almost fully occupied Ag d-band. [1] B. Roldan Cuenya et al., to be published. [2] Roldan et al, Phys. Rev. B 77, 165410 (2008).

1Work supported in part by DOE Grant No. DOE-DE-FG02-07ER4635
10:36AM E5.00014 Magneto-optical mapping of the domain wall pinning potential in ferromagnetic films

ROBERT BADEA, JESSE BEREZOVSKY, Case Western Reserve Univ. — The propagation of domain walls in ferromagnetic films is influenced by defects which suppress and pin the motion of the domain walls. We map the nanoscale effective pinning potential in a ferromagnetic film by raster scanning a single ferromagnetic vortex domain and measuring the hysteretic displacement vs. applied magnetic field. [1] We use a differential magneto-optical microscopy technique which yields spatial sensitivity of ~ 10 nm to measure the motion of the vortex domain. [2] Using a simple algorithm, we extract the effective pinning potential from the measured vortex displacement vs. applied field. The resulting effective pinning potential maps reveal different types of nanoscale pinning features which we attribute to different structural defects of the film. By comparing the pinning map to atomic force microscopy maps, we identify correlations between pinning sites and topographic features. [1] R. Badea, and J. Berezovsky, cond-mat/1510.07059, (2015). [2] R. Badea, J. A. Frey, and J. Berezovsky, Journal of Magnetism and Magnetic Materials 381, 463 (2015).

10:48AM E5.00015 Kinetic Monte Carlo simulations of thermally activated magnetization reversal in multi-layer Exchange Coupled Composite recording media.

M. L. PLUMER, A. M. ALMUDALLAL, J. I. MERCER, J. P. WHITEHEAD, Memorial University of Newfoundland, T. J. FAL, University of Colorado at Colorado Springs — The kinetic Monte Carlo (KMC) method developed for thermally activated magnetic reversal processes in single-layer recording media [1] has been extended to study multi-layer Exchange Coupled Composite (ECC) media used in current and next generations of disc drives [2]. The attempt frequency is derived from the Langer formalism with the saddle point determined using a variant of Bellman Ford algorithm. Complication (such as stagnation) arising from coupled grains having metastable states are addressed. MH-hysteresis loops are calculated over a wide range of anisotropy ratios, sweep rates and inter-layer coupling parameter. Results are compared with standard micromagnetics at fast sweep rates and experimental results at slow sweep rates.


Tuesday, March 15, 2016 8:00AM - 11:00AM
Session E6 GMAG DMP FIAP: Spin Excitations in Ultrathin Films, Nanostructures and Domain Walls
302 - Behrouz Khodadadi, University of Alabama

8:00AM E6.00001 Nonlinear spin-wave excitations at low magnetic bias fields

GEORG WOLTERSDORF, Martin Luther University Halle — We investigate experimentally and theoretically the nonlinear magnetization dynamics in magnetic films at low magnetic bias fields. Nonlinear magnetization dynamics is essential for the operation of numerous spintronic devices ranging from magnetic memory to spin torque microwave generators. Examples are microwave-assisted switching of magnetic structures and the generation of spin currents at low bias fields by high-amplitude ferromagnetic resonance. In the experiments we use X-ray magnetic circular dichroism to determine the number density of excited magnons in magnetically soft Ni80Fe20 thin films. Our data show that the common Suhl instability model of nonlinear ferromagnetic resonance is not adequate for the description of the nonlinear behavior in the low magnetic field limit. Here we derive a model of parametric spin-wave excitation, which correctly predicts nonlinear threshold amplitudes and decay rates at high and at low magnetic bias fields. In fact, a series of critical spin-wave modes with fast oscillations of the amplitude and phase is found, generalizing the theory of parametric spin-wave excitation to large modulation amplitudes. For these modes, we also find pronounced frequency locking effects that may be used for synchronization purposes in magnetic devices. By using this effect, effective spin-wave sources based on parametric spin-wave excitation may be realized. Our results also show that it is not required to invoke a wave vector-dependent damping parameter in the interpretation of nonlinear magnetic resonance experiments performed at low bias fields.

8:36AM E6.00002 Spin torque ferromagnetic resonance in Heusler based magnetic tunnel junctions

JIE ZHANG, TIMOTHY PHUNG, AAKASH PUSHP, JAEOWO JEONG, YARI FERRANTE, CHARLES RETTNER, BRIAN P. HUGHES, SEE-HUN YANG, STUART P. PARKIN, IBM Almaden Res Ctr — Heusler compounds are of interest as electrode materials for use in magnetic tunnel junctions (MTJs) due to their half metallic character, which leads to high spin polarization and high tunneling magnetoresistance. Whilst much work has focused on the influence of the half metallic character of the Heusler compounds on the magnetoresistance of MTJs, there is much less work investigating the influence of this electronic structure on the spin transfer torque. Here, we investigate the bias dependence of the anti-damping like and field-like spin transfer torque components as a function of the bias voltage in symmetric (CoMnSi/MgO/CoMnSi) and asymmetric (CoMnSi/MgO/CoFe) structure magnetic tunnel junctions using spin transfer torque ferromagnetic resonance. Lastly, we report on the effect of asymmetric bias dependence of the differential conductance on the spin transfer torque.

8:48AM E6.00003 Parametric excitation of magnetization by electric field

YU-JIN CHEN, HAN KYU LEE, Univ of California - Irvine, ROMAN VERBA, Institute of Magnetism, Kyiv, Ukraine, JORDAN KATINE, M. L. PLUMER, A. M. ALMUDALLAL, ANDREI SLAVIN, Oakland University, IGOR BARSUKOV, ILYA KRIVOROTOV, Univ of California - Irvine — Manipulation of magnetization by electric field is of primary importance for development of low-power spintronic devices. We present the first experimental demonstration of parametric generation of magnetic oscillations by electric field. We realize the parametric generation in CoFeB/MgO/SAF nanoscale magnetic tunnel junctions (MTJs). The magnetization of the free layer is perpendicular to the sample plane while the magnetizations of the synthetic antiferromagnet (SAF) lie in the plane. We apply microwave voltage to the MTJ at 2f, where f is the ferromagnetic resonance frequency of the free layer. In this configuration, the oscillations can only be driven parametrically via voltage-controlled magnetic anisotropy (VCMA) whereby electric field across the MgO barrier modulates the free layer anisotropy. The parametrically driven oscillations are detected via microwave voltage from the MTJ near f and show resonant character, observed only in a narrow range of drive frequencies near 2f. The excitation also exhibits a well-pronounced threshold drive voltage of approximately 0.1 Volts. Our work demonstrates a low threshold for parametric excitation of magnetization by VCMA that holds promise for the development of energy-efficient nanoscale spin wave devices.

9:00AM E6.00004 Control of Spin Wave Band Structure in YIG using Electric Fields

GLADE SIETSEMA, MICHAEL E. FLATTE, University of Iowa — It has previously been shown that a uniform electric field can be used to modify the dispersion relations of spin waves in YIG [1]. The application of the electric field results in a Dzyaloshinskii-Moriya interaction, which then produces a linear shift of the spin wave band structure. In this work, we consider the effects of a periodically varying electric field on a slab of YIG. The spin wave frequencies and linewidths of the system are obtained from the Landau-Lifshitz-Gilbert equation using the plane-wave expansion method. We demonstrate that the periodic variation of the electric field opens band gaps in the spin wave dispersion relations. A band gap width of several hundred MHz is observed when the electric field strength is alternating between 0 and 8 × 10−7 V/m over a length scale of 200 nm. The frequency and width of these band gaps can be tuned by adjusting the electric field strength and the lattice constant associated with the periodicity, and quality factors on the order of 100 can be achieved.

[3] This work is supported in part by DARPA.
9:12AM E6.00005 Measuring magnon propagation in magnonic crystals at millikelvin temperatures

9:24AM E6.00006 Torque-mixing Magnetic Resonance Spectroscopy

9:36AM E6.00007 Ferromagnetic resonance of a YIG film in the low frequency regime

9:48AM E6.00008 Current driven asymmetric domain wall propagation

10:00AM E6.00009 Notch-Boosted Domain Wall Propagation in Magnetic Nanowires

1The authors acknowledge support from the EPSRC (EP/K032690/1).

Further information and context can be found in the full presentations and discussions at the conference.
10:12AM E6.00010 Magnetic domain walls as reconfigurable spin-wave nano-channels\textsuperscript{1}. KAI WAGNER, 1. Helmholtz-Zentrum Dresden - Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany. 2. TU Dresden, Dresden, Germany — Research efforts to utilize spin waves as information carriers for wave based logic in micro- and nano-structured ferromagnetic materials have increased tremendously over the recent years [1,2]. However, finding efficient means of tailoring and downscaling guided spin-wave propagation in two dimensions, while maintaining energy efficiency and reconfigurability, still remains a delicate challenge. Here we target these challenges by spin-wave transport inside nanometer-scaled potential wells formed along magnetic domain walls. For this, we investigate the magnetization dynamics of a rectangular-like element in a Landau state exhibiting a so called 180° Nel wall along its center. By microwave antennae the rf-excitation is constricted to one end of the domain wall and the spin-wave intensities are recorded by means of Brillouin-Light Scattering microscopy revealing channeled transport. Additional micromagnetic simulations [3] with pulsed as well as cw-excitation are performed to yield further insight into this class of modes. We find several spin-wave modes quantized along the width of the domain wall yet with well defined wave vectors along the wall, exhibiting positive dispersion. In a final step, we demonstrate the flexibility of these spin-wave nano-channels based on domain walls. In contrast to wave guides realised by fixed geometries, domain walls can be easily manipulated. Here we utilize small external fields to control its position with nanometer precision over a micrometer range, while still enabling transport. Domain walls thus, open the perspective for reprogrammable and yet non-volatile spin-wave waveguides of nanometer width. [1]: A. V. Chumak, V. I. Vasyuchka, and B. Hillebrands, Nat. Phys. 11, 453-461 (2015).

\textsuperscript{1}Financial support by the Deutsche Forschungsgemeinschaft within project SCHU2922/1-1 is gratefully acknowledged.

10:48AM E6.00011 Studying Kittel-like modes in a 3D YIG disk using Torque-mixing Magnetic Resonance Spectroscopy\textsuperscript{1}. FATEMEH FANI SANI, JOSEPH LOSBY, Univ. of Alberta, Department of Physics and National Institute for Nanotechnology, DYLAN GRANDMONT, Univ. of Alberta, Department of Physics, ZHU DIAO, Univ. of Alberta, Department of Physics and National Institute for Nanotechnology, MIRO BELOV, National Institute for Nanotechnology, JACOB BERGESS, SHAWN COMPTON, Univ. of Alberta, Department of Physics and National Institute for Nanotechnology, WAYNE HIEBERT, DOUG VICK, National Institute for Nanotechnology, KAVEH MOHAMMAD. ELHAM SALIMI, GREGORY BRIDGES, DOUGLAS THOMSON, Electrical and Computer Engineering, University of Manitoba, MARK FREEMAN, Univ. of Alberta, Department of Physics and National Institute for Nanotechnology — We report a study of ferrimagnetic resonance in a mesoscopic, single-crystalline YIG disk using torque-mixing magnetic resonance spectroscopy (TMRS). The Kittel model for magnetic resonance is a touchstone in measuring fundamental magnetic properties for magnetic films, which does not significantly depend on the film size. In 3D structures, ladders of confined resonance modes are observed, and these can exhibit the non-monotonic evolution of frequency with field familiar from Kittel modes. TMRS is a tool uniquely suited for observing this physics in individual 3D structures, on account of its combination of high sensitivity and broadband capability coupled with fine frequency resolution.

Tuesday, March 15, 2016 8:00AM - 11:00AM — Session E11 DMP GMAG: Electronic Structure and Magnetism in Fe-based Superconductors

8:00AM E11.00001 The role of Hund’s coupling in the correlations and the nematicity of iron superconductors\textsuperscript{1}. ELENA BASCONES, Instituto de Ciencia de Materiales de Madrid — Since their discovery in 2008 the strength and the nature of correlations in iron superconductors have been widely discussed [1]. Understanding the correlations is key to unveil the nature of the superconducting, nematic and magnetic instabilities which appear in the phase diagram. Due to their multi-orbital character, correlations in iron superconductors are strongly affected by Hund’s coupling and these materials have been classified by some authors as Hund metals. For a long time there has been a strong controversy on the nature of correlations induced by Hund’s coupling and its relation to Mott physics. While some authors describe Hund metals as strongly correlated systems which are not in proximity to a Mott insulating state, others, have described iron superconductors as doped Mott insulators. In the talk, after some introduction, I will first show our recent results which show that while the spin polarization of the atoms, promoted by Hund’s coupling induces strong correlations, this does not necessarily mean that the total charge is more localized [2]. On the contrary, in some cases this polarization promotes itinerancy [2]. I will then present a generic framework to address the correlations in iron superconductors and discuss the role of Hund’s coupling in the nematicity of iron superconductors, with special emphasis on FeSe. [1] Magnetic interactions in iron superconductors: a review, E. Bascones, B. Valenzuela and M.J. Calderon, (in press) arXiv:1503.04223 [2] Electronic correlations in Hund metals. L. Fanfarillo and E. Bascones, Phys. Rev. B 92, 075136 (2015)

\textsuperscript{1}Funding from Ministerio de Ciencia y Tecnologa FIS2011-29689, FIS2014-53219-P and Fundacion Ramon Areces

8:36AM E11.00002 Itinerancy-Enhanced Quantum Fluctuation of Magnetic Moments in Iron-Based Superconductors\textsuperscript{1}. YU-TING TAM, DAO-XIN YAO, Sun Yat-sen university, WEI KU, Brookhaven National Laboratory — We investigate the influence of itinerant carriers on dynamics and fluctuation of local moments in Fe-based superconductors, via linear spin-wave analysis of a spin-fermion model containing both itinerant and local degrees of freedom. Surprisingly against the common lore, instead of enhancing the influence of itinerant carriers on dynamics and fluctuation of local moments in Fe-based superconductors, via linear spin-wave analysis of a spin-fermion model containing both itinerant and local degrees of freedom, we show that the fluctuations of magnetic moments are increased tremendously over the recent years [1,2]. This challenges the validity of ferromagnetically compensated first-neighbor coupling reported from short-range fitting and temporal quantum fluctuation that leads to the observed small ordered moment. Interestingly, the underlying mechanism is shown to be intra-pocket nesting-associated long-range coupling rather than the previously believed ferromagnetic double-exchange effect. This challenges the validity of ferromagnetically compensated first-neighbor coupling reported from short-range fitting to the experimental dispersion, which turns out to result instead from the ferro-orbital order that is also found instrumental in stabilizing the magnetic order.

\textsuperscript{1}Work supported by US DOE No.DE-AC02-98CH10886 and CHN No. NBRPC-2012CB821400, No. NSFC-11275279
8:48AM E11.00003 Competing magnetic fluctuations in iron pnictide superconductors: role of ferromagnetic spin correlations revealed by NMR

YUJI FURUKAWA, PAUL WIECKI, BEAS ROY, DAVID C. JOHNSTON, SERGEY L. BUD’KO, PAUL C. CANFIELD, Ames Laboratory, Dept. of Phys. and Astro, Iowa State Univ., COLLaboration — The role of magnetic fluctuations in iron pnictide superconductors has been extensively studied since their discovery. As the parent materials have antiferromagnetic (AFM) ground states, attention has been focused on stripe-type AFM fluctuations, which are widely believed to give rise to the Cooper pairing in the systems. On the other hand, according to density functional theory calculations, the static magnetic susceptibility is enhanced at not only the stripe-type AFM but also ferromagnetic (FM) wavevectors. Nevertheless, FM fluctuations have not been investigated microscopically. In this talk, based on 23As NMR data [1,2], we report clear evidence for the existence of strong FM correlations in the hole-doped (Ba1−xKx)Fe2As2 and electron-doped Ba(Fe1−yCoy)2As2. We will discuss the role of FM spin correlations in the occurrence of superconductivity in these systems. [1] P. Wiecki, et al., Phys. Rev. B 91, 220406 (2015). [2] P. Wiecki, et al., Phys. Rev. Lett. 115, 137001 (2015).

9:00AM E11.00004 Spin-liquid polymorphism in an underdoped iron-chalcogenide superconductor

IGOR ZALIZNYAK, Brookhaven National Laboratory, ANDREI SAVICI, MARK LUMSDEN, Oak Ridge National Laboratory, ALEXEI TSVELIK, Brookhaven Natl Lab, RONGWEI HU, Rutgers University, CEDOMIR PETROVIC, Brookhaven National Laboratory — We report neutron scattering measurements which reveal spin-liquid polymorphism in an 11 iron chalcogenide superconductor. It occurs when a poorly metallic magnetic state of FeTe is driven toward superconductivity by substitution of a small amount of tellurium with isoelectronic sulfur. We observe a liquid-like magnetic response, which is described by the coexistence of two disordered magnetic phases with different local structures whose relative abundance depends on temperature. One is the ferromagnetic (FM) plaquette phase observed in undoped, nonsuperconducting FeTe, which preserves the C4 symmetry of the underlying square lattice and is favored at high temperatures, whereas the other is the antiferromagnetic plaquette phase with broken C4 symmetry, which emerges with doping and is predominant at low temperatures. These findings suggest the coexistence of and competition between two distinct liquid states, and a liquid-liquid phase transformation between these states, in the electronic spin system of FeTe1−x(S,Se)x. Our results shed light on many recent experimental data in unconventional superconductors. The phase with lower, C2 local symmetry, whose emergence precedes superconductivity, naturally accounts for a propensity to electronic nematic states.

1Supported by USDOE under Contract No. DE-AC02-07CH11358.

9:12AM E11.00005 Studying the morphology of the magnetic C4 phase in the 122 superconductors.

KEITH TADDEI, Northern Illinois University, JARED ALLRED, University of Alabama, DANIEL BUGARIS, Argonne National Laboratory, MATTHEW KROGSTAD, Northern Illinois University, SAUL LAPIDUS, Advanced Photon Source ANL, RYAN STADEL, Northern Illinois University, DUCK CHUNG, HELMUT CLAUS, Argonne National Laboratory, MERCOURI KANATZIDIS, Northwestern Illinois University, DENNIS BROWN, Northern Illinois University, STEPHAN ROSENKRANZ, RAYMOND OSBORN, Argonne National Laboratory, OMAR CHMAISSEM, Northern Illinois University — The iron based superconductors continue to prove an exciting system for the study of superconductivity: the recent discovery of a reentrant tetragonal phase with SDW magnetic ordering in FeTe has also allowed for the determination of spin fluctuations as the driving mechanism behind the phase evolution in these materials. Evidence has been mounting of the universality of C4 for the electronic nematicity in the phase of these compounds. Now, Mössbauer data shows that the new phase also establishes the itinerant character of the antiferromagnetism of these materials and the primary role played by magnetic over orbital degrees of freedom. Neutron diffraction had shown that the magnetic order in the C4 phase was compatible with a double-Q structure arising from a collinear spin-density wave along both the X and Y directions simultaneously. The coherent superposition of the two modulations produces a non-uniform magnetic structure, in which the spin amplitudes vanish on half of the sites and double on the others, a uniquely itinerant effect that is incompatible with local moment magnetism. Mössbauer spectra in the C4 phase confirm this double-Q structure, with 50% of the spectral weight in a zero-moment peak and 50% with double the magnetic splitting seen in the C2 phase.

1Supported by the Office of Basic Energy Sciences, US DOE, under Contract DE-SC00112704.

9:24AM E11.00006 Itinerant Double-Q Spin-Density Wave in Iron Arsenide Superconductors

RAYMOND OSBORN, Argonne Nati Lab, JARED ALLRED, University of Alabama, OMAR CHMAISSEM, STEPHAN ROSENKRANZ, Argonne Nati Lab, DENNIS BROWN, Northern Illinois University, KEITH TADDEI, MATTHEW KROGSTAD, DANIEL BUGARIS, DUCK-YOUNG CHUNG, HELMUT CLAUS, SAUL LAPIDUS, MERCOURI KANATZIDIS, Argonne Nati Lab, JIAN KANG, RAFAEL FERNANDES, University of Minnesota, ILYA EREMINE, Ruhr-Universitat Bochum — The recent observation of a tetragonal magnetic (C4) phase in hole-doped iron arsenide superconductors has provided evidence of a magnetic origin for the electronic nematicity in the C2 phase of these compounds. Now, Mössbauer data shows that this new phase also establishes the itinerant character of the antiferromagnetism of these materials and the primary role played by magnetic over orbital degrees of freedom. Neutron diffraction had shown that the magnetic order in the C4 phase was compatible with a double-Q structure arising from a collinear spin-density wave along both the X and Y directions simultaneously. The coherent superposition of the two modulations produces a non-uniform magnetic structure, in which the spin amplitudes vanish on half of the sites and double on the others, a uniquely itinerant effect that is incompatible with local moment magnetism. Mössbauer spectra in the C4 phase confirm this double-Q structure, with 50% of the spectral weight in a zero-moment peak and 50% with double the magnetic splitting seen in the C2 phase.

1Supported by the US DOE Office of Science, Materials and Engineering Division

9:36AM E11.00007 ABSTRACT WITHDRAWN

9:48AM E11.00008 Emergent Ising degrees of freedom in the J1-J2-J3 model for the iron tellurides

GUANGHUA ZHANG, Ames Laboratory, Dept of Physics and Astronomy, Iowa State University, RAFAEL FERNANDES, School of Physics and Astronomy, University of Minnesota, REBECCA FLINT, Ames Laboratory, Dept of Physics and Astronomy, Iowa State University — The iron-telluride family of superconductors form a double-stripe (Q = (π/2, π/2)) magnetic order, which can be captured within a J1 − J2 − J3 Heisenberg model in the regime J3 ≫ J2 ≫ J1. Intriguingly, besides breaking spin-rotational symmetry, the ground state manifold has three additional Ising degrees of freedom. Via their coupling to the lattice, they give rise to a monoclinic distortion and to two non-uniform lattice distortions with wave-vector (π, π). Because the ground state is four-fold degenerate (mod rotations in spin space), only two of these Ising order parameters are independent. Here we introduce an effective field theory to treat all Ising order parameters, as well as magnetic order. All three transitions (corresponding to the condensations of two Ising and one magnetic order parameter) are simultaneous and first order in three dimensions, but lower dimensionality (or equivalently weaker interlayer coupling) and weaker magnetoelastic coupling can split the three transitions, and in some cases allows for two separate Ising phase transitions.
10:00AM E11.00009 Non-Fermi liquid behavior in quantum critical iron-pnictide metal Ba(Fe,Ni,Co)\textsubscript{2}As\textsubscript{2}. YASUYUKI NAKAJIMA, KEVIN KIRSHENBAUM, ALEX HUGHES, CHRISTOPHER ECKBERG, RENXIONG WANG, TRISTIN METZ, SHANTA SAHA, JOHNPIERRE PAGLIONE, Univ of Maryland-College Park. The breakdown of Landau’s Fermi liquid theory has been believed to be induced by quantum fluctuations in the vicinity of a quantum critical point (QCP), occasionally accompanied by exotic superconductivity in the strongly correlated electron systems, such as cuprate and iron pnictide superconductors [1]. However, the superconducting dome of such materials with high Tc precludes us from investigating the interplay between quantum fluctuations and the exotic superconductivity. We report non-Fermi liquid behavior associated with quantum fluctuations in the transport and thermodynamic properties of the non-superconducting iron pnictide Ba(Fe,Co,Ni)\textsubscript{2}As\textsubscript{2}, which allows us to elucidate the behavior on cooling down to near absolute zero without distractions from the superconductivity. We will discuss the evolution of non-Fermi liquid behavior with magnetic field, highlighting the presence of field tuned QCP. [1] T. Shibauchi et al., Annu. Rev. Condens. Matter Phys. 5, 113 (2014).

10:12AM E11.00010 Spin-fluctuation induced non-Fermi-liquid behaviour with suppressed superconductivity in LiFe\textsubscript{1-x}Co\textsubscript{x}As. HU MIAO, YAOMIN DAI, Brookhaven National Laboratory, LINGYI XING, XIANCHENG WANG, Institute of physics, Chinese Academy of Sciences, PENGSHUAI WANG, Renmin University, HONG XIAO, TIAN QIAN, PIERRE RICHARD, XIANGQING QIU, Institute of physics, Chinese Academy of Sciences, WEIQIANG YU, Renmin University, CHANGQING JIN, ZIQIANG WANG, Institute of physics, Chinese Academy of Sciences — We study a series of LiFe\textsubscript{1−x}Co\textsubscript{x}As compounds with different Co concentrations by transport, optical spectroscopy, angle-resolved photoemission spectroscopy, and nuclear magnetic resonance. We observe a Fermi-liquid to non-Fermi-liquid to Fermi-liquid (FL-NFL-FL) crossover alongside a monotonic suppression of the superconductivity with increasing Co content. In parallel to the FL-NFL-FL crossover, we find that both the low-energy spin fluctuations and Fermi surface nesting are enhanced and then diminished, strongly suggesting that the NFL behaviour in LiFe\textsubscript{1−x}Co\textsubscript{x}As is induced by low-energy spin fluctuations that are very likely tuned by Fermi surface nesting. Our study reveals a unique phase diagram of LiFe\textsubscript{1−x}Co\textsubscript{x}As where the region of NFL is moved to the boundary of the superconducting phase, implying that they are probably governed by different mechanisms.

10:24AM E11.00011 Study of non-Fermi Liquid behavior from partial nesting in multi-orbital superconductors. CHANDAN SETTY, PHILIP PHILLIPS, University of Illinois at Urbana-Champaign — Partial nesting between two connected or disconnected regions of the Fermi surface leads to fractional powers of the Coulomb scattering lifetime as a function of temperature and frequency. This result is first demonstrated for a toy band structure where partial nesting occurs within a single band and between different regions of the Brillouin zone. A comparison is then made to a multiband scenario by studying the scattering rate of an effective two orbital model that was proposed in the context of multi-orbital superconductors. In the process, various model independent factors affecting the temperature exponent, n, are identified. The logographically divergent contributions of the lowest order vertex correction to the multi-orbital susceptibility, and the role played by nesting in suppressing these divergences is analysed. The relevance of these results is discussed keeping the recently observed anomalous resistivity in the Co doped Iron superconductor LiFeAs as a backdrop.

10:36AM E11.00012 Sensitivity of quantum critical pairing to Fermi surface topology: a Quantum Monte Carlo study. XIAOYU WANG, University of Minnesota, YONI SCHATTNER, EREZ BERG, Weizmann Institute of Science, RAFAEL FERNANDES, University of Minnesota — In many iron-based and copper-based materials, unconventional superconductivity appears in close proximity to an antiferromagnetic instability. This fact has motivated intense theoretical investigations of the impact of magnetic fluctuations, particularly those associated with the putative quantum critical point (QCP), on the formation of the Cooper pairs. Although significant advance has been achieved using analytical methods to solve the so-called spin-fermion model, in which low-energy electronic states couple to quantum critical bosonic fluctuations, there remain significant challenges in establishing a perturbative scheme that accounts for both non-Fermi liquid behavior and superconductivity near the QCP. Here we present a sign-problem-free Quantum Monte Carlo (QMC) study of the spin-fermion model for a generic two-band Hamiltonian. We show that properties of the Fermi surface topology beyond the existence of hot spots play a fundamental role in determining the superconducting properties. In particular, we find that proximity to perfect nesting strongly suppresses the enhancement of the pairing susceptibility promoted by the QCP. We also compare our QMC results with an Eliashberg analysis of the quantum critical problem.

10:48AM E11.00013 Density Functional Theory insights into the mechanism of noncollinear incommensurate spin density waves in Iron Arsenide. ROBERT SCHOONMAKER, STEWART CLARK, TOM LANCaster, THOMAS FRAWLEY, PETER HATTON, Durham University — Iron arsenide exhibits interesting physics between novel superconductors and other helical magnetic ordering in Pnma metal arsenide materials. Recent diffraction data has found a more complex ordering than a simple helical incommensurate spin density wave. Instead iron arsenide exhibits a definite chirality to the helimagnetism, an ellipticity in the spiral not aligned with the crystal axis, and resonant diffraction peaks forbidden by the Pnma symmetry. From non-magnetic and collinear density functional theory calculations we present insight into the mechanisms for the formation of this helimagnetic state. We find that ferromagnetic superexchange is a likely mechanism for the spin ordering and that the noncollinear ordering under this regime is caused by the spins on neighbouring ions arranging to minimise direct exchange between iron atoms, and also minimize disruption of the ferromagnetic superexchange between privileged iron-arsenic pairs. To explain the forbidden peaks in the diffraction we have performed second-order spin-orbit perturbation calculations on the nonmagnetic calculation, which finds that the orbital ordering on the iron atoms couples to the helimagnetism will lead to the otherwise symmetry-forbidden peaks.
the apparent spin Hall angle (assuming long Py spin diffusion length) of Py is estimated to be 0.010 at 295K and 0.017 at 4.5K.

injected from F1 into Cu, and the nonlocal voltage is measured between two ends of F2. The in-plane magnetic field is applied perpendicular to F1/F2 stripes.

placed at all interfaces. For SHE, a charge current passes through F2, and a nonlocal voltage is detected between F1 and Cu. For ISHE, a charge current is

structure consists of a Py spin injector/detector (F1), a Cu channel, and a second Py stripe (F2) where SHE/ISHE occurs. Low-resistance AlOx layers are

SHUHAN CHEN, YUNJIAO CAI, YI JI, University of Delaware — The spin Hall effect (SHE) and inverse spin Hall effect (ISHE) have been explored primarily

mechanism for the creation of damping-like and field-like torques; it also leads to possible reinterpretations of experiments in which interfacial torques are thought to be suppressed. We discuss the interpretation of experiments involving spin orbit torque, spin pumping/memory loss, the Rashba-Edelstein effect, and the spin Hall magnetoresistance.

8:48AM E18.00003 Spin-Hall Non-Local Transport Mediated by a Magnetic Insulator1, MASSOUD RAMEZANI MASIR, HUA CHEN, Department of physics, University of Texas at Austin, Texas 78712, USA, INTI SODEMANN, Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA, ALLAN. H. MACDONALD, Department of physics, University of Texas at Austin, Texas 78712, USA — Magnetic systems with easy-plane order support dissipationless spin supercurrents that can lead to non-local coupling between electrically separated conductors. Recently the electrical properties of a system containing two magnetic multilayer stacks with perpendicular magnetic anisotropy electrodes and a shared easy-plane magnetic layer have been discussed. In this research we discuss a closely related system in which the two conducting channels that are coupled by the easy-plane magnetic layer are co-planar thin film metals with large spin Hall effects. We theoretically explained the non-local relationship between the current-voltage relationships of two thin film metallic conductors. Coupling occurs because both conductors inject spins into the magnetic insulator and because this information is communicated between conductors via exchange interactions within the magnetic system. We investigate the non-local transport properties of the system in the macrospin and long thin nanomagnet limits, deriving conditions for the critical currents and using solutions to the Landau-Lifshitz-Gilbert equation to characterize the dynamic steady state case.

1This work was supported by as part of SHINES, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award SC0012670.

9:00AM E18.00004 Nonlocal anomalous Hall effect1, SHULEI ZHANG, GIOVANNI VIGNALE, Department of Physics and Astronomy, University of Missouri — Anomalous Hall effect (AHE) is a distinctive transport property of ferromagnetic metals arising from spin orbit coupling (SOC) in concert with spontaneous spin polarization. Nonetheless, recent experiments have shown that the effect also appears in a nonmagnetic metal in contact with a magnetic insulator. The main puzzle lies in the apparent absence of spin polarized electrons in the non-magnetic metal. Here, we theoretically demonstrate that the scattering of electrons from a rough metal-insulator interface is generally spin-dependent, which results in mutual conversion between spin and charge currents flowing in the plane of the layer. It is the current-carrying spin polarized electrons and the spin Hall effect in the bulk of the metal layer that conspire to generate the AHE current. This novel AHE differs from the conventional one only in the spatial separation of the SOC and the magnetization, so we name it as nonlocal AHE. In contrast to other previously proposed mechanisms (e.g., spin Hall AHE and magnetic proximity effect (MPE)), the nonlocal AHE appears on the first order of spin Hall angle and does not rely on the induced moments in the metal layer, which make it experimentally detectable by contrasting the AHE current directions of two layered structures such as Pt/Cu/YIG and β-Ta/Cu/YIG (with a thin inserted Cu layer to eliminate the MPE).

We predict that the directions of the AHE currents in these two trilayers would be opposite since the spin Hall angles of Pt and β-Ta are of opposite signs.

1Work supported by NSF Grants DMR-1406568.

9:12AM E18.00005 Spin Hall effects from mesoscopic ferromagnetic NiFe thin films, CHUAN QIN, SHUHAN CHEN, YUNJIAO CAI, YI JI, University of Delaware — The spin Hall effect (SHE) and inverse spin Hall effect (ISHE) have been explored primarily in nonmagnetic metals such as Pt. In this work, we probe SHE/ISHE from mesoscopic ferromagnetic NiFe (Py) films in nonlocal lateral structures. The structure consists of a Py spin injector/detector (F1), a Cu channel, and a second Py stripe (F2) where SHE/ISHE occurs. Low-resistance AlOx layers are placed at all interfaces. For SHE, a charge current passes through F2, and a nonlocal voltage is detected between F1 and Cu. For ISHE, a charge current is injected from F1 into Cu, and the nonlocal voltage is measured between two ends of F2. The in-plane magnetic field is applied perpendicular to F1/F2 stripes. For both measurements, the nonlocal signal for large positive field is different from that of large negative field owing to the SHE/ISHE. Using a simple model, the apparent spin Hall angle (assuming long Py spin diffusion length) of Py is estimated to be 0.010 at 295K and 0.017 at 4.5K.

9:24AM E18.00006 Demonstration of Kirchhoff’s First Law for Pure Spin Currents, JOSEPH BATLEY, M. C. ROSAMOND, M. ALI, E. H. LINFIELD, G. BURNELL, B. J. HICKEY, University of Leeds — In conventional electronics a fundamental component of circuit design is the principle of fan-out, which allows multiple operations to be performed in order to build up complex logical procedures. A fan-out device relies on the condition that electrical currents obey Kirchoff’s laws and in order for spin-logic to be viable, the same must be shown for pure spin currents. Both fan-out and fan-in experiments have been performed to observe how spin currents behave in a multi-terminal circuit. The development of a 3-dimensional nonlocal IV and matrix fitting method provides information about each spin current, along with the thermal current generated at the injection point, and how they interact with each other. The fan-out geometry demonstrates that a pure spin current will divide between the different branches in a circuit, with a magnitude determined through the spin resistances of each arm. The fan-in measurements demonstrate that two pure spin currents will add and subtract with each other in a conventional manner expected from Kirchhoff’s first law. These experiments have demonstrated the symmetry of pure spin currents with respect to the injection current and shown that they obey Kirchhoff’s current law.

9:36AM E18.00007 ABSTRACT WITHDRAWN —

9:48AM E18.00008 ABSTRACT WITHDRAWN —

9:48AM E18.00008 Abstract is Withdrawn —

Anomalous Hall effect driven by dipolar spin waves in uniform ferromagnets, KOJI SATO, AIMR, Tohoku University, KEI YAMAMOTO, Kobe University, EIJJI SAITO, AIMR, Tohoku University, HIROSHI KOHNO, Nagoya University — An anomalous Hall effect is shown to arise from the exchange interaction of conduction electrons with dipolar spin waves in ferromagnets. This effect exists even in homogeneous ferromagnets with relativistic spin-orbit coupling. The leading contribution to the Hall conductivity is proportional to the chiral spin correlation of dynamical spin textures and is physically understood in terms of the skew scattering by dipolar magnons.
10:00AM E18.00009 Strong Spin Hall effect in PtMn

YONGXI OU, SHENGJE SHI, DANIEL RALPH, ROBERT BUHRMAN, Cornell Univ — Recent reports indicate that certain metallic antiferromagnets (AFM) can exhibit a significant spin Hall effect. Here we report a large damping-like spin torque efficiency ($\xi_{DL}$) in PtMn/ferromagnet(FM) bilayer structures, determined from both FM-thickness-dependent spin-torque ferromagnetic resonance (ST-FMR), and harmonic response (HR) measurements of layers with perpendicular magnetic anisotropy (PMA). We find that $\xi_{DL}$ can vary from $<0.1$ to $>0.15$, depending on the thickness of PtMn, the stacking order of the samples, and the choice of the FM material. The field-like spin torque efficiency ($\xi_{FL}$) is also quite variable, $0<|\xi_{FL}|<0.5$. The large broadening of the ST-FMR linewidth suggests extra spin attenuation at the AFM/FM interface that is possibly due to intermixing. The PtMn/FeCoB/MgO structures that exhibit PMA have a comparatively low switching current density and an unusual asymmetric switching phase diagram. These results indicate that AFM PtMn has significant potential both for advancing the understanding of the spin Hall effect in Pt alloys, and for enabling new spintronics functionality.

10:12AM E18.00010 Large anomalous Hall effect in Pt interfaced with perpendicular anisotropy ferrimagnetic insulator

CHI TANG, PATHIKUMAR SELLAPPAN, YAWEN LIU, JAVIER GARAY, JING SHI, University of California-Riverside, SHINES TEAM — We demonstrate the strain induced perpendicular magnetic anisotropy (PMA) in a ferrimagnetic insulator (FMI), $\text{Tm}_2\text{Fe}_3\text{O}_{12}$ (TIG) and the first observation of large anomalous Hall effect (AHE) in TIG/Pt bilayers. Atomically flat TIG films were deposited by a laser molecular beam epitaxy system on (111)-oriented substituted gadolinium gallium garnet substrates. The strength of PMA could be effectively tuned by controlling the oxygen pressure during deposition. Sharp squared anomalous Hall hysteresis loops were observed in bilayers of TIG/Pt over a range of thickness of Pt, with the maximum AHE conductivity reaching 1 S/cm at room temperature. The AHE vanishes when a 5 nm Cu layer was inserted between Pt and TIG, strongly indicating the proximity-induced ferromagnetism in Pt. The large AHE in the bilayer structures demonstrates a potential use of PMA-FMI related heterostructures in spintronics.

1This work was supported as part of the SHINES, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award SC0012670.

10:24AM E18.00011 Direct measurement of spin accumulation in the Cu layer due to spin currents from Co

ROOPALI KUKREJA, UC San Diego — Spin transport is the key for reading or writing bits in spintronic devices by utilizing the Giant Magnetoresistance effect or the spin transfer torque effect. Spin currents have also been shown to play important role in the ultrafast manipulation of magnetization via all optical switching. Hence, detailed understanding of spin currents from ferromagnet to non-magnets is a crucial step in the development of spintronic devices. However, directly observing these spin currents is extremely challenging due to magnetic moment injected into non-magnet being very small, less than 1/10000 of a regular ferromagnet. In this talk, we will present our recent measurements on the spin currents from a thin film Co ferromagnet into non-magnetic Cu metal in a nanopillar device. We have developed an extremely sensitive spectro-microscopy detection method based on element specific x-ray magnetic circular dichroism where current pulses driving the spin currents into the Cu layer are synchronized with the synchrotron x-ray photons. The sensitivity of this ‘lock-in’ technique has allowed us to detect the extremely small transient Cu magnetization. We observe two spin currents induced effects in the Cu layer. The first effect is the transiently induced magnetization which occurs in bulk of the Cu layer due to spin accumulation and has a magnitude of 0.00003 μB per atom. The second effect occurs at the Co/Cu interface where we observe a 10% increase or 0.004 μB per atom for the hybridized Cu atoms due to spin torque alignment.
8:48AM E19.00003 Understanding the Origin of Ferromagnetism in LaNiO$_2$/CaMnO$_3$ Superlattices, CHARLES FLINT, Stanford University, ALPHA N'DIAYE, PADRAIC SHAFER, ELKE ARENHOLZ, Advanced Light Source, YURI SUZUKI, Stanford University — Interfacial ferromagnetism (FM) in transition metal oxide heterostructures is a promising route for engineering new low-dimensional magnetic materials. In 2001, FM was discovered in CaRuO$_3$/CaMnO$_2$ superlattices (SLs), which is attributed to an itinerant electron-mediated Mn-Mn double-exchange (DE) interaction. Since then we have discovered interfacial FM in (LaNiO$_3$)$_n$/CaMnO$_3$ SLs that is consistent with this DE interaction. Now we have explored even further reduced dimensionality by fabricating [(LaNiO)$_{n-2}$/CaMnO$_3$]$_n$ SLs. However, a systematic study of the magnetic properties of these interfacial FM is still missing. In this work, we systematically studied transport measurements reveal interfacial FM in insulating and conducting SLs. Since there are no itinerant electrons in the insulating SLs, this FM must arise from a different source. Using x-ray absorption spectroscopy and magnetic circular dichroism, we have identified the coexistence of Ni$^{2+}$ and Ni$^{3+}$ and Nm magnetism. We therefore speculate that the FM in insulating SLs originates from a Mn-Ni superexchange interaction. We discuss the role of these interactions in interfacial FM and methods for controlling them.

9:00AM E19.00004 Exploring interfacial ferromagnetism in manganite-based superlattices, DI YI, CHARLES FLINT, YURI SUZUKI, Department of Applied Physics, Stanford University — Heterointerface of complex oxides provides a rich playground to explore the emergent phenomena that are not found in bulk. In particular, emergent interfacial ferromagnetism has been successfully demonstrated in heterostructures composed of materials which are paramagnetic and antiferromagnetic in bulk. In our previous work, leakage of itinerant electrons from a paramagnetic metal to an antiferromagnetic insulator has been shown to give rise to interfacial ferromagnetism in CaMnO$_3$. Based on such behavior, we have recently discovered interfacial ferromagnetism in manganite-based superlattices.

9:12AM E19.00005 Magnetotransport in LaNiO$_3$/La$_2$/Sr$_1$/3MnO$_3$ superlattices with non-collinear magnetic ordering, JASON HOFFMAN, University of British Columbia, STEPHEN WU, Argonne National Laboratory, BRIAN KIRBY, National Institute of Standards and Technology, ANAND BHATTACHARYA, Argonne National Laboratory — Non-collinear magnetic textures can give rise to exotic charge and spin transport behaviors, and may allow for the control of magnetism using small electric currents. While these textures have been observed in a number of bulk materials and in thin films, realizing non-collinear magnetism in heterostructures presents new avenues to tune their properties using tailored interfaces and gate electric fields. We have previously used polarized neutron reflectometry (PNR) to demonstrate that superlattices of paramagnetic LaNiO$_3$ (LNO) and ferromagnetic La$_{2}$/Sr$_{1}$/3MnO$_3$ (LSMO) adopt a non-collinear magnetic structure. In this work, we characterize the non-collinearity as a function of temperature and magnetic field using anisotropic magnetoresistance (AMR) and Nernst effect measurements. We observe rotational hysteresis at low fields, while the magnitude of the AMR is found to vary non-monotonically with applied field. To understand this behavior, we develop a simple free-energy model that includes contributions from biaxial anisotropy, Zeeman energy, and exchange coupling between the LSMO and the LNO layers. From this analysis, we are able to extract the orientation of the magnetization of the individual LSMO layers, which agrees well with the values measured using PNR.

9:24AM E19.00006 Influence of quantum confinement and strain on orbital polarization of strained four-layer LaNiO$_2$ superlattices: a DFT+DMFT study, HYOWON PARK, University of Illinois at Chicago, ANDREW MILLIS, CHRIS MARIANETTI, Columbia University — Here we use the combination of density functional theory and dynamical mean field theory to study Ni d orbital polarization in strained LaNiO$_2$/LaNiO$_2$ superlattices consisting of four layers of nominally metallic LaNiO$_2$ and four layers of insulating AlO$_2$ separated by LaO layers. The layer-resolved orbital polarization is calculated as a function of strain and analysed in terms of structural, quantum confinement, and correlation effects. The overall dependence of orbital polarization on strain in superlattices is qualitatively consistent with recent X-ray absorption spectroscopy and resonant reflectometry data. However, interesting differences of detail are found depending on the sign of strain. Under tensile strain, the two inequivalent Ni ions display different behavior, similar to that seen in strained bulk LaNiO$_2$, and observe itinerant metallic behavior. Compressive strain produces a larger dependence of orbital polarization on Ni position and even the inner Ni layer exhibits orbital polarization different from that calculated for strained bulk LaNiO$_2$. The quantum confinement effect is as important as the strain effect and more stronger for tensile strain.

9:36AM E19.00007 Interfacial Symmetry Control of Emergent Ferromagnetism, ALEXANDER GRUTTER, JULIE BORCHERS, BRIAN KIRBY, Natl Inst of Stds and Tech, CHUNYONG PARK, University of California at Berkeley, ELKE ARENHOLZ, Lawrence Berkeley National Lab, ARTURAS VAILIONIS, CHARLES FLINT, YURI SUZUKI, Stanford University — Atomically precise complex oxide heterostructures provide model systems for the discovery of new emergent phenomena since their magnetism, structure and electronic properties are strongly coupled. Octahedral tilts and rotations have been shown to alter the magnetic properties of complex oxide heterostructures, but typically induce small, gradual magnetic changes. Here, we demonstrate sharp switching between ferromagnetic and antiferromagnetic order at the emergent ferromagnetic interfaces of CaRuO$_3$/CaMnO$_2$ superlattices. Through synchrotron X-ray diffraction and neutron reflectometry, we show that octahedral distortions in superlattices with an odd number of CaMnO$_3$ unit cells in each layer are symmetry mismatched across the interface. In this case, the rotation symmetry switches across the interface, reducing orbital overlap, suppressing charge transfer from Ru to Mn, and disrupting the interfacial double exchange. This disruption switches half of the interfaces from ferromagnetic to antiferromagnetic and lowers the saturation magnetic of the superlattice from 1.0 to 0.5 $\mu_B$/interface Mn. By targeting a purely interfacial emergent magnetic system, we achieve drastic alterations to the magnetic ground state with extremely small changes in layer thickness.

9:48AM E19.00008 4d electron Ruthenate systems: their unique and new magnetic properties, SEUNGKRAN LEE, YEONGJAE SHIN, CCES-IBS, Seoul 151-747, Republic of Korea, M.S. ANWAR, YUSUKE SUGIMOTO, Dep. of Physics, Graduate School of Science, Kyoto Univ., Kyoto 606-8502, MINCHEOL LEE, SUNGJIN KANG, CCES-IBS, Seoul 151-747, Republic of Korea, SHINGO YONEZAWA, YOSHITERU MAENO, Dep. of Physics, Graduate School of Science, Kyoto Univ., Kyoto 606-8502, TAEWON NOH, CCES-IBS, Seoul 151-747, Republic of Korea — The Ruddlesden-Popper series (PR) of Sr$_{n+1}$Ru$_n$O$_{3n+1}$ has attracted much interest of their unique physical properties. Among them, SrRuO$_3$ ($n = \infty$) (SRO) is the only ferromagnetic metallic oxide especially in Ru 4d transition metal oxides. Bulk SRO has orthorhombic structure showing the Curie temperature ($T_C$) $\sim 160$ K. It is well known that Ru$_2$O$_4$ octahedral distortion plays critical roles in its magnetic properties. In film systems, such Ru$_2$O$_4$ octahedra can be easily controlled by strain-engineering. In this talk, with high quality SRO films fully strained ($-1.7\%$)$\sim 1\%$ using various substrates, we systematically studied their structural changes and associated magnetic properties. Compared to theoretical predictions, the structural changes can be explained, while the magnetic property changes cannot be understood. Surprisingly, when SRO113 is grown on its PR series of Sr$_2$Ru$_2$O$_7$ (n=1) (SRO214) single crystal, the exact substrate of SRO214 magnetization results in strongly enhanced magnetization ($M < \mu_B$/Ru, $T_C \sim 160$ K), which has never found SRO113 (001) since the low-spin configuration of SRO113 prevent M never exceed 2 $\mu_B$/Ru. The mystery of M in SRO113 (especially SRO113/SRO214) will be further discussed.
10:00AM E19.00009 Chemical Ordering Modulated Electronic Phase Separation and Macroscopic Properties in Colossal Magnetoresistance Manganites, YINYAN ZHU, KAI DU, LIFENG YIN, JIAN SHEN, Fudan University, LOW-DIMENSIONAL MATERIAL PHYSICS TEAM — Using unit cell by unit cell superlattice growth technique, we determine the role of chemical ordering of the Pr dopant in a colossal magnetoresistance (La$_{1-x}$Pr$_x$)$_2$Ca$_x$MnO$_3$ (LPCMO) system, which has been well known for its large length scale electronic phase separation (EPS) phenomena. Our experimental results show that the chemical ordering of Pr leads to dramatic reduction of the length scale of EPS. Moreover, compared to the conventional Pr-disordered LPCMO system, the Pr-ordered LPCMO system has ~100 K higher metal-insulator transition temperature. We have further investigated the n-dependence of the physical properties of the (LPCMO)$_n$/(PCMO)$_n$ superlattices. Magnetic and transport measurements indicate that the physical properties change nonmonotonically, i.e., reaching a minimum for both the Curie temperature and the meta-insulator transition temperature. The crossover thickness thus reflects the characteristic correlation length scale along the vertical direction of the superlattice. For superlattices with n smaller than the correlation length, we combine MFM studies and model calculations to explain the weakened ferromagnetism and metallicity with increasing n.

10:12AM E19.00010 Polarized Neutron Reflectometry Study of Tunable Metal-insulator Superlattices, QIANG WANG, YAOHUA LIU, SUZANNE TE VELTHUIS, Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA, MICHAEL FITZSIMMONS, Quantum Condensed Matter Division, Oak Ridge National Laboratory, Oak Ridge TN 37831, USA, DAISUKE OKUYAMA, Institute of Multidisciplinary Research for Advanced Materials (IMRAM), Tohoku University, Sendai 980-8577, Japan, MASAO NAKAMURA, MASASHI KAWASAKI, YOSHINORI TOKURA, RIKEN Center for Emergent Matter Science (CEMS), Wako, 351-0198, Japan — Superlattices composed of equal thickness of ferromagnetic (FM) metal La$_0$Sr$_0.5$MnO$_3$ (LSMO) and charge-ordered magnetic insulator Pr$_{0.5}$Ca$_{0.5}$MnO$_3$ (PCMO) on (111)-oriented LaAlO$_3$, SrTiO$_3$/Sr$_3$Tl$_2$O$_7$ substrate have been investigated using polarized neutron reflectometry. In a 200-Oe magnetic field, the magnetization depth profile shows strong temperature dependence. Between the FM transition temperature of LSMO and the COO transition temperature of PCMO, a uniform magnetization throughout the superlattices was obtained. Below the COO transition temperature of PCMO, the magnetization depth profile shows a strong contrast between the LSMO and PCMO regions. At 5000 Oe, both LSMO and PCMO show magnetizations close to their bulk saturation value at low temperature. Our result demonstrates the tunability of the PCMO/LSMO superlattices’ magnetic structure with field and temperature and the behavior of this system could be explained as the result of coexistence of the FM and COO phases and their competition.

1Work at Argonne was supported by DOE, Office of Science, BES, MSE.

10:24AM E19.00011 Superparamagnetism at oxide interfaces revealed by scanning SQUID-on-tip microscopy, YONATHAN ANAHORY, L. EMBON, Weizmann Institute of Science, C. J. LI, National University of Singapore, S. BANERJEE, A. MELTZER, H. R. NAREN, A. YAKOVENKO, J. CUPPENS, Y. MYASOEDOV, M. L. RAPPAPORT, Weizmann Institute of Science, M. E. HUBER, University of Colorado Denver, K. MICHAELI, Weizmann Institute of Science, T. VENKATESAN, A. ARIANDO, National University of Singapore, E. ZELDOV, Weizmann Institute of Science — Our novel scanning SQUID-on-tip technique is used to study nanoscale magnetism present in systems such as atomically sharp oxide heterostructures. Here we report a new emergent phenomenon at the LaMnO$_3$/SrTiO$_3$ interface in which an antiferromagnetic insulator abruptly transforms into a magnetic state that exhibits unexpected nanoscale superparamagnetic dynamics. Upon increasing the thickness of LaMnO$_3$ above five unit cells, our scanning nano-SQUID-on-tip microscopy shows spontaneous formation of isolated magnetic islands of 10 to 50 nm diameter, which display random moment reversals by thermal activation or in response to an in-plane magnetic field. Our charge reconstruction model of the polar LaMnO$_3$/SrTiO$_3$ heterostructure describes the sharp emergence of thermodynamic phase separation leading to nucleation of metallic ferromagnetic islands in an insulating antiferromagnetic matrix. The model further suggests that the nearby superparamagnetic-ferromagnetic transition can be gate tuned, holding potential for applications in magnetic storage and spintronics.


10:36AM E19.00012 Giant structural modulation & abnormal ferromagnetism in ferroelectric & ultrathin ferromagnetic digital superlattices, HANGWU GUO, ZHEN WANG, MOHAMMAD SAGHAYEHZIAN, LINA CHEN, RONGYING JIN, WARD PLUMMER, JIANDI ZHANG, Louisiana State University, SHUAI DONG, Southeast University, China — The nature of magnetic polaron coupling in oxide heterostructures remains interestingly complex due to the competing effects of magnetoelectric coupling, quantum tunneling and diffusion. In this work, we present our ability to fabricate superlattices consist of ferroelectric BTO & ferromagnetic LSMO, with minimum interfacial mixing confined within half a unit cell. Such high quality superlattices with sharp interfaces allow us to explore magnetoelectric coupling effect into ultrathin region (reduced dimensionality) and observe ferroelectric induced abnormal magnetic behavior. A detailed STEM study reveals that the traditional electron/hole carrier doping scenario does not play a major role. Instead, distinct modulation of lattice displacement and octahedron tilting is responsible for the coupling effect and abnormal magnetic behavior. Our study highlights the importance of structural-property relationship in oxide heterostructures.

1Supported by U.S. DOE under Grant No. DOE DE-SC0002136

Tuesday, March 15, 2016 8:00AM - 10:36AM — Session E20 GMAG DCMP FIAP: II-VI Magnetic Semiconductors 319 - Denis Kochan, U. Regensburg

8:00AM E20.00001 Dynamics of the matrix in DMS Type-II quantum dot systems, COLLIN R. BROWN, VINCE R. WHITESIDE, IAN R. SELLERS, Department of Physics & Astronomy, University of Oklahoma, Norman, Oklahoma 73019, USA, ATHOS PETROU, Department of Physics, University at Buffalo SUNY, Buffalo, New York 14260, USA, W-C. CHOU, Department of Electro-physics, National Chiao Tung University, Hsinchu 300, Taiwan — Magnetic field, temperature, and polarization dependent continuous wave photoluminescence spectroscopy (PL) is used to study two related Type-II quantum dots (QDs). These techniques were used to study how the location of magnetic impurities affects the formation of magnetic polarons in these two (related) systems. The ZnMnTe/ZnSe system has Mn impurities located within the QDs, with (ideally) no Mn in the surrounding ZnSe matrix. The ZnTe/ZnMnSe QDs have Mn impurities grown within the matrix, which ideally is excluded from the QDs. For both these systems, the holes are confined within the dots, while the electrons are located in the surrounding matrix. The location of the Mn and its coupling with the spin of the corresponding carrier leads to distinct characteristics for each system. Due to difficulties growing these systems, some diffusion of Mn during the growth of these samples is suspected, leading to a percentage of magnetic impurities unintentionally located in the non-magnetic region for both samples. The emission from the matrix in particular was studied to determine the effect/composition of Mn in this region and its contribution to the characteristics of the QDs.

1This work is supported by NSF DMR-1305770
8:12AM E20.00002 Mn$^{2+}$-Doped CdSe/CdS Core/Multishell Colloidal Quantum Wells Enabling Tunable Carrier-Dopant Exchange Interactions$^1$, SAVAS DELIKANLI, Bilkent University, THOMAS SCRACE, JOSEPH MURPHY, BIBLOP BARMAN, YUTSUNG TSAI, PEIYAO ZHANG, State University of New York, University at Buffalo, PEDRO LUDWIG HERNANDEZ-MARTINEZ, Nanyang Technological University, JOSEPH CHRISTODOULIDES, Naval Research Laboratory, ALEXANDER N. CARTWRIGHT, ATHOS PETROU, State University of New York, University at Buffalo, HILMI VOLKAN DEMIR, Nanyang Technological University — We report the manifestations of carrier-dopant exchange interactions in colloidal Mn$^{2+}$-doped CdSe/CdS core/multishell quantum wells. In our solution-processed quantum well heterostructures, Mn$^{2+}$ was incorporated by growing a Cd$_{98.5}$Mn$_{0.5}$S$_{15}$ monolayer shell on undoped CdSe nanoplatelets using the colloidal atomic layer deposition technique. The carrier-magnetic ion exchange interaction effects are tunable through wave function engineering. This is realized by controlling the spatial overlap between the carrier wave functions with the manganese ions through adjusting the location, composition, and number of the CdSe, Cd$_{1-x}$Mn$_x$S, and CdS layers. Our colloidal quantum wells, which exhibit magneto-optical properties analogous to those of epitaxially grown quantum wells, offer new opportunities for solution-processed spin-based semiconductor devices.

1H.V.D. acknowledges support from EU-FP7 Nanophotonics4Energy NoE, TUBITAK, NRF-CRP-6-2010-02 and A*STAR of Singapore. Work at the University at Buffalo was supported by NSF DMR 1305770.

8:24AM E20.00003 Time resolved photoluminescence study of CdSe/CdMnS/CdS core/shell/nanoplatelets heterostructures$^1$, THOMAS SCRACE, State Univ of NY - Buffalo, SAVAS DELIKANLI, MEHMET ZAFTER AKGUL, Bilkent University, JOSEPH MURPHY, TIM THOMAY, PEIYAO ZHANG, TENZIN NORDEN, ALEXANDER CARTWRIGHT, ATHOS PETROU, State Univ of NY - Buffalo, HILMI VOLKAN DEMIR, Bilkent University — We have recorded the time evolution of the photoluminescence (PL) for CdSe/CdMnS/CdS core/shell/nanoplatelets (NP) using ultrafast pulses at 400 nm and 514 nm. Our NPs consist of a core with 5 monolayers (1.5 nm) of CdSe and average lateral dimensions of 5x10 nm$^2$. Using 400 nm pulses we excite electron-hole pairs above the CdSe shell bandgap; with 514 nm pulses we excite only in the CdSe core. The holes are primarily localized in the CdSe core, while the electrons are delocalized. Our measurements show that at $\Delta t=0$, the peak PL energy for both kind of excitations is the same. As a function of time, both types of excitations result in a red-shift. The red shift of with 400 nm excitation is 60 meV and is described by two time scales: $\tau_1 =270$ ps and $\tau_2 =2.5$ ns. The red shift with the 514 nm excitation is 30 meV and is described by a single time scales: $\tau =2.5$ ns. These results are discussed in terms of dipole layer formation$^1$. [1] Gu, Y et. al. Phys. Rev. B 71 045340 (2005).

1H.V.D. is supported by EU-FP7 Nanophotonics4Energy NoE, and TUBITAK EEEAG 109E002, 109E004, NRF-RF-2009-09, NRF-CRP-6-2010-02 and A*STAR of Singapore. A.P. is supported by NSF DMR 1305770.

8:36AM E20.00004 Spin-orbit twisted spin-flip waves in CdMnTe quantum wells$^1$, SHAHRZAD KARIMI, University of Missouri, FLORENT PEREZ, Institut des Nanosciences de Paris, CNRS/Universite Paris VI, FLORENT BABOUX, Laboratoire de Photonique et de Nanostructures, LPN/CNRS, IRENE D’AMICO, University of York, GIOVANNI VIGNALE, CARSTEN ULLRICH, University of Missouri — We present a numerical study of spin-flip wave dispersions in a spin-polarized electron gas in a dilute magnetic semiconductor heterostructure, using time-dependent density-functional response theory. The system under study is an n-doped CdMnTe quantum well with an in-plane magnetic field. Rashba and Dresselhaus spin-orbit coupling induces a wavevector-dependent spin splitting in the conduction bands. The spin waves hence travel through a spin-orbit twisted medium. We calculate the spin-wave dispersion to second order in spin-orbit coupling, including impurity scattering effects. Our results are compared with recent inelastic light scattering experiments.

1Work supported by by DOE Grant No. DE-FG02-05ER46213.

8:48AM E20.00005 Magnetic properties of nano-patterned GaMnAs films grown on ZnCdSe buffer layers$^1$, SINING DONG, XIANG LI, VASILY KANZYUBA, TAAHEE YOO, XINYU LIU, MALGORZATA DOBROWOLSKA, JACEK FURDYNA, Physics Department, University of Notre Dame — Magnetic semiconductor nanostructures are attracting intense attention, both because of their fundamental physical properties, and because of the promise which they hold for building smaller, faster and more energy-efficient devices. In this study we report successful MBE growth of GaMnAs films on the GaAs (100) substrates with ZnCdSe buffer layers, which results in perpendicular magnetic easy axis in the GaMnAs films. The GaMnAs/ZnCdSe films have been etched into nano-stripe shapes with various widths below 200nm by e-beam lithography, which resulted in a new geometry of interest for perpendicular magnetic recording. Magnetic anisotropy of as-grown GaMnAs films and nano-stripes was then studied by SQUID magnetometry. The results indicate that the GaMnAs films consist of magnetic domains with magnetization normal to the film plane, having rather high coercivity, which survives after nanofabrication. This is also confirmed by the dynamics of the domain motion as shown by AC susceptibility measurements. These findings are of interest for understanding the magnetic anisotropy mechanisms in GaMnAs and its domain structures, as well as for designing of nano-sized spintronic devices which require hard ferromagnetic behavior with perpendicular easy axes.

1This work was supported by the National Science Foundation Grant DMR1400432.

9:00AM E20.00006 Gate tunable spin exchange interaction and inversion of magnetoresistance in ferromagnetic ZnO nanowire, VILAYAKUMAR MODEPALLI, MI-JIN JIN, JUNGMIN PARK, JINHYEON JO, JI-HYUN KIM, JEONG MIN BAIK, Ulsan national institute of science and technology, JEONGYONG KIM, Sungkyunkwan University, JUNG-WOO YOO, Ulsan national institute of science and technology — Tuning magnetism in diluted magnetic semiconductor (DMS) is one of the central issues to the development of future spintronic device applications. Particularly, realizing such control in nanostructure has received growing attention. Here, we report the dramatic change of MR in ferromagnetic ZnO nanowire with varied gate voltages (+50 V to -40 V) at different temperatures (2 K to 50 K). The MR signal was greatly influenced by the gate voltage induced carrier concentrations which results the inversion of MR from positive to negative sign while pertaining the coexistence of both parts before inversion in the range of -2T to 2T. The origin of negative MR is mainly due to spin scattering while the positive one is due to a field induced change in relative populations of conduction bands with different conductivities. The extracted spin exchange related parameter was well tuned with the varied gate voltages at different temperatures. More importantly this type of gate tuning of spin exchange interactions in ferromagnetic single ZnO nanowire is well suitable for future spintronic device applications.
9:12AM E20.00007 The State of the Art in (Cd,Mn)Te Heterostructures: Fundamentals and Applications1, TOMASZ WOJTOWICZ, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland — In my talk I will review recent progress in the MBE technology of (Cd,Mn)Te nanostructures containing two dimensional electron gas (2DEG) that led to the first ever observation of fractional quantum Hall effect in magnetic system [1]. This opens new directions in spintronics. I will first discuss already demonstrated applications of such high mobility magnetic-semiconductor 2DEG system for: a) THz and microwave radiation induced zero-bias generation of pure spin currents and very efficient magnetic field induced conversion of them into spin polarized electric current [2]; b) clear demonstration of THz radiation from spin-waves excited via efficient Raman generation process [3]; c) experimental demonstration of working principles of a new type of spin transistor based on controlling the spin transmission via tunable Landau-Zener transitions in spatially modulated spin-split bands [4]. I will also explain the possibility to use magnetic-2DEG for developing of a new system where non-Abelian excitations can not only be created, but also manipulated in a two-dimensional plane. The system is based on high mobility CdTe quantum wells with engineered placement of Mn atoms, where sign of the Lande g-factor can be locally controlled by electrostatic gates at high magnetic fields. Such a system may allow for building a new platform for topologically protected quantum information processing. I will also present results demonstrating electrostatic control of 2D gas polarization in a quantum Hall regime [5].

1The research was partially supported by National Science Centre (Poland) grant DEC-2012/06/A/ST3/00247 and by ONR grant N000141410339.

9:48AM E20.00008 Structural and Optical properties of Er doped ZnO diluted magnetic semiconductor nano thin films produced by sol gel method.1, A. TOLGA TASI, OZGUR OZTURK, ELIF ASIKZUZEN, KASTAMONU UNIVERSITY, LUTFI ARDA, Bahcesehir University, SUKRU CELIK, Sinop University, CABIR TERZIAGOGLU, Abant Izzet Baysal University — Undoped and Er doped ZnO (Zn1−xErxO) transparent semiconductor thin films were coated using sol-gel method on non-alikali glass. Erbium was doped 1%, 2%, 3%, 4% and 5% ratio. Methanol and monoethanolamine (MEA) were used as solvent and stabilizer. In this study, the effect of Er doping was examined on the structural and optical properties of ZnO DMS thin films. XRD, SEM and UV-VIS-NIR spectrometer measurements were performed for the structural and optical characterization. XRD results showed that, all of Er doped ZnO thin films have a hexagonal structure. The optical transmittance of rare earth element (Er) doped ZnO thin films were increased. The Er doped ZnO thin films showed high transparency (>84) in the visible region (400-700 nm).

1This research has been supported by the Kastamonu University Scientific Research Projects Coordination Department under the Grant No. KUBAP-03/2013-41 and the Scientific and Technological Research Council of Turkey (TUBITAK) Project No. 114F259.

10:00AM E20.00009 Microstructural and Optical properties of transition metal (Cu) doped ZnO diluted magnetic semiconductor nano thin films fabricated by sol gel method.1, OZGUR OZTURK, ELIF ASIKZUZEN, A. TOLGA TASI, Kastamonu University, LUTFI ARDA, Bahcesehir University, SEVIM DEMIROZU SENOL, Abant Izzet Baysal University, SUKRU CELIK, Sinop University, CABIR TERZIAGOGLU, Abant Izzet Baysal University — Undoped and Cu doped ZnO (Zn1−xCuxO) semiconductor thin films were produced by using sol-gel method. Cu was doped 1%, 2%, 3%, 4% and 5% ratio. Methanol and monoethanolamine (MEA) were used as solvent and stabilizer. In this study, the effect of Cu doping was investigated on microstructural and optical properties of ZnO DMS thin films. XRD, SEM, AFM and UV-VIS spectrometer measurements were performed for the microstructural and optical characterization. XRD, SEM and AFM results were showed that all of Cu doped ZnO thin films have a hexagonal structure. The grain size of Cu doped ZnO thin films and morphology of surface were changed with increasing Cu doping. The optical transmittance of transition metal (Cu) doped ZnO thin films were decreased with doping. Keywords: Diluted Magnetic Semiconductor (DMS), Thin Film, Cu-doping, Bandgap Energy, ZnO.

1This research has been supported by the Kastamonu University Scientific Research Projects Coordination Department under the Grant No. KU-BAP-05/2015-12 and the Scientific and Technological Research Council of Turkey (TUBITAK) Project No. 114F259.

10:12AM E20.00010 Oxygen vacancies induced Spin polarized current in Co-doped ZnO by Andreev reflection technique. KUNG-SHANG YANG, HSUIUNG CHOU, WEN LING CHAN, BO-YU CHEN, Department of Physics, NSYSU, Kaohsiung 804, Taiwan, SHANG-FAN LEI COLLABORATION — Dilute magnetic semiconductor (DMS) is a semiconductor system with spin-polarized carriers and magnetic properties. However, since most studies had been focused on existence of FM, the proportion of spin-polarized current (SPC) in DMO is far from being determined. We used Point-contact Andreev reflection measurements on various Zn0.97Co0.03O thin films, with controlled oxygen vacancies by sputtering in various H2 partial pressure with Ar atmosphere. We found that conductance versus voltage (G-V) spectra suppresses as oxygen vacancy concentration increases. It indicates oxygen vacancies play significant role in inducing the SPC. To understand the origin of spin polarized current at the interface of the superconducting tip/CZO system, we use modified Blonder–Tinkham–Klapwijk (MBTK) model in ballistic and diffusive regime to interpret G-V curve. The extracted SPC value were up to 70% in ballistic regime and 65% in diffusive regime. The results suggest tiny routes have been formed by oxygen vacancies which are extended throughout the whole films. This result confirmed that MBTK model in ballistic regime is more suitable for our GV spectra and this explains the observation of such a high SPC.

1Institute of Physics, Academia Sinica Taiwan

10:24AM E20.00011 Study of the new diluted magnetic semiconductors based on the doping of iron-based superconductors. LI ZHANG, SHAN FENG, LINXIAN LI, SHAOLEI WANG, YUKIE LI, China Jiliang University — Diluted magnetic semiconductors(DMSs) have attracted increasing attention because of their potential applications in spintronics. Recently, a series of new bulk DMS materials1-5 were synthesized by doping in the 122 and 111 phases of iron-based superconductors(Fe-SC), which sheds light on the DMS research[3]. In this report, we have synthesized two systems of 1111 phases of DMSs based on Fe-SC materials (La1−xSz)(Sr2−2x) (Ag0.925Mn0.075)(SO)(x=0, 0.025, 0.05, 0.075 and 0.1) and (Y1−xSr)x(Cu0.925Mn0.075)(SO) (x=0, 0.025, 0.05, 0.075 and 0.1) by solid state method. The structure and electrical, magnetic and optical properties have been investigated by means of XRD, 4KCCS, MPMS, PL, UV-Vis and Raman technique, respectively. Some interesting phenomena are found (Such as the Curie temperature TC and band-gap energy Eg change regularly with the dopants addition). The results are helpful to clarify the intrinsic mechanism of the DMSs, and will provide new insights on the fabrication and application of devices based on these materials. This work was supported by the National Science Foundation of China (Grant No 61376094). Li Zhang would like to acknowledge a scholarship granted by China Scholarship Council (CSC-201408330028). References: [1] K.Zhao,Z.Deng and X.C.Wang et al., Nature Communications 4, 1442 (2013). [2] X.J. Yang, Y.K. Li, C.Y. Shen et al., Appl. Phys. Lett. 103, 022410 (2013). [3]T. Ditel and H.Ohno, Rev.Mod.Phys., 86,187(R)(2014).
11:15AM F3.00001 The road to superconducting spintronics1, MATTHIAS ESCHRIG, Royal Holloway, University of London — Energy efficient computing has become a major challenge, with the increasing importance of large data centres across the world, which already today have a power consumption comparable to that of Spain, with steeply increasing trend. Superconducting computing is progressively becoming an alternative for large-scale applications, with the costs for cooling being largely outweighed by the gain in energy efficiency. The combination of superconductivity and spintronics - "superspintronics" - has the potential and flexibility to develop into such a green technology. This young field is based on the observation that new phenomena emerge at interfaces between superconducting and other, competing, phases. The past 15 years have seen a series of pivotal predictions and experimental discoveries relating to the interplay between superconductivity and ferromagnetism. The building blocks of superspintronics are equal-spin Cooper pairs, which are generated at the interface between superconducting and a ferromagnetic materials in the presence of non-collinear magnetism. Such novel, spin-polarised Cooper pairs carry spin-supercurrents in ferromagnets and thus contribute to spin-transport and spin-control. Geometric Berry phases appear during the singlet-triplet conversion process in structures with non-coplanar magnetisation, enhancing functionality of devices, and non-locality introduced by superconducting order leads to long-range effects. With the successful generation and control of equal-spin Cooper pairs the hitherto notorious incompatibility of superconductivity and ferromagnetism has been not only overcome, but turned synergistic. I will discuss these developments and their extraordinary potential. I also will present open questions posed by recent experiments and point out implications for theory.

1This work is supported by the Engineering and Physical Science Research Council (EPSRC Grant No. EP/J010618/1).

11:51AM F3.00002 Nanoscale memory elements based on the superconductor-ferromagnet proximity effect and spin-transfer torque magnetization switching, BURM BAEK, NIST - Boulder — Superconducting-ferromagnetic hybrid devices have potential for a practical memory technology compatible with superconducting logic circuits and may help realize energy-efficient, high-performance superconducting computers. We have developed Josephson junction devices with pseudo-spin-valve barriers. We observed changes in Josephson critical current depending on the magnetization state of the barrier (parallel or anti-parallel) through the superconductor-ferromagnet proximity effect. This effect persists to nanoscale devices in contrast to the remanent field effect. In nanopillar devices, the magnetization states of the pseudo-spin-valve barriers could also be switched with applied bias currents at 4 K, which is consistent with the spin-transfer torque effect in analogous room-temperature spin valve devices. These results demonstrate devices that combine major superconducting and spintronic effects for scalable read and write of memory states, respectively. Further challenges and proposals towards practical devices will also be discussed.


12:27PM F3.00003 Spin-polarized superconductivity for spintronics1, JASON ROBINSON, Cambridge University — The feasibility of superconducting spintronics depends on the spin sensitivity of ferromagnets to the spin of equal-spin triplet Cooper pairs (1). Such pairs are generated at superconductor(F)/ferromagnet(F) interfaces in which certain forms of magnetic inhomogeneity (2,3) are present. In this talk I will introduce the topic of the triplet proximity effect in S-F heterostructures and will discuss my group’s recent progress, which includes: spin-selectivity of triplet Cooper pairs in F-S-F superconducting spin-valves (4) and evidence for the formation of a spin-polarized superconducting densities of state in an s-wave superconductor proximity coupled to a magnetically inhomogeneous antiferromagnet (5).


1Royal Society

1:03PM F3.00004 Quasiparticle-mediated spin Hall effect in a superconductor, TARO WAKAMURA, Univ of Paris - Sud 11 CNRS — Superconductivity often brings novel phenomena to spintronics. According to theoretical predictions, superconductivity may enhance the spin Hall effect (SHE) due to the increase in the resistance of superconducting quasiparticles which mediate spin transport in superconductors. In this work, we show a first experimental observation of quasiparticle-mediated SHE in a superconducting NbN, which exhibits an enormous enhancement below the superconducting critical temperature ($T_C=10 K$). We fabricated a lateral device structure composed of Py (NiFe) and NbN wires bridged by a nonmagnetic Cu wire. A pure spin current is generated in the Cu bridge by a spin injection current ($I$) between the Py and the Cu, and absorbed into the NbN wire. The absorbed spin currents are converted into charge currents via the inverse SHE, thereby generating the inverse SH voltage ($V_{ISH}$). When NbN is in the normal state at $20 K (T=0 K)$, inverse SH signals $\Delta R_{ISH} (R_{ISH} \equiv V_{ISH}/I)$ are independent of $I$. However, at 3 K ($T_T K$), as $I$ decreases $\Delta R_{ISH}$ dramatically increases, and when $I=0.01 \mu A$, the signal becomes more than 2000 times greater than that in the normal state. Our experimental demonstration shows a great potentiality of superconductors for spintronics and its future applications.
1:39PM F3.00005 Cryogenic Memories based on Spin-Singlet and Spin-Triplet Ferromagnetic Josephson Junctions

ERIC GINGRICH, Northrop Grumman Corporation — The last several decades have seen an explosion in the use and size of computers for scientific applications. The US Department of Energy (DOE) has set an exciting goal for high performance computing that is projected to be unattainable by current CMOS computing designs [1]. This has led to a renewed interest in superconducting computing as a means of beating these projections. One of the primary requirements of this thrust is the development of an efficient cryogenic memory. Estimates of power consumption of early Rapid Single Flux Quantum (RSFQ) memory designs are on the order of MW, far too steep for any real application [1]. Therefore, other memory concepts are required. S/F/S Josephson Junctions, a class of device in which two superconductors (S) are separated by one or more ferromagnetic layers (F) has shown promise as a memory element. Several different systems have been proposed utilizing either the spin-singlet or spin-triplet superconducting states [2]. This talk will discuss the concepts underlying these devices, and the recent work done to demonstrate their feasibility. [1] - Energy-Efficient Superconducting Computing - Power Budgets and Requirements, D. Scott Holmes, Andrew L. Ripple, Marc A. Manheimer, IEEE Trans. Appl. Supercon., Vol 23, No. 3, June 2013 [2] - B. M. Niedzielski et al., “Use of Pd-Fe and Ni-Fe-Nb as soft magnetic layers in ferromagnetic Josephson junctions for nonvolatile cryogenic memory,” IEEE Trans. Appl. Supercond., vol. 24, no. 4, Aug. 2014, Art. ID. 1800307.

This research is supported in part by the Office of the Director of National Intelligence (ODNI), Intelligence Advanced Research Projects Activity (IARPA), via U.S. Army Research Office contract W911NF-14-C-0115.

Tuesday, March 15, 2016 11:15AM - 2:03PM – Session F5 GMAG DCMP FIAP: Spin Transport in Semiconductors

11:15AM F5.00001 Spin-orbit fields at semiconductor interfaces [1], MARTIN GMITRA, University of Regensburg — Solids without space inversion symmetry exhibit spin-orbit fields, which are emerging manifestations of spin-orbit coupling of the underlying atomic structure. Primary examples of spatially asymmetric systems are interfaces, which are omnipresent in electronic devices. As the device dimensions scale down, interfaces imprint their symmetries into the transport channel by proximity effects. Proximity spin-orbit fields already play important roles in anisotropic magnetoresistance of ultrathin structures such as Fe/GaAs [1], in the physics of Majorana fermions [2,3] and Andreev reflection [4] of semiconductor/superconductor junctions, in Skyrmion textures [5] in ferromagnets, or in spin-orbit torques [6]. It is thus of vital interest to gain qualitative insight and realistic quantitative description of the interfacial spin-orbit fields for various hybrid materials settings. We have proposed a methodology to extract spin-orbit fields, both their magnitudes and directions, and applied it to investigate Fe/GaAs junctions [7]. Only at low momenta the traditional description of the fields in terms of linear Rashba and Dresselhaus works. At generic momenta the fields exhibit what we call butterfly patterns, conforming to the interfacial symmetry. Remarkably, the spin-orbit fields depend rather strongly on the magnetization orientation. We will also discuss our recent results on the spin-orbit coupling in zinc-blende and wurtzite semiconductor nanostructures.


The work is supported by the DFG SFB 689.

11:51AM F5.00002 Realization of an all-electric spin transistor using quantum point contacts , TSE-MING CHEN, POJEN CHUANG, SHENG-CHIN HO, National Cheng Kung University, LUKE SMITH, FRANÇOIS SFIGARI, University of Cambridge, MICHAEL PEPPER, UNIV COLLEGE LONDON, JUHAN LIN, HUANG CHEN, JU-CHUN FAN, National Cheng Kung University, JONATHAN GRIFFITHS, IAN FARRER, HARVEY BEERE, GEB JONES, DAVE RITCHIE, University of Cambridge — The spin field effect transistor envisioned by Datta and Das opens a gateway to spin information processing. Although the coherent manipulation of electron spins in semiconductors is now possible, the realization of a functional spin field effect transistor for information processing has yet to be achieved, owing to several fundamental challenges such as the low spin-injection efficiency due to resistance mismatch, spin relaxation, and the spread of spin precession angles. Alternative spin transistor designs have therefore been proposed, but these differ from the field effect transistor concept and require the use of optical or magnetic elements, which pose difficulties for the incorporation into integrated circuits. Here, we present an all-electric all-semiconductor spin field effect transistor, in which these obstacles are overcome by employing two quantum point contacts as spin injectors and detectors. Distinct engineering architectures of spin-orbit coupling are exploited for the quantum point contacts and the central semiconductor channel to achieve complete control of the electron spins—spin injection, manipulation, and detection—in a purely electrical manner. Such a device is compatible with large-scale integration and hold promise for future spintronic devices for information processing. Ref: P. Chuang et al., Nat. Nanotechnol. 10, 35 (2015).

12:03PM F5.00003 Current-induced spin polarization in InGaAs epilayers with varying doping densities , MARTA LUENGO-KOVAC, SIMON HUANG, DAVIDE DEL GAUDIO, JORDAN OCCENA, RACHEL GOLDMAN, VANESSA SIH, Univ of Michigan - Ann Arbor — Current-induced spin polarization (CISP) is a phenomena in which an applied electric field produces a bulk spin polarization in the channel to achieve complete control of the electron spins—spin injection, manipulation, and detection—in a purely electrical manner. Such a device is compatible with large-scale integration and hold promise for future spintronic devices for information processing.

12:15PM F5.00004 Effective spin Hall properties of a mixture of materials with and without spin-orbit coupling: Tailoring the effective spin-diffusion length

YUE ZHANG, MEGAN PRESTGARD, ASHUTOSH TIWARI, MIKHAIL RAIKH, Univ of Utah — We study theoretically the effective spin Hall properties of a composite consisting of two materials with and without spin-orbit (SO) coupling. In particular, we assume that SO material represents a system of grains of radius, a, and density, n, in a matrix with no SO. We calculate the effective spin Hall angle, $\theta_{eff}$, and the effective spin diffusion length, $\lambda_{eff}$, of the mixture. Our main qualitative finding is that, if the bare spin diffusion length, $\lambda$, is much smaller than $a$, then $\lambda_{eff}$ is strongly enhanced, well beyond $\lambda/(na^2)^{1/2}$, which can be expected from purely "geometrical" consideration. The physical origin of this additional enhancement is that, with small diffusion length, $\lambda < a$, the spin current mostly flows around the grain without suffering much loss. We also demonstrate that the voltage, created by a spin current, is sensitive to a very weak magnetic field directed along the spin current, and even reverses sign in a certain domain of fields. The origin of this sensitivity is that the spin precession, caused by magnetic field, takes place outside the grains where SO is absent.

Supported by NSF through MRSEC DMR-1121252.
12:27PM F5.00005 Spin relaxation via exchange with donor impurity-bound electrons1. IAN APPELBAUM, Univ of Maryland-College Park — In the Bir-Aronov-Pikus depolarization process affecting conduction electrons in $p$-type cubic semiconductors, spin relaxation is driven by exchange with short-lived valence band hole states. We have identified an analogous spin relaxation mechanism in nominally undoped silicon at low temperatures, where many electrons are bound to dilute dopant potentials. Inelastic scattering with externally injected conduction electrons accelerated by electric fields can excite transitions into highly spin-orbit-mixed bound excited states, driving strong spin relaxation of the conduction electrons via exchange interaction. We reveal the consequences of this spin depolarization mechanism both below and above the impact ionization threshold, where conventional charge and spin transport are restored.

1Based upon: Lan Qing, Jing Li, Ian Appelbaum, and Hanan Dery, Phys. Rev. B 91, 241405(R) (2015). We acknowledge support from NSF, DTRA, and ONR.

1:03PM F5.00006 Electrical spin injection and detection in Si nanowires with axial doping gradient. KONSTANTINOS KOUNTOURIOTIS, JORGE BARREDA, TIM KIEPER, MEI ZHANG, PENG XIONG, Florida State Univ — Due to the technological importance and potential long spin coherence time in silicon, there have been significant recent efforts to realize spin injection, coherent transport, and electrical spin detection in Si nanowires (NWs). The nature of the electronic transport at the interface and its resistance are crucial factors in realizing efficient spin injection/detection between a ferromagnet (FM) and a semiconductor (SC). In this work, we examine the effects on electrical spin injection and detection by FM/SC interfaces with well-defined Schottky barriers in Si NW devices. The Si NWs are synthesized via a vapor-liquid-solid method using silane and phosphine precursor gases for the growth and doping respectively, which results in a graded phosphorus doping profile along the length of the NW. The Si NWs are dispersed on a $p$-Si/SiO$_2$/SiN$_x$ substrate, and a series of CoFe electrodes are defined along a Si NW with electron beam lithography and magnetron sputtering after the removal of the native oxide by HF treatment. As a consequence of the doping gradient, the FM electrodes form Ohmic and Schottky barrier contacts of varying heights along the length of a single NW. Two-terminal local and four-terminal non-local spin-valve measurements are performed to probe spin accumulation and transport at different FM contacts, enabling a study of the dependence of the spin signals on the Schottky barrier height and interface resistance on a single device. *Work supported by NSF grant DMR-1308613.

1:15PM F5.00007 Room-temperature operation of Si spin MOSFET with high on/off spin signal ratio, MASASHI SHIRAISHI, Department of Electronic Science and Engineering, Kyoto University, HAYATO KOIKE, Technology HQ, TDK Corporation, TAKAYUKI TAHARA, Department of Electronic Science and Engineering, Kyoto University, TOMOYUKI SASAKI, MAKOTO KAMENO, Technology HQ, TDK Corporation, YUICHIRO ANDO, Department of Electronic Science and Engineering, Kyoto University, KAZUHITO TANAKA, SHINJI MIWA, YOSHISHIGE SUZUKI, Graduate School of Engineering Science, Osaka University — Spintronics is now one of the pivotal fields in semiconductor spintronics. After the first report on successful propagation of pure spin current in Si, much effort has been paid for realization of Si spin-metal-oxide-semiconductor field-effect transistor (MOSFET), since Si spin MOSFETs allow reconfiguring logic circuits with ultra-low energy consumption. Our group achieved the first operation of spin MOSFET at room temperature using non-degenerate $n$-type Si [1]. However, the remaining issue to be solved was low on/off ratio of spin signals. In this presentation, we report on our experimental demonstration of Si spin MOSFET with high on/off ratio of spin signals. The on/off ratio is greater than $10^5$, whereas on/off ratio in a conventional MOSFET operation is ca. $10^3$. More importantly, the gate voltage dependence of the spin signals and the MOSFET signals are in good agreement [2]. This achievement can pave the way to a practical application of Si spin MOSFETs. References: [1] T. Sasaki, M. Shirai et al., Phys. Rev. Applied 2, 034005 (2014). [2] T. Tahara, M. Shiraiishi et al., Appl. Phys. Express, in press (selected as Spotlight Paper).

1:27PM F5.00008 Electronic measurement of strain effects on spin transport in silicon1. LAN QING, HOLLY TINKEY, IAN APPELBAUM, Center for Nanophysics and Advanced Materials and Department of Physics, University of Maryland, College Park, Maryland 20742 — Spin transport in silicon is limited by the Elliott-Yafet spin relaxation mechanism, which is driven by scattering between degenerate conduction band valleys. Mechanical strain along a valley axis partially breaks this degeneracy, and will ultimately quench inter-valley spin relaxation for transitions between states on orthogonal axes. Using a custom-designed and constructed strain probe, we study the effects of uniaxial compressive strain along the (100) direction on ballistic tunnel junction devices used to inject spin-polarized electrons into silicon. The influence of strain-induced valley splitting will be presented and compared to our theoretical model.

1This work is supported by the Office of Naval Research under Contract No. N00014140317, the National Science Foundation under Contract No. ECCS-1231855, the Defense Threat Reduction Agency under Contract No. HDDTRA1-13-1-0013, and the Maryland NanoCenter.

1:39PM F5.00009 Three-terminal experiments on epitaxial Si/MgO tunnel junctions, JULIANE LAURER, MAREEN SCHAEFER, MATTHIAS KRONSEDER, MICHAELA TROTTMANN, MARKUS HAERTINGER, JOSEF ZWECK, CHRISTIAN H. BACK, DIETER WEISS, MARIUSZ CIORGĂ, DOMINIQUE BOUGEARD, Institut fuer Experimentelle und Angewandte Physik, Universitaet Regensburg, Germany — In the field of spin injection into semiconductors, experiments in a three-terminal (3T) Hanle geometry are widely used to determine spin life times and spin diffusion lengths. However, as charge and spin current are not separated in the 3T geometry, it is yet unclear how reliable 3T experiments are to reveal spin-related quantities of the semiconductor channel. In particular, the impact of defect states in the tunnel barrier or at its interfaces on measured 3T Hanle-like signals has intensely been discussed recently.

In our contribution, we compare 3T experiments on entirely MBE-grown epitaxial Si/MgO/Fe/Au and Si/MgO/Au, i.e. ferromagnetic and nonmagnetic tunnel junctions. Both sample types show a similar Lorentzian signal comparable to those obtained by the Hanle effect of a precessing and dephasing spin ensemble. In contrast to the ferromagnetic sample, the resistance of the nonmagnetic sample increases for increasing external magnetic field. We discuss the dependence of the signal on bias, temperature and orientation of the external magnetic field, taking into account the high crystalline quality of our epitaxial tunnel junctions with atomically sharp interfaces.

1:51PM F5.00010 Spin Transport and Precession in Epitaxial BaTiO$_3$/Ge Heterostructures, YICHEN JIA, CRISTINA VISANI, LIOR KORNBLOM, ERIC JIN, CHARLES AHN, FRED WALKER, Yale University — Spintronics has opened up new possibilities to leverage the spin degree of freedom in electronic devices. Spin injection from ferromagnets into semiconductors has been realized by inserting a thin tunnel barrier layer, which adjusts the conductivity mismatch. Spin injection from ferromagnets into semiconductors has been realized by inserting a thin tunnel barrier layer, which adjusts the conductivity mismatch. However, limited functionality in conventional tunnel barriers hinders the control and manipulation of spin. Here we report the spin injection and detection in $p$-type Germanium (p-Ge) through a functional BaTiO$_3$ (BTO) tunnel barrier. Epitaxial BTO thin films are grown on p-Ge by molecular beam epitaxy (MBE), followed by electron beam pattern generation (EBPG) to fabricate multi-terminal spin devices. Spin accumulation is demonstrated using the Hanle technique, where the spin signal shows a non-monotonic temperature dependence. Using this temperature dependence, we investigate the dominant spin damping pathways in each temperature regime. Furthermore, we discuss the possibility of manipulating spin transport using the BTO layer, which would allow one to integrate the unique functionalities of complex oxides with semiconductor spintronics devices.

Tuesday, March 15, 2016 11:15AM - 2:03PM – Session F6 GMAG DMP: Iridates II 302 - Ilija Zeljkovic, Boston College
11:15AM F6.00001 The role of correlations in the low energy electronic structure of lightly electron doped Sr$_2$IrO$_4$ and Sr$_2$Ir$_{1-x}$O$_{3x}$.
ALBERTO DE LA TORRE, FLAVIO BRUNO, ZHIMING WANG, ANNA TAMAI, CHRISTOPHE BERTHOD, DIDIER JACCARD, University of Geneva, ALASKA SUBEDI, Max Planck - Hamburg, ANTOINE GEORGES, Ecole Polytechnique, CNRS, ROBIN PERRY, University College London, FELIX BAUMBERGER, University of Geneva — We characterized the emergence of exotic electronic ground states in lightly electron doped (Sr$_{1−x}$La$_x$)$_2$IrO$_4$ and (Sr$_{1−x}$La$_x$)$_2$Ir$_2$O$_7$ by ARPES. In the single layer iridate, a large Fermi surface with nodal coherent spectral weight and antinodal pseudogap emerges, concomitantly with the collapse of the Mott gap, upon doping [1]. On the other hand, in Sr$_2$IrO$_4$ a small non-gapped Fermi surface with coherent quasiparticles, together with a reduction of the correlated gap throughout the entire Brillouin Zone is observed when doping above lightly electron doped Sr$_{1−x}$La$_x$IrO$_4$ with (1). [1] A. de la Torre et al, PRL 115, 176402 (2015); [2] A. de la Torre et al, PRL 113, 256402 (2014)

HEIDI SEINIGE, CHENG WANG. The University of Texas at Austin, GAO CANG, University of Kentucky, JIANSHI-S. ZHOU, JOHN B. GOODENOUGH, MAXIM TSOI, The University of Texas at Austin — Recently we demonstrated experimentally the existence of interconnections between magnetic state and transport currents in antiferromagnetic (AFM) Mott insulator Sr$_2$IrO$_4$. We found a very large anisotropic magnetoresistance [1] and demonstrated a reversible resistive switching driven by high-density currents/high electric fields [2]. These results support the feasibility of AFM spintronics, where antiferromagnets are used in place of ferromagnets, however a low Néel temperature of this material (240 K) questions any practical applications. Here we present a comparative magnetic transport study of its sister compound Sr$_2$IrO$_4$ which has a higher transition temperature (285 K). Similar to the case of Sr$_2$IrO$_4$, we find a continuous reduction in the resistivity of Sr$_3$Ir$_2$O$_7$ as a function of increasing electrical bias and abrupt reversible changes above a threshold bias current. We explain these results by a reduction of activation energy associated with a field-driven lattice distortion. [1] C. Wang et al., Phys. Rev. X 4, 041034 (2014); [2] C. Wang et al, PRB 92, 315136 (2015).

11:39AM F6.00003 Magnetic excitations and lattice distortions in highly-doped (Sr$_{1−x}$La$_x$)$_2$Ir$_2$O$_7$.
TOM HOGAN, University of California Santa Barbara, MARY UPTON, Argonne National Laboratory, XIAOPING WANG, Oak Ridge National Laboratory, STEPHEN WILSON, University of California Santa Barbara — (Sr$_{1−x}$La$_x$)$_2$Ir$_2$O$_7$ has been shown to undergo a first-order phase transition from a localized antiferromagnetic insulating state to a correlated metal. We discuss the further characterization of these correlations by examining the excitation spectra of a highly-doped sample. These reveal evidence of a dispersive feature associated with an over-damped magnon mode, similar to the behavior of the undoped parent compound, as well as a higher energy excitation. The nature of the lattice distortion brought on by La-doping will also be discussed.

MARK P. M. DEAN, Brookhaven National Laboratory — In the iridates, competition between spin-orbit coupling, crystal field, and electronic correlation has lead to the observation of several novel states. Particularly notable is the spin-orbit Mott insulating state in Sr$_2$IrO$_4$ which has close analogies to the high temperature superconducting cuprates. This talk will describe the nature of the magnetic correlations in Sr$_2$IrO$_4$ and how the magnetic correlations can be modified by two different doping schemes. I will first describe doping via photo-excitation in which we use femtosecond infrared pulses to excite carriers across the Mott gap. After excitation, we probe the resulting magnetic state as a function of time delay using the first implementation of magnetic resonant inelastic X-ray scattering at a free electron laser. We find that the non-equilibrium state 2 ps after the excitation has strongly suppressed long-range magnetic order, but hosts photo-carriers that induce strong, non-thermal magnetic correlations. The magnetism recovers its two-dimensional in-plane Néel correlations on a timescale of a few ps, while the three-dimensional long range magnetic order is restored over a far longer, fluence-dependent, timescale. This opens a window into the magnetic response of a few photo-doped holes in Sr$_2$IrO$_4$. In this situation, we find that with increased Ru concentration, the dispersive magnetic excitations in the parent compound become almost momentum-independent, opening a magnetic gap > 150 meV. We attribute this gap to the combined effects of disorder and Ir-Ru interactions.

EKATERINA PLOTNIKOVA, Leibniz Institute for Solid State and Materials Research Dresden, Germany, MARIA DAGHOFER, University of Stuttgart, Germany, JEROEN VAN DEN BRINK, Leibniz Institute for Solid State and Materials Research Dresden, Germany, KRZYSZTOF WOHLFELD, Stanford University and SLAC National Accelerator Laboratory, USA and University of Warsaw, Poland — When strong spin-orbit coupling removes orbital degeneracy, it would at the same time appear to render the Jahn-Teller mechanism ineffective. We discuss such a situation, the $t_{2g}$ manifold of iridates, and show that, while the Jahn-Teller effect does indeed not affect the $j = 1/2$ antiferromagnetically ordered ground state, it leads to distinctive signatures in the $j = 3/2$ spin-orbit exciton. It allows for a hopping of the spin-orbit exciton between the nearest neighbor sites without producing defects in the $j = 1/2$ antiferromagnet. This arises because the lattice-driven Jahn-Teller mechanism only couples to the orbital degree of freedom, but is not sensitive to the phase of the wave function that defines isospin $j_z$. This contrasts sharply with purely electronic propagation, which conserves isospin, and presence of Jahn-Teller coupling can explain some of the peculiar features of measured resonant inelastic x-ray scattering spectra of Sr$_2$IrO$_4$.

12:39PM F6.00006 Unveiling the Origin of the Basal-plane Antiferromagnetism in the $J_{eff}=1/2$ Mott Insulator Ba$_2$IrO$_4$: A Density Functional and Model Hamiltonian Study.
YUSHENG HOU, HONGJUN XIANG, XINGAO GONG, Fudan University, KEY LABORATORY OF COMPUTATIONAL PHYSICAL SCIENCES (MINISTRY OF EDUCATION) COLLABORATION — Based on the density functional theory and our new model Hamiltonian, we have studied the basal-plane antiferromagnetism in the novel $J_{eff}=1/2$ Mott insulator Ba$_2$IrO$_4$. By comparing the magnetic properties of the bulk Ba$_2$IrO$_4$ with those of the single-layer Ba$_2$IrO$_4$, we demonstrate unambiguously that the basal-plane antiferromagnetism is caused by the intralyer magnetic interactions rather than by the previously proposed interlayer ones. In order to reveal the origin of the basal-plane antiferromagnetism, we propose a new model Hamiltonian by adding the single ion anisotropy and pseudo-quadrupole interactions into the general bilinear pseudo-spin Hamiltonian. The obtained magnetic interaction parameters indicate that the single ion anisotropy and pseudo-quadrupole interactions are unexpectedly strong. Systematical Monte Carlo simulations demonstrate that the basal-plane antiferromagnetism is caused by the isotropic Heisenberg, bond-dependent Kitaev and pseudo-quadrupole interactions. Our results show for the first time that the single ion anisotropy and pseudo-quadrupole interaction can play significant roles in establishing the exotic magnetism in the $J_{eff}=1/2$ Mott insulator.
12:51PM F6.00007 Frustration in square lattice of Iridium Jeff=1/2 moments at high pressure1

1Present address: Argonne National Laboratory, GILBERTO FABBRI, Brookhaven National Laboratory, JONG WOO KIM, JUNG HO KIM, Advanced Photon Source, Argonne National Laboratory, BUMJOON KIM, Max Plank Institute for Solid State Research, GANG CAO, University of Kentucky, VIKTOR STRUZHCKIN, Geophysical Laboratory, Carnegie Institution of Washington — We study the evolution of magnetic order in the weakly ferromagnetic, insulator Sr2IrO4 under applied pressure using x-ray resonant magnetic scattering and x-ray magnetic circular dichroism techniques in the diamond anvil cell. The weak inter-layer coupling is readily tunable with pressure giving rise to a change in magnetic structure followed by coexisting and competing magnetic phases with different inter-layer coupling. Application of moderate magnetic fields stabilizes one of the magnetic phases. Higher pressures drive the system into a magnetically disordered state, possibly a quantum paramagnetic state. We discuss the results in the context of a J1-J2 model where the increasing strength of next-nearest-neighbor exchange coupling with pressure leads to frustration of in-plane interactions

1Work at Argonne is supported by the US Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC-02-06CH11357.

1:03PM F6.00008 Effect of longer-range lattice anisotropy on the electronic structure and magnetism of spin-orbit-coupled 5d transition-metal oxides , NIKOLAY BOGDANOV1, VAMSHI KATUKURI2, JUDIT ROMHÁNYI3, Institute for Theoretical Solid State Physics, IFW Dresden, Germany, VIKTOR YUSHANKHAI, Joint Institute for Nuclear Research, Dubna, Russia, VLADISLAV KATAEV, BERNDT BÜCHNER, Institute for Solid State Research, IFW Dresden, Germany, JEROEN VAN DEN BRINK, LIVIU HOZOI, Institute for Theoretical Solid State Physics, IFW Dresden, Germany — We have investigated the insulating nature of Na2IrO3 using both the density-functional theory (DFT) and the combination of the DFT and the dynamical mean-field theory (DFT+DMFT). We have obtained the paramagnetic (PM) insulating state even above the Neel temperature (TN), which reveals that Na2IrO3 is a Mott-type insulator. The photoemission spectrum is well described by the density of states from the DFT+DMFT in this PM insulating state. However, the analysis of optical conductivity suggests that the non-local correlation effect is also important in Na2IrO3. We have also found sizable redistribution of both charge and spin densities upon cooling below TN which suggests that Na2IrO3 is not a standard Mott insulator having rigid charge density. Therefore, despite the Mott-type insulating state of Na2IrO3, the itineracy and the non-local correlation are important as well in describing its electronic and magnetic properties due to the extended nature of Ir 5d state.

1Present address: Electronic structure theory, MPI-FKF, Stuttgart
2Present address: Ecole polytechnique fédérale de Lausanne
3Present address: Quantum materials, MPI-FKF, Stuttgart

1:15PM F6.00009 Influence of isovalent doping of Ca2+ on the Spin orbit Mott insulator Sr2IrO4 , NAKHEON SUNG, H. GRETARSSON, D. PROEPPER, J. PORRAS, M. LE TACON, A. V. BORIS, B. KEIMER, J. KIM, Max Planck Institute for Solid State Research — We report on the growth of stoichiometric Sr2IrO4 single crystals, which allow us to unveil their intrinsic magnetic properties. The effect of different growth conditions has been investigated for crystals grown by the flux method. We find that the magnetic response depends very sensitively on the details of the growth conditions. We assess the defect concentration based on magnetization, X-ray diffraction, Raman scattering, and optical conductivity measurements. We find that samples with a low concentration of electronically active defects show much reduced in-gap spectral weight in the optical conductivity and a pronounced two-magnon peak in the Raman scattering spectrum. A prolonged exposure at high temperature during the growth leads to higher defect concentration likely due to creation of oxygen vacancies. We further demonstrate a systematic intergrowth of Sr2IrO4 and Sr3Ir2O7 phases by varying the growth temperature. Our results thus emphasize that revealing the intrinsic magnetic properties of Sr2IrO4 and related materials requires a scrupulous control of the crystal growth process.

1:27PM F6.00010 Crystal growth and intrinsic magnetic behavior of Sr2IrO4 , XIAOCHEN CHEN, Boston Coll, STEPHEN WILSON, UCSB, WILSON GROUP TEAM — Here we investigate the influence of isoelectronic doping into the spin-orbit Mott materials Sr2IrO4. Specifically, we explore the influence of isovalent Ca substitution as a perturbation to the J_{eff} = 1/2 Mott ground state by combined transport, bulk magnetization, and scattering measurements. The evolution of the lattice geometry/structure-type as well as the electronic phase behavior will be presented as Ca^{2+} is substituted on the Sr^{2+} site.

1:39PM F6.00011 Magnetic Properties comparison of 3D Kitaev candidate materials beta and gamma Li2IrO3 , RAMON RUIZ, Univ of California - Berkeley, NICHOLAS BREZNAZ COLLABORATION, ALEX FRANO COLLABORATION, TONI HELM COLLABORATION, JAMES ANALYTIS COLLABORATION, GRETARSSON, D. PROEPPER, J. PORRAS, M. LE TACON, A. V. BORIS, B. KEIMER, J. KIM, Max Planck Institute for Solid State Research — Honeycomb iridates have been the focus of substantial interest due to the strong spin-orbit Mott insulator character and engineering in the context of oxide heterostructures. While the tetravalent Ir^{4+} ions associated complications do not arise for such layers, our results highlight the tetravalent d-metal 214 oxides as ideal platforms to explore d-level reconstruction and engineering in the context of oxide heterostructures.

1:51PM F6.00012 The Mott Insulating Nature of Na2IrO3 : DFT+DMFT Study , MINJAE KIM, NAKHEON SUNG, BIKRAMJIT BHATTACHARYA, MINJAE KIM, CPHT, Ecole Polytechnique & College de France, BEOM HYUN KIM, RIKEN, Saitama, B. I. MIN, Pohang University of Science and Technology — We have investigated the insulating nature of Na2IrO3, employing both the density-functional theory (DFT) and the combination of the DFT and the dynamical mean-field theory (DFT+DMFT). We have obtained the paramagnetic (PM) insulating state even above the Neel temperature (TN), which reveals that Na2IrO3 is a Mott-type insulator. The photoemission spectrum is well described by the density of states from the DFT+DMFT in this PM insulating state. However, the analysis of optical conductivity suggests that the non-local correlation effect is also important in Na2IrO3. We have also found sizable redistribution of both charge and spin densities upon cooling below TN which suggests that Na2IrO3 is not a standard Mott insulator having rigid charge density. Therefore, despite the Mott-type insulating state of Na2IrO3, the itineracy and the non-local correlation are important as well in describing its electronic and magnetic properties due to the extended nature of Ir 5d state.

Tuesday, March 15, 2016 11:15AM - 2:15PM –
Session F18 GMAG DMP: Frustrated Magnetism: Pyrochlore and Spin Ice 317 - Kate Ross, Colorado State University
2+ zone technique. This talk will present the structure and physical properties of a Yb
\text{praseodymium} (\text{Pr}) for 
\text{magnetic and physical properties of the off-stoichiometric series sheds light both on the magnetic ordering of the ideal spin ice candidate compound as well as its lack of magnetic moment which isolates the magnetic ordering of
\text{Pr}, the comparative ease of making single crystals via the floating 
\text{YTO}, where the spin ice physics starts to develop. This will enable a most carefully controlled determination of the Hamiltonian of Dy\text{2TiO}_7.

11:27 AM F18.00022 Radio-frequency magnetic susceptibility of spin ice crystals Dy\text{2TiO}_7 using tunnel diode resonator, SERAFIM TEKNOVIJOYKO, KYUIL CHO, MAKARIY A. TANATAR, RUSLAN PROZOROV, Ames Laboratory and Iowa State University, ROBERT J. CAVA, JASON W. KRIZAN, Princeton University, AMES LABORATORY AND IOWA STATE UNIVERSITY TEAM, PRINCETON UNIVERSITY COLLABORATION — Spin ice compound, Dy\text{2TiO}_7, has shown complex frequency – dependent magnetic behavior at low temperatures. While the DC measurements show conventional paramagnetic behavior, finite frequency susceptibility shows two regimes, - complex kagomé ice behavior at around 2 K and spin collective behavior above 10 K, depending on the frequency. Conventional AC susceptibility is limited to frequencies in a kHz range, but to get an insight into the possible Arhenius activated behavior and characteristic relaxation times, higher frequencies are desired. We used self-oscillating tunnel-diode resonator (TDR) to probe magnetic susceptibility at 14.6 MHz, in the presence of a DC magnetic field and down to 50 mK. We found an unusual non-monotonic field dependence of the lower transition temperature, most likely associated with different spin configurations in a kagomé ice and an activated behavior of the upper transition, which has now shifted to 50 K range. This work was supported by the U.S. DOE BES MSED and was performed at the Ames Laboratory, Iowa State University under contract DE-AC02-07CH13158. The work at Princeton university was supported by DOE BES grant number DE-FG02-08ER46544.

11:39 AM F18.00033 Possible observation of photon excitations in the quantum spin-ice Pr\text{2ZrO}_7, YOSHIFUMI TOKIWA, TAKUYA YAMASHITA, DAIKI TERAZAWA, TAKAHITO TERASHIMA, Kyoto University, KENTA KIMURA, Osaka University, MARIO HALIM, SATORU NAKATSUJI, University of Tokyo, YUJI MATSUDA, Kyoto University — It has been theoretically shown that the ground state of spin-ice system with quantum fluctuations can be quantum spin liquid, where new elementary excitations, photon, emerge [1]. In the rare-earth pyrochlore, Pr\text{2ZrO}_7, which contains spin-ice correlations with significant quantum fluctuations, the absence of magnetic ordering even at very low temperature suggests formation of quantum spin liquid state [2]. In order to examine the emergence of new exotic excitations, we have performed low-temperature thermal conductivity (\kappa) measurements of Pr\text{2ZrO}_7. Interestingly, our data of \kappa/T shows a steep increase with decreasing temperature below 0.2K. Since the monopole density is negligibly small at such low temperature, the steep increase possibly indicates emergence of new elementary excitations. Anomalous magnetic-field dependence of \kappa/T observed below 0.2K further supports this possibility. [1] M. Hermele et al., Phys. Rev. B 69, 064404 (2004). [2] K. Kimura et al., Nature Commun. 4, 1934 (2013).

11:51 AM F18.00044 Thermal transport measurements of spin ice materials

2 This research was supported by NSERC of Canada.

12:03 PM F18.00005 Atomic Structure Study of the Quantum Spin-ice Pyrochlore Yb\text{2TiO}_7, ALI MOSTAED, GEETHA BALAKRISHNAN, MARTIN LEES, RICHARD BÉANLAND, Department of Physics, University of Warwick, MICROSCOPY TEAM, SUPERCONDUCTIVITY AND MAGNETISM TEAM — The quantum spin-ice candidate Yb\text{2TiO}_7 (\text{YTO}) lies on the boundary between a number of competing magnetic ground states. Features in the low-temperature specific heat capacity are found to vary in sharpness and temperature depending on materials processing. It has been suggested that these changes in the magnetic ground state could be influenced by several factors, including the degree of cation stuffing, changes in magnetic ground states. Features in the low-temperature specific heat capacity are found to vary in sharpness and temperature depending on materials processing.

The Institute of Quantum Matter is supported by Department of Energy (DOE), Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under award DE-FG02-08ER46544.
12:27PM F18.00007 Magnetic monopole condensation transition out of quantum spin ice: application to Pr2Ir2O7 and Yb2Ti2O7, GANG CHEN1. State Key Laboratory of Surface Physics, Fudan Univ; Perimeter Institute for Theoretical Physics — We study the proximate magnetic orders and the related quantum phase transition out of quantum spin ice (QSI). We apply the electromagnetic duality of the compact quantum electrodynamics to analyze the condensation of the magnetic monopoles for QSI. The monopole condensation transition represents a unconventional quantum criticality with unusual scaling laws. The magnetic monopole condensation leads to the magnetic states that belong to the 2-in 2-out spin ice manifold and generically have an enlarged magnetic unit cell. We demonstrate that the antiferromagnetic state with the ordering wavevector $Q = 2p(001)$ is proximate to QSI while the ferromagnetic state with the ordering wavevector $Q = (000)$ is not proximate to QSI. This implies that if there exists a direct transition from QSI to the ferromagnetic state, the transition must be strongly first order. We apply the theory to the puzzling experiments on two pyrochlore systems Pr2Ir2O7 and Yb2Ti2O7.

12:39PM F18.00008 How quantum are classical spins?1, MICHEL J P GINGRAS, JEFFREY G RAU, Univ of Waterloo — The pyrochlore spin ice compounds Dy2Ti2O7 and Ho2Ti2O7 are well described by classical Ising models down to low temperatures. Given the empirical success of this description, the question of the importance of quantum effects in these materials has been mostly ignored. We argue that the common wisdom that the strictly Ising moments of non-interacting Dy3+ and Ho3+ ions imply Ising interactions is too naive and that a more complex argument is needed to explain the close agreement between the classical Ising model theory and experiments. By considering a microscopic picture of the interactions in rare-earth oxides, we show that both systems are antiferromagnetically ordered in the $B_2$ phase for the Yb sample and a $B_2$ phase for the Er sample, which suggests “Order by Disorder” physics. Furthermore, we unify the various magnetic ground states of all known R$^2$Ge$_2$O$_7$ ($R = Er, Yb$) by showing that both systems are antiferromagnetically ordered in the $B_2$ phase for the Yb sample and a $B_2$ phase for the Er sample, which suggests “Order by Disorder” physics. Furthermore, we unify the various magnetic ground states of all known R$^2$Ge$_2$O$_7$ ($R = Er, Yb$) by showing that both systems are antiferromagnetically ordered in the $B_2$ phase for the Yb sample and a $B_2$ phase for the Er sample, which suggests “Order by Disorder” physics. Furthermore, we unify the various magnetic ground states of all known R$^2$Ge$_2$O$_7$ ($R = Er, Yb$).

1:03PM F18.00009 Low-temperature Spin-Ice State of Quantum Heisenberg Magnets on Pyrochlore Lattice, YUAN HUANG, KUN CHEN, University of Massachusetts, Amherst; University of Science and Technology of China, YOIJIN DENG, University of Science and Technology of China; University of Massachusetts, Amherst; Russian Research Center “Kurchatov Institute” — We establish that the isotropic spin-1/2 Heisenberg antiferromagnet on pyrochlore lattice enters a spin-ice state at low, but finite, temperature. Our conclusions are based on results of the bold diagrammatic Monte Carlo simulations that demonstrate good convergence of the skeleton series down to temperature $T = J/6$. The “smoking gun” identification of the spin-ice state is done through a remarkable accurate microscopic correspondence for static spin-spin correlation function between the quantum Heisenberg and classical Heisenberg/Ising models at all accessible temperatures. In particular, at $T/J = 1/6$, the momentum dependence shows a characteristic bow-tie pattern with pinch points. By numerical analytical continuation method, we also obtain the dynamic structure factor at real frequencies, showing a diffusive spinon dynamics at pinch points and spin wave continuum along the nodal lines.

1:15PM F18.00011 Antiferromagnetic order in the pyrochlores R$_2$Ge$_2$O$_7$ ($R = Er, Yb$), ZHILING DUN, Univ. of Tennessee, Knoxville, XUAN LI, Beijing National Laboratory for Condensed Matter Physics, RAFAEL FREITAS, EVERTON ARRHIGI, Instituto de Fisica, Universidade de Sao Paulo, Brazil, CLARINA CRUZ, Oak Ridge National Laboratory, MINSEONG LEE, EUN SANG CHOI, Florida State University and NHMFL, HUIBO CAO, Oak Ridge National Laboratory, HARLYN SILVERSTEIN, University of Manitoba, CHRIS WIEBE, Florida State University and NHMFL, University of Manitoba, University Institute for Advanced Research, JINGUANG CHEN, Beijing National Laboratory for Condensed Matter Physics, HAIHONG ZHOU, Univ. of Tennessee and NHMFL — Elastic neutron scattering, ac susceptibility, and specific heat experiments on the pyrochlores $Er_2Ge_2O_7$ and $Yb_2Ge_2O_7$ show that both systems are antiferromagnetically ordered in the $I_5$ manifold. The ground state is a $v_5$ phase for the Er sample and a $v_2$ or $v_3$ phase for the Yb sample, which suggests “Order by Disorder” (OdB) physics. Furthermore, we unify the various magnetic ground states of all known $R_2X_2O_7$ ($R = Er, Yb, X = Sn, Ti, Ge$) compounds through the enlarged XY type exchange interaction $J_{xy}$ under chemical pressure. The mechanism for this evolution is discussed in terms of the phase diagram proposed in the theoretical study [Wong et al., Phys. Rev. B 88, 144402, (2013)].

1:27PM F18.00012 Theory for magnetic excitations in quantum spin ice, SHIGEKI ONODA, Condensed Matter Theory Lab., RIKEN and Quantum Matter Theory Research Team, RIKEN Center for Emergent Matter Science, TRINANJAN DATTA, Dept. of Chemistry and Physics, Georgia Regents Univ. — Magnetic excitations in magnetic rare-earth pyrochlore oxides called quantum spin ice (QSI) systems such as Yb$_2$Ti$_2$O$_7$, Pr$_2$Zr$_2$O$_7$, and Tb$_2$Ti$_2$O$_7$ have attracted great interest for possible observations of the quantum dynamics of spin ice monopoles and emergent photon excitations. However, their spectral properties remain open especially for cases relevant to experimental systems. Here, we develop a theoretical framework that incorporates gauge fluctuations into a modified gauge mean-field approach, so that it reproduces key features of recent quantum Monte-Carlo results on the double broad specific heat in the simplest QSI model and can describe a continuous growth of a coherence in gauge-field correlations on cooling down to Coulomb-phase ground states. Using this new approach, we provide a theory for magnetic neutron-scattering spectra. It is found that spin-flip exchange interactions produce dispersive QSI monopole excitations which create a particle-hole continuum neutron-scattering spectrum. Gauge fluctuations give multi-particle contributions to the spectrum, which will be possibly detected in Higgs phases.

1:39PM F18.00013 Ubiquitous Magnetic Excitations in the Ytterbium Pyrochlores, ALANNAH HALLAS, JONATHAN GAUDET, McMaster University, NICHOLAS BUTCH, NIST Center for Neutron Research, MAKOTO TACHIBANA, National Institute for Materials Science, RAFAEL FREITAS, Universidade de Sao Paulo, CHRIS WIEBE, University of Winnipeg, GRAEME LUKE, BRUCE GAULIN, McMaster University — The ytterbium pyrochlores, Yb$_2$B$_2$O$_7$ ($B = Sn, Ti, Ge$) are well described in terms of $S_{eff} = 1/2$ quantum spins with local XY anisotropy, decorating the cubic pyrochlore lattice and interacting via anisotropic exchange. While structurally only the non-magnetic B-site cation, and hence, primarily the lattice manifold, is changing across the series $Yb_2B_2O_7$ ($B = Sn, Ti, Ge$), a range of magnetic behavior is observed. The low temperature magnetism in $Yb_2Ti_2O_7$ and $Yb_2Sn_2O_7$ has ferromagnetic character. Conversely, $Yb_2Ge_2O_7$ displays an antiferromagnetically ordered Neel state at low temperatures. We present a comparative analysis of the spin dynamic properties of these three systems using inelastic neutron scattering. While the static properties of the ytterbium pyrochlores are distinct from one another, we find a ubiquitous characteristic to the spin dynamics. The inelastic scattering for each of these ytterbium pyrochlores show a gapless continuum of spin excitations, that tends to resemble over-damped ferromagnetic spin waves at low $Q$. Furthermore, the specific heat for each of these materials follows a common form with a broad, high-temperature anomaly followed by a sharp low-temperature anomaly. We find that the dynamic properties correlate strongly with the broad specific heat anomaly but remain unchanged across the sharp, low temperature specific heat anomaly.
11:15AM F19.00001 Robust antiferromagnetism in the $R_{1-x}$La$_x$Cu$_2$Ge$_2$ series: comparison of Ce$_{1-x}$La$_x$Cu$_2$Ge$_2$ and Nd$_{1-x}$La$_x$Cu$_2$Ge$_2$ $^{1,2}$, SERGEY L. BUD’KO, SCOTT M. SAUNDERS, HALYNA HODOVANETS, PAUL C. CANFIELD, Ames Laboratory/Iowa State University — Recently, remarkably robust and correlated coherence and antiferromagnetism were found in the Ce$_{1-x}$La$_x$Cu$_2$Ge$_2$ series [H. Hodovanets et al., PRL 114, 236601 (2015)]. Whereas Ce is known to hybridize and its compounds often show a strongly correlated behavior, Nd magnetism is associated with a local moment nature. In this talk, we report new measurements on the Ce$_{1-x}$La$_x$Cu$_2$Ge$_2$ series that extend the antiferromagnetic and coherent lines even further and then compare the data for Ce$_{1-x}$La$_x$Cu$_2$Ge$_2$ and the data for a local moment based Nd$_{1-x}$La$_x$Cu$_2$Ge$_2$ series to separate effects of Ce - hybridization from the behavior that might be common in the R(R=metal) family.

$^{1}$Supported by US DOE under the Contract No. DE-AC02-07CH11358

11:27AM F19.00002 Possible Kondo-Lattice-Enhanced Magnetic Ordering at Anomalously High Temperature in Nd Metal under Extreme Compression $^{1}$, JAMES S. SCHILLING, JING SONG, VIKAS SONI, JINHYUK LIM, Washington University in St. Louis — Most elemental lanthanides order magnetically at temperatures $T_o$, well below ambient, the highest being 292 K for Gd. Sufficiently high pressure is expected to destabilize the well localized magnetic 4$f$ state of the heavy lanthanides, leading to increasing influence of Kondo physics on the RKKY interaction. For pressures above 80 GPa, $T_o$ for Dy and Tb begins to increase dramatically, extrapolating for Dy to a record-high value near 400 K at 160 GPa. This anomalous increase may be an heretofore unrecognized feature of the Kondo lattice state; if so, one would expect $T_o$ to pass through a maximum and fall rapidly at even higher pressures. A parallel is suggested to the ferromagnet CeRh$_2$Si$_2$ where $T_o = 115$ K at ambient pressure, a temperature more than 100-times higher than anticipated from simple de Gennes scaling. Here we discuss recent experiments on Nd where anomalous behavior in $T_o(P)$ is found to occur at lower pressures, perhaps reflecting that Nd’s 4$f$ wave function is less localized.

$^{1}$Work at Washington University is supported by NSF grant DMR-1104742 and CDAC through NNSA/DOE grant DE-FCS2-08NA28554.

11:39AM F19.00003 Competition between Kondo and indirect exchange at the edges and bulk of graphene, and 2D materials $^{1,2}$, ANDREW ALLERDT, Northeastern University, GEORGE MARTINS, Oakland University, ADRIAN FEIGLUIN, Northeastern University — We study the problem of two magnetic impurities at the surface of graphene, BN, MoS$_2$, phosphorene, silicene and germanene using exact numerical methods. We map the band structure of these materials onto one dimensional tight-binding chains in the same spirit as Wilson’s numerical renormalization group. We use the density matrix renormalization group to solve the problem exactly, keeping all the information about the underlying lattice. Competition between Kondo and Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions is non-trivial, due to strong non-perturbative effects. Depending on the presence of a pseudogap, or gap, we identify an important directionality and position dependence of the correlations. We present scenarios and regimes where impurities prefer to form their own Kondo clouds instead of an RKKY singlet state, or remain as uncoupled local moments. In the particular case of graphene, ferromagnetism is only stable at half-filling. In addition, we study the effects of spin-orbit coupling, and the presence of edge states.

11:51AM F19.00004 Revisiting the Toulouse limit of a Kondo junction $^{1,2}$, C.J. BOLECH, NAYANA SHAH, University of Cincinnati — Following the development of a scheme to bosonize and deboseonize consistently $^{1,2}$, we present in detail the Toulouse-point analytic solution of the two-lead (nonequilibrium) Kondo junction model. The existence and location of the solvable point is not modified, but the calculational methodology and the final expressions for observable quantities change markedly as compared to the previously accepted results.

$^{1}$ See arXiv:1508.03078 and arXiv:1508.03079

$^{2}$ See also N. Shah, invited talk
12:03PM F19.00005 Magnetic-field tuned ground states of CeAuBi$_2$ single crystals, H. HODOVANETS, T. METZ, H. KIM, Y. NAKAJIMA, K. WANG, J. YONG, S. R. SAHA, J. S. HIGGINS, Center for Nanophysics and Advanced Materials, Department of Physics, University of Maryland, College Park 20742, USA, N. BUTCH, CNAM, UMD, College Park 20742, USA — We present detailed temperature- and field-dependent data obtained from magnetization, resistivity and heat capacity measurement performed on nearly stoichiometric CeAuBi$_2$ single crystals. The compound orders antiferromagnetically at $\sim 13$ K and shows large magnetic anisotropy at low temperatures with the c-direction being an easy axis. The field-dependent magnetization data at low temperatures reveal the existence of a spin-flip transition for $H\parallel (H_c \sim 75$ kOe and $T = 1.8$ K). The zero-field resistivity and heat capacity data show features characteristic of a Ce-based intermetallic with crystal electric field splitting and possible correlated, Kondo lattice effects. The constructed $T - H$ phase diagram for the magnetic field applied along the easy, [001], direction shows that the magnetic field required to suppress $T_N$ is $\sim 75$ kOe. The possibility of realization of the field-tuned quantum critical point (QCP) in CeAuBi$_2$ will be discussed.

12:15PM F19.00006 Neutron scattering, magnetic, and transport properties of non-centrosymmetric UlrSi$_3$, SHANTA SAHA, L-LIN LIU, Center for Nano Physics and Advanced Materials, Department of Physics, University of Maryland, College Park, MD 20742, CRAIG BROWN, NICHOLAS BUTCH, NIST Center for Neutron Research, Gaithersburg, MD 20899, JOHNPIERRE PAGLIONE, Center for Nano Physics and Advanced Materials, Department of Physics, University of Maryland, College Park, MD 20742 — Heavy-fermion superconductivity in the non-centrosymmetric crystal structure has drawn much attention [1]. It is argued that the order parameter contains not only a spin-singlet part, but also an admixture of a spin-triplet state. The compound UlrSi$_3$ crystallizes in the non-centrosymmetric BaNiS$_3$ structure which is closely related to the well-known ThCr$_2$Si$_2$-type [2]. Preliminary study on polycrystalline UlrSi$_3$ shows antiferromagnetic order below Neel temperature $T_N \approx 42$ K [2]. Its lanthanide analog CeSr$_3$ shows heavy-fermion superconductivity under pressure [1]. Therefore, further investigation on UlrSi$_3$ would be meaningful. We would like to present the results of our investigation on UlrSi$_3$ by neutron scattering, magnetic, and transport measurement on poly and single crystals grown by Czochralski method in a tetra-arc-furnace. [1] Onuki et al., J. Phys. Soc. Jpn. 77, suppl. A 37 (2008). [2] Buffat et al., J. Mag. Mag. Mat. 62, 53 (1986).


12:39PM F19.00008 Physical properties of the van der Waals bonded ferromagnet Fe$_{3-x}$GeTe$_2$, ANDREW MAY, Materials Science and Technology Division, ORNL, STUART CALDER, Quantum Condensed Matter Division, ORNL, CLAUDIA CANTONI, Materials Science and Technology Division, ORNL, HUBO CAO, Quantum Condensed Matter Division, ORNL, MICHAEL MCGUIRE, Materials Science and Technology Division, ORNL — Fe$_{3-x}$GeTe$_2$ is an itinerant ferromagnetic with a layered structure held together by van der Waals bonds. The material has been synthesized using a flux-growth technique that results in large single crystals suitable for neutron scattering, and its magnetic structure and phase diagram have been investigated. The flux-grown crystals possess a Curie temperature $T_C \approx 150$ K, which is less than that reported for polycrystalline Fe$_{3-x}$GeTe$_2$ with $T_C \approx 230$ K. The difference is explained by intrinsic Fe-deficiency in these single crystals. This talk will summarize the physical properties of the flux grown single crystals and a series of polycrystalline samples with varying concentrations of Fe, which reveal how Fe content is correlated to structural parameters and $T_C$. In combination with the magnetic properties, Hall effect and thermoelectric data reveal that Fe$_{3-x}$GeTe$_2$ compounds are multi-carrier type, itinerant ferromagnets. Research supported by the US DOE, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

12:51PM F19.00009 Complex magnetic phases in non-centrosymmetric heavy fermion CeCoGe$_3$, SHAN WU, Johns Hopkins University, Institute for Quantum Matter, CHRIS STOCK, University of Edinburgh, CEDOMIR PETROVIC, Brookhaven National Laboratory, J.A. RODRIGUEZ-RIVERA, NIST center for Neutron Research, COLLIN BROHOLM, Johns Hopkins University, Institute for Quantum Matter — The non-centrosymmetric nature of the tetragonal heavy fermion system CeCoGe$_3$ has attracted much interest in the high pressure superconducting state of the material. We have explored the related ambient pressure magnetism using neutron scattering. There are three successive phase transitions at $T_N \approx 21$, $T_{N2} \approx 12$K and $T_{N3} \approx 8$K. The upper transition greatly enhances the susceptibility and there are meta-magnetic transitions in the lower T phases. We confirmed the previously determined AFM spin structure for $T_{N2} < T < T_{N1}$[1]. At lower T we find a complex commensurate structure that can be described as intertwined antiferromagnetic segments. We also report inelastic magnetic neutron scattering, which is dominated by the periodicity of the chemical cell rather than the magnetic unit cell.[1]M.Smidman, et al. Phys. Rev. B, 88, 134416 (2013)

![Image](https://via.placeholder.com/150)

The work at IQM was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46444.

1:03PM F19.00010 Quantum criticality on magnetic systems: it is not where you think it is!, VALENTIN TAUFOUR, UDHARA KALUARACHCHI, MANH CUONG NGUYEN, STELLA K KIM, XIAO LIN, EUN DEOK MUN, HYUNSOO KIM, YU FURUKAWA, CAI ZHUNGL WANG, KAI MING HO, SERGEY L BUD'KO, PAUL C CANFIELD, Ames Laboratory / Iowa State University, Ames, IA 50011, USA, ZURAB GUGUCHIA, RUSTEM KHASANOV, Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland, PIETRO BONFA, ROBERTO DE RENZI, Dipartimento di Fisica e Scienze della Terra, Parco Area delle Scienze 7/A, I-43124 Parma, Italy — When a quantum critical point, i.e. a second order transition at $T_c$, appears in a ferromagnetic to a paramagnetic phase, or to a spatially modulated phase. We will illustrate this case on a new material: LaCrGe$_3$. We will present the temperature-pressure-magnetic field phase diagram of LaCrGe$_3$ and show that quantum criticality is avoided by the appearance of a modulated phase. We will also explain how quantum criticality can be re-introduced. Work at Ames Laboratory was supported by US DOE under the Contract No. DE-AC02-07CH11358. Magnetization measurements under pressure were supported by Ames Laboratory’s laboratory-directed research and development (LDRD) funding.
1:15PM F19.00011 Theory of electronic and magnetic properties of weak antiferromagnetic TiAu\(^1\), WEN FONG GOH, WARREN PICKETT, Univ of California - Davis — To date, only a few itinerant magnetic compounds have been found, viz. ZrZn\(_2\), TiB\(_2\) and SrIn, all comprised of nonmagnetic elements. TiAu, a newly synthesized itinerant weak antiferromagnet, orders antiferromagnetically below 36 K. Neutron diffraction reveals an ordered local moment of only 0.15 \(\mu_B\)/Ti at a wave vector \(Q=(0,\pi/b,0)\). Hole doping, viz. Ti\(_{1-x}\)Sc\(_x\)Au, causes the magnetic moment to disappear at a quantum critical point \(x_{sc} \approx 0.13\). We present results of an extensive study of the electronic and magnetic properties of TiAu. DFT calculations reveal vane singularities at \((0,0.45\pi/b,0.49\pi/c)\), 4 meV above the Fermi level. Several types of analysis will be discussed: fixed spin moment studies and Stoner enhancement; magnetic energies; magnetism versus doping; Fermi surface nesting; corrections for spin fluctuations.

\(^1\)Supported by Grant NSF DMREF DMR 1534719

1:27PM F19.00012 Quantum Criticality in YFe\(_2\)Al\(_{10}\) \(^2\), WILLIAM GANNON, Texas AM University, LIUSUO WU, Oakland Ridge National Laboratory, IGOR ZALIZNYAK, Brookhaven National Laboratory, YIMING QIU, JOSE RODRIGUEZ-RIVERA, National Institute of Standards and Technology, MEIGAN ARONSON, Texas AM University — Quantum criticality has been studied in many systems, but there are few systems where observed scaling can be unified with a critical free energy \(F\), and where the critical exponents form the basis for QC universality classes. We have identified a new layered material YFe\(_2\)Al\(_{10}\) that shows remarkably strong QC behavior, where the scaling properties of the magnetic susceptibility and specific heat are consistent with the same \(F\). Recent neutron scattering experiments paint a remarkable picture of the QC fluctuations in YFe\(_2\)Al\(_{10}\). In contrast to classical transitions, where fluctuations are relatively long ranged and inelastic scattering is observed at a magnetic zone center, in YFe\(_2\)Al\(_{10}\) the scattering is independent of wave vector in the critical plane, indicating that the fluctuations are spatially localized, while out of plane scattering indicates that the interlayer interactions are restricted to nearest neighbors. The dynamical susceptibility \(\chi'' \sim E^{-2}\), and is wholly temperature independent, indicating that \(E/T\) scaling is present, the signature of QC fluctuations. These results hint that the QC criticality in YFe\(_2\)Al\(_{10}\) is local, which until now has only been found in a few f-electron based compounds.

1:39PM F19.00013 Quantum criticality in single crystalline YFe2Al10 determined from zero-field and longitudinal-field muon spin relaxation\(^3\), KEVIN HUANG, CHENG TAN, JIAN ZHANG, ZHAOFENG DING, Department of Physics, Fudan University, DOUGLAS MACLAUGHLIN, Department of Physics, UC Riverside, OSCAR BERNAL, Department of Physics, CSU Los Angeles, PEI-CHUN HO, Department of Physics, CSU Fresno, LIUSUO WU, MEIGAN ARONSON, Department of Physics, Stony Brook University, LEI SHU, Department of Physics, Fudan University — Muon spin relaxation (\(\mu\)SR) measurements were performed on single crystalline YFe\(_2\)Al\(_{10}\) down to 19 mK and in magnetic fields up to \(\sim 100\) Oe. Zero-field-\(\mu\)SR measurements showed no evidence of magnetic order down to 19 mK, consistent with previous measurements. However, we also find that the depolarization rate \(\Lambda\) is temperature independent above 1 K but increases in an exponential behavior for \(T < 1\) K. Longitudinal-field \(\mu\)SR measurements also reveals a time-field scaling where \(G(t,H) = G(t/H^\gamma)\), with \(\gamma = 0.67\). This is further confirmed from the magnetic field dependence of \(\Lambda\), which finds \(\Lambda(H) \propto H^{0.67}\) at 19 mK. This is further evidence that single crystalline YFe\(_2\)Al\(_{10}\) is in close proximity to a ferromagnetic quantum critical point.

\(^3\)The research performed in this study was supported by the National NSF of China under Grant no. 11474060 and STCSM of China (No. 15XD1500200). Work at CSU funded by NSF/DMR-1105390. Research at CSU-Fresno is supported by NSF DMR-1506677

1:51PM F19.00014 Doping-Induced Quantum Critical Point in an Itinerant Antiferromagnet TiAu\(^2\), JESSICA SANTIAGO, ETERI SVANIDZE, Rice University, TIGLET BESARA, THEO SIEGRIST, National High Magnetic Field Laboratory, Florida State University, EMILIA MOROSAN, Rice University — The recently discovered itinerant magnet TiAu is the first antiferromagnet composed of non-magnetic constituents. The spin density wave ground state develops below \(T^N \sim 36\) K, about an order of magnitude smaller than in Cr. Achieving a quantum critical point in this material would provide a better understanding of weak itinerant antiferromagnets, while giving long-sought-after insights into the effects of spin fluctuations in itinerant electron systems. While the application of pressure increases the ordering temperature \(T^N\), partial substitution of Ti provides an alternative avenue towards achieving a quantum critical point. The non-Fermi liquid behavior accompanies the quantum phase transition, as evidenced by the divergent specific heat coefficient and linear temperature dependence of the resistivity. The transition is accompanied by enhanced electron-electron correlations as well as strong spin-fluctuations, providing an experimental avenue for the verification of the self-consistent theory of spin fluctuations.

2:03PM F19.00015 Itinerant magnetism in quantum critical YFe\(_2\)Al\(_{10}\) \(^2\), WENHUI XU, WEIGOU YIN, ROBERT KONIK, ALEXEI TSVELIK, Brookhaven Natl Lab, GABRIEL KOTLIAR, Rutgers University — The absence of magnetic order and the scaling laws in thermodynamic and transport properties in layered compound YFe\(_2\)Al\(_{10}\) suggest competition among different types of collective quantum states. Measurements on magnetic susceptibility have demonstrated a Curie-Weiss (CW) behavior with a reduced fluctuating Fe moment of 0.45B and \(T_{CW} \sim 28\) K. Using first principle methods, we show that the correlation in YFe2Al10 is moderate and the Fe magnetism is itinerant. Competing ground states include a paramagnetic state, an in-plane antiferromagnetic ordering (G-type) state and an in-plane collinear ordering (C-type) state. Although a bulk ferromagnetic order is not favored in total energy, both the G-type and C-type ground state prefer ferromagnetic inter-layer coupling.


11:15AM F21.0001 Coherent manipulation of quantum spin states in a single molecular nanomagnet, WOLFGANG WERNDSORFER, Institut Neel, CNRS, Grenoble — The endeavor of quantum electronics is driven by one of the most ambitious technological goals of today's scientists: the realization of an operational quantum computer (http://qurope.eu). We started to address this goal by the new research field of molecular quantum spintronics. The building blocks are magnetic molecules, i.e. well-defined spin qubits. We will discuss this still largely unexplored field and present our first results: For example, using a molecular spin-transistor, we achieved the electronic read-out of the nuclear spin of an individual metal atom embedded in an SMM. We could show very long spin lifetimes (>10 s). Using the hyperfine Stark effect, which transforms electric fields into local effective magnetic fields, we could not only tune the resonance frequency by several MHz, but also perform coherent quantum manipulations on a single nuclear qubit faster than \(\mu\)s by means of electrical fields only, establishing the individual addressability of identical nuclear qubits. Using three different microwave frequencies, we could implement a simple four-level Grover algorithm. S. Thiele, F. Balestro, R. Ballou, S. Klyatskaya, M. Ruben, W. Wernsdorfer, Science 344, 1135 (2014).
11:51AM F21.00002 Landau-Zener in a continuously measured molecular spin 1. FELIPPO TROIANI, Istituto Nanoscienze, CNR (Italy), MARCO AFFRONTI, Università di Modena e Reggio Emilia (Italy), STEPHAN THIELE, CLEMENT GODFRIN, FRANCK BALESTRO, WOLFGANG WERNDSORFER, Institut NeI, CNRS (France), SVETLANA KLYATSKAYA, MARIO RUBEN, Karlsruhe Institute of Technology (Germany) — The dynamics of a quantum system driven through an avoided level crossing represents a relevant problem in many physical contexts. Here we present a joint theoretical and experimental investigation of a single-molecule magnet (namely, a terbium double-decker complex) in a three-terminal geometry. The Tb spin is driven through an avoided level crossing by a time-dependent magnetic field, and its dynamics is monitored through a continuous measurement of the conductance. The dependence of the spin-reversal probability on the field sweeping rate presents clear deviations from the Landau-Zener formula, which applies to the case of closed systems. The comparison between direct and inverse Landau-Zener transitions points at the dominance of dephasing, with respect to inelastic incoherent processes. The spin dynamics is simulated within a master equation approach. The observed behaviors are reproduced by assuming that dephasing takes place in the basis of the time-dependent Hamiltonian eigenstates. The spin dephasing is traced back to the continuous measurement of the electron spin, and a fundamental role is played by the finite time resolution of the conductance measurement.

12:03PM F21.00003 Magnetic hysteresis in a lanthanide molecular magnet dimer system 1. JAMES ATKINSON, REBECCA CEBULKÁ, ENRIQUE DEL BARCO, University of Central Florida, Physics Department, Orlando, FL, USA, OLIVIER ROUBEUX, Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC and Universidad de Zaragoza, Zaragoza, Spain, VERONICA VELASCO, LEO BARRIOS, GUILLERAMORI, Universitat de Barcelona, Departament de Química Inorgànica, Barcelona, Spain — Molecular magnets present a wonderful means for studying the dynamics of spin. Often synthesized as a crystal lattice of identical systems, ensemble measurements enable thorough detailing of the internal degrees of freedom. Here we present the results of characterization performed on a dimer system, CeTm(3H2L)4(N2O3)pyH2O (L = ligand, C24H35O3N2), consisting of two lanthanide spins (Cerium and Thulium) with expected local axial anisotropies tilted with respect to each other. Microwave EPR spectroscopy at low temperature reveals hysteresis in observed absorption features, with angle dependence studies indicating the presence of several easy axis orientations. We attempt to understand this system through modelling via a spin Hamiltonian, and to determine the strength and nature of the coupling between the lanthanide centers.

12:15PM F21.00004 Search for giant magnetic anisotropy in transition-metal dimers on defected hexagonal boron nitride sheet 1. JIE LI, State Key Lab. of Surface Physics, Key Lab. of Computational Physical Sciences, and Dept. of Physics, Fudan Univ., HUI WANG, Dept. of Physics and Astronomy, Univ. of California, JUN HU, College of Physics, Optoelectronics and Energy, Soochow Univ., RUIQIAN WU, Dept. of Physics and Astronomy, Univ. of California — For a magnetic units at the nanometer scale, one of the most important issues is how to hold thermal fluctuation of its magnetization, i.e., how to enhance its blocking temperature \(T_B\) to above 300K. Through systematic density functional calculations, the structural stability and magnetic properties of many transition-metal dimers embedded in a defected hexagonal boron nitride monolayer are investigated. We find twelve cases that may have magnetic anisotropy energies (MAEs) larger than 30 meV. In particular, Ir-IrO-DhBN has both large MAE (126 meV) and high structural stability, which makes it a promising candidate of magnetic unit in spintronics and quantum computing devices.

1 Work at Fudan was supported by the Chinese National Foundation (11474056) and National Basic Research Program of China (2015CB921400). Work at UCI was supported by DOE-BES (Grant No. DE-FG02-05ER46237).

12:27PM F21.00005 Molecular Magnetism in MnTe Clusters 1. JIA CHEN, Department of Applied Physics, Columbia University, ARUN NANDURI, BONNIE CHOI, Department of Chemistry, Columbia University, ANDREW MILLIS, Department of Physics, Columbia University, DAVID REICHMAN, XAVIER ROY, Department of Chemistry, Columbia University — Electron correlation in recently synthesized molecular clusters with Mn4Te8 cores in cubic structures and ligand exteriors are studied experimentally and theoretically. We used density functional theory with on-site Coulomb interactions (DFT+U) to construct effective spin Hamiltonians and estimate the dependence of parameters on choice of ligand. The lack of inversion symmetry combined with the heavy tellurium ions leads to a significant Dzyaloshinskii-Moriya (DM) interaction. Comparison of measurements to the magnetic susceptibility calculated from the spin model is used to validate the results. We also extend this work to more complex clusters with more than one cubanes, where interesting high-spin ground state may occur. It has been measured recently, \(\text{Fe}_8\text{Te}_8\) in dicubane structure has ground state with magnetization of \(\text{Fe}^{2+}\), which makes it promising candidate for single molecular magnets.

1 A.J.M. acknowledges support from NSF under contract DMR-1308236. J.C. is supported by the NSF MRSSEC program through Columbia in the Center for Precision Assembly of Superstratic and Superatomic Solids under Grant No.DMR-1420634.


12:51PM F21.00007 Magnetic dipole-dipole sensing at atomic scale using electron spin resonance STM 1. T. CHOI, W. PAUL, IBM Almaden Research, S. ROLF-PISSARCYZK, Max Planck Institute, Germany, A. MACDONALD, U. of British Columbia, Canada, K. YANG, Chinese Academy of Sciences, F.D. NATTERER, EPFL, Switzerland, C.P. LUTZ, A.J. HEINRICH, IBM Almaden Research — Magnetometry having both high magnetic field sensitivity and atomic resolution has been an important goal for applications in diverse fields covering physics, material science, and biomedical science. Recent development of electron spin resonance STM (ESR-STM) promises coherent manipulation of spins and studies on magnetic interaction of artificially built nanostructures, leading toward quantum computation, simulation, and sensors In ESR-STM experiments, we find that the ESR signal from an Fe atom underneath a STM tip splits into two different frequencies when we position an additional Fe atom nearby. We measure an ESR energy splitting that decays as \(1/r^3\) (\(r\) is the separation of the two Fe atoms), indicating that the atoms are coupled through magnetic dipole-dipole interaction. This energy and distance relation enables us to determine magnetic moments of atoms and molecules on a surface with high precision in energy. Unique and advantageous aspects of ESR-STM are the atom manipulation capabilities, which allow us to build atomically precise nanostructures and examine their interactions. For instance, we construct a dice arrangement of five Fe atoms, and probe their interaction and energy degeneracy. We demonstrate the ESR-STM technique can be utilized for quantum magnetic sensors.

1:03PM F21.00008 ABSTRACT WithDRAWN
1:15PM F21.00009 Spin blockade effect in single-molecule transistors1. GUANGPU LUO, KYUNGWHA PARK, Virginia Tech, Blacksburg, Virginia — Recently single-molecule transistors consisting of individual single-molecule magnets trapped between electrodes have been experimentally realized and electron transport properties through individual single-molecule magnets have been measured. For a single-molecule magnet the (25+1)-fold degeneracy of magnetic levels in a given spin multiplet is lifted even in the absence of external magnetic field, due to the magnetic anisotropy induced by spin-orbit coupling. This is the anisotropic nature of single-molecule magnets allowed one to discover interesting, unexpected transport properties. A recent theoretical study showed that an Eu-based anisotropic magnetic molecule can switch its magnetic anisotropy between magnetic easy plane and easy axis upon varying the charge state of the molecule. Motivated by this report, we investigate how this switch of magnetic anisotropy influences the electron transport through the molecule, by considering sequential electron tunnelling. We calculate current-voltage characteristics by solving the master equation based on the model Hamiltonians. We explore this interesting effect in the absence and presence of external magnetic field.

1:27PM F21.00010 Hybrid quantum systems with YBCO coplanar resonators and spin ensembles of organic radicals. ALBERTO GHIRRI, Istituto Nanoscienze - CNR, Centro S3, via Campi 213/a, 41125 Modena, Italy, CLAUDIO BONIZZONI, Dipartimento FIM, Universita di Modena e Reggio E. and Istituto Nanoscienze - CNR, via Campi 213/a, 41125 Modena, Italy, FILIPPO TROIANI, Istituto Nanoscienze - CNR, via Campi 213/a, 41125 Modena, Italy, ANTONIO CASSINESE, CNR-SPIN and Dipartimento di Fisica, Universita?? di Napoli Federico II, 80138 Napoli, Italy, MASSIMILIANO D’ARIENZO, LUCA BEVERINA, Department of Materials Science State University of Milano-Bicocca Via Cozzi 55 I-20125 Milano, Italy, MARCO AFFRONTE, Dipartimento FIM, Universita di Modena e Reggio E. and Istituto Nanoscienze - CNR, via Campi 213/a, 41125 Modena, Italy — We have studied the coherent coupling of microwave photons in a superconducting coplanar resonator with a spin ensemble of stable open-shell organic radicals. We fabricated YBCO/sapphire coplanar resonator resonators that show quality factors ≃ 3*10^4 at 1.8 K, that remain remarkably stable in high magnetic field applied parallel to the YBCO film [QL (7 T) = 90% QL (0 T)] [1]. Spin ensembles of (3,5-Dichloro-4-pyridyl)bis(2,4,6-trichlorophenyl)methyl organic radical (PyBTM) show sharp EPR linewidth (8 MHz) due to the effect of the exchange narrowing. The frequency of the spin transition is tuned by means of the external magnetic field. We show the achievement of the strong collective coupling with the resonant photons with coupling rates exceeding 90 MHz at 1.8 K. [1] A. Ghirri, C. Bonizzoni, D. Gerace, S. Sanna, A. Cassinese and M. Affronte, Appl. Phys. Lett. 106, 184101 (2015).

1:39PM F21.00011 First-principles study on magnetism of Ru monolayer under an external electric field. YUKIE KITAOKA, HIROSHI IMAMURA, AIST, Spintronics Research Center — Electric field control of magnetic properties such as magnetic moment and magnetic anisotropy has been attracted. For the 4d TMs, on the other hand, it was recently reported that the ferromagnetism Pd thin-film is induced by application of an external electric field otherwise Pd thin-film shows paramagnetic [1]. However, little attention has been paid to the magnetism of other 4d TMs. Here, we investigate the magnetism of the free-standing Ru monolayer and that on MgO(001) substrate under an external electric field by using first-principles FLAPW method [2]. We found that the free-standing Ru monolayer is ferromagnet with magnetic moment of 1.50 \( \mu \text{B}/\text{atom} \) and decreases to 1.33 \( \mu \text{B}/\text{atom} \) by application of electric field \( E=1 \) \( \text{V/\AA} \). The Ru monolayer on MgO(001) substrate is also ferromagnet with magnetic moment of 0.89 \( \mu \text{B}/\text{atom} \). The MA energy is 1.49 meV/atom, indicating perpendicular MA, at \( E=0 \) and increases up to 3.84 meV/atom by application of \( E=1 \) \( \text{V/\AA} \). The Ru monolayer on MgO(001) substrate is also ferromagnet with magnetic moment of 0.89 \( \mu \text{B}/\text{atom} \). The MA energy is 1.49 meV/atom, indicating perpendicular MA, at \( E=0 \) and increases up to 3.84 meV/atom by application of \( E=1 \) \( \text{V/\AA} \). [1] T. Ito, A. J. Freeman, L. Zhong, J. Fernandez-de-Castro, PRB, 67, 014420 (2003).

1:51PM F21.00012 Chemically Controllable Ferromagnetic Graphene for High-Performance Spintronic Devices. JEONGMIN HONG, UC Berkeley — The spin and charge of the electron when taken together, offer many opportunities for the creation of new information processing and storage devices applications with ultralow power consumption. Chemically controllable growth of large area nanocarbon structures has attracted considerable interests due to their superior properties. If large area nanocarbon could have by-design magnetic properties, multifunctional electronic devices could be built through modulation controlled by external factors such as 1) functionalization onto basal plane of carbon, 2) substrates effects (proximity induced ferromagnetism), and 3) external electric field. We performed soft X-ray measurement techniques using X-ray magnetic circular dichroism (XMCD) and revealed the controllable ferromagnetic properties on graphene structures. The chemically controllable nanomagnet would be an excellent building block for the applications of graphene-based high-performance spintronic devices.

2:03PM F21.00013 Energy gap of Graphene Nanoflakes: Edge Magnetism and Self-Energy Corrections. ROMEO DE COSS GOMEZ, CARLOS MANUEL RAMOS CASTILLO, Departamento de applied physics centro de investigacion y de estudios avanzados del instituto politecnico nacional — Previous theoretical works has predicted that graphene nanostructures with zigzag edge exhibit metallic behavior around 6-7 nm, however in such calculations the metallic nature of zigzag edges was not considered. In this work, the influence of the edge magnetism on the size dependence of energy-gap in hexagonal graphene nanoflakes (GNFs) with zigzag borders is studied by density functional theory calculations. Thus, we found that meanwhile the calculations without spin polarization predicts that the metallic behaviour for GNFs begin at 6 nm deviating from the trend predicted for effective model of Dirac fermions, spin-polarized calculations predicts semiconducting behavior at 6 nm. This result shows clearly that the origin of metallic behaviour predicted at 6 nm in previous works is not related with the well known band-gap problem of Kohn-Sham scheme, but with neglecting spin polarization. Furthermore, to correct the band-gap problem of Kohn-Sham Scheme, we have calculated the size dependence of fundamental energy-gap using the quasiparticle formalism by adding/removing an electron to/from the system.

**Tuesday, March 15, 2016 2:30PM - 5:30PM —**

Session H2 DCMP DMP GMAG: Emergent Topological Phenomena in Pyrochlore Iridates II

Ballroom II - Zhi-Xun Shen, Stanford Univ
2:30PM H2.00001 Metal-insulator transitions of bulk and domain-wall states in pyrochlore iridates... KENTARO UEDA, RIKEN CEMS — A family of pyrochlore iridates \( R_2\text{Ir}_2\text{O}_7 \) offers an ideal platform to explore intriguing phases such as topological Mott insulator and Weyl semimetal [1]. Here we report transport and spectroscopic studies on the metal-insulator transition (MIT) induced by the modulations of effective electron correlation and magnetic structures, which is finely tuned by external pressure, chemical substitutions (\( R = \text{Nd}_{1-y}\text{Pr}_y \) and \( \text{Sm}_y\text{Nd}_{1-y} \)), and magnetic field. A reentrant metal-insulator transition is observed near the paramagnetic insulator-metal phase boundary reminiscent of a first-order Mott transition for \( R = \text{Sm}_y\text{Nd}_{1-y} \) compounds (\( y > 0.8 \)). The metallic states on the magnetic domain walls (DWs), which are observed for \( R = \text{Nd} \) in real space [2] as well as in transport properties [3], is simultaneously turned into the insulating one. These findings imply that the DW electronic structure is intimately linked to the bulk states. For the mixed \( R = \text{Nd}_{1-y}\text{Pr}_y \) compounds, the divergent behavior of resistivity with antiferromagnetic order is significantly suppressed by applying a magnetic field along [001] direction [4]. It is attributed to the phase transition from the antiferromagnetic insulating state to the novel Weyl (semi-)metal state accompanied by the change of magnetic structure. The present study combined with experiment and theory suggests that there are abundant exotic phases such as electron correlation and Ir-5d magnetic order pattern. Work performed in collaboration with J. Fujikai, B.-J. Yang, C. Terakura, N. Nagaosa, Y. Tokura (University of Tokyo, RIKEN CEMS), J. Shiogai, A. Tsukazaki, S. Nakamura, S. Awaji (Tohoku University). 1This work was supported by JSPS FIRST Program and Grant-in-Aid for Scientific Research (Grants No. 80609488 and No. 24224009). [1] W. Witzczak-Krempa, G. Chen, Y. B. Kim, and L. Balents, Annu. Rev. Condens. Matter Phys. 5, 57 (2014). [2] Eric Yue Ma, Yong-Tao Cui, Kentaro Ueda, Shujie Tang, Kai Chen, Nobumichi Tamura, Phillip M. Wu, Jun Fujikai, Yoshinori Tokura, and Zhi-Xun Shen, Science 350, 538 (2015). [3] K. Ueda, J. Fujikai, Y. Takahashi, T. Suzuki, S. Ishiwata, Y. Taguchi, M. Kawasaki, and Y. Tokura, Phys. Rev. B 89, 075127 (2014). [4] K. Ueda, J. Fujikai, B.-J. Yang, J. Shiogai, A. Tsukazaki, S. Nakamura, S. Awaji, N. Nagaosa, and Y. Tokura, Phys. Rev. Lett. 115, 056402 (2015).

3:06PM H2.00002 Mobile metallic domain walls in an all-in-all-out magnetic insulator1, ERIC YUE MA, Stanford Univ — Magnetic domain walls are boundaries between regions with different configurations of the same magnetic order. In a magnetic insulator where the magnetic order is tied to its bulk insulating property, it has been postulated that electronic properties are drastically different along the domain walls, where the order is inevitably disturbed. Here we report the discovery of highly conductive magnetic domain walls in a magnetic insulator \( \text{Nd}_2\text{Ir}_2\text{O}_7 \), which has an unusual all-in-all-out magnetic order, via transport and spatially resolved microwave impedance microscopy. The domain walls have a virtually temperature-independent sheet resistance (averaged over mesoscopic distances) of 1 kilohm per square, show smooth morphology with no preferred orientation, are free from pinning by disorders, and have strong thermal and magnetic field responses that agree with expectations for all-in-all-out magnetic order.

1This work is supported by funding from NSF, Moore Foundation, JSPS, NSFC and DOE


1This work is based on the collaboration with Nakatsui Satoru, Kohama Yoshimitsu, Tomita Takahiro, Kindo Koichi, Jyun J. Ishikawa, Baleta Leon, Ishizuka Hiroaki, Timothy H. Hsieh. ZM. Tian was supported by JSPS Postdoctoral Fellowship (No.P1402)

4:54PM H2.00005 Interplay of magnetic and electronic states in pyrochlore iridesates, LEON BALENTS, Kavli Institute for Theoretical Physics, UCSB — The pyrochlore iridates are a series of compounds undergoing antiferromagnetic ordering and metal-insulator transitions. They are of interest because they combine electron correlation effects and the potential for non-trivial band topology. We will discuss the theoretical picture of these materials, from electronic structure to magnetism and phase transitions, and how they may be controlled through applied fields and temperature. Comparison will be made between theory and recent experiments.

Tuesday, March 15, 2016 2:30PM - 5:30PM — Session H5 GMAG DMP: Frustrated Magnetism: Spin Liquids in 2D — Arun Paramekanti, University of Tornoto

2:30PM H5.00001 Paired states of Chern-Simons fermions in quantum spin models, ANDREW ALLOCCA, Univ of Maryland-College Park; TIGRAN SEDRAKYAN, Fine Theoretical Physics Institute, Univ of Minnesota and Physics Frontier Center, Joint Quantum Institute, University of Maryland—Varying strength of the Chern-Simons term on the two-dimensional quantum spin-1/2 XY model on the square and hexagonal lattices. By applying a Chern-Simons transformation we represent the quantum spin model as a system of spinless fermions interacting via attached fluxes. The interaction is then decoupled in the Cooper and excitonic channels giving possible unconventional states constructed from the two-dimensional quantum spin-1/2 XY model on the square and hexagonal lattices. We show that the presence of the full SO(3) spin-rotational symmetry and if there is an odd number of spin-\( \frac{1}{2} \) per unit cell, the symmetry fractionalization of visons is completely fixed. On the other hand, visons can have different classes of symmetry fractionalization if the spin-rotational symmetry is reduced. As a concrete example, we show that visons in the Balents-Fisher-Girvin \( Z_2 \) spin liquid have crystal symmetry fractionalization classes which are not allowed in SO(3) symmetric spin liquids, due to the reduced spin-rotational symmetry.

2:42PM H5.00002 Symmetry fractionalization of visons in \( Z_2 \) spin liquids, YANG QI, Perimeter Institute for Theoretical Physics, MENG CHENG, Station Q, Microsoft Research, CHEN FANG, Massachusetts Institute of Technology — In this work we study symmetry fractionalization of vison excitations in topological \( Z_2 \) spin liquids. We show that in the presence of the full SO(3) spin-rotational symmetry and if there is an odd number of spin-\( \frac{1}{2} \) per unit cell, the symmetry fractionalization of visons is completely fixed. On the other hand, visons can have different classes of symmetry fractionalization if the spin-rotational symmetry is reduced. As a concrete example, we show that visons in the Balents-Fisher-Girvin \( Z_2 \) spin liquid have crystal symmetry fractionalization classes which are not allowed in SO(3) symmetric spin liquids, due to the reduced spin-rotational symmetry.
2:54PM H5.00003 Haldane-Hubbard Mott Insulator: From Tetrahedral Spin Crystal to Chiral Spin Liquid, CIARAN HICKEY, University of Toronto, LUKASZ. CINCO, Perimeter Institute for Theoretical Physics, ZLATKO PAPIC, University of Leeds, ARUN PARAMEIKANTI, University of Toronto — Motivated by recent experimental realizations of artificial gauge fields in ultracold atoms, we study the honeycomb lattice Haldane-Hubbard Mott insulator of spin-1/2 fermions using exact diagonalization and density matrix renormalization group methods. We show that this model exhibits various chiral magnetic orders including a wide regime of triple-Q tetrahedral order. Incorporating third-neighbor hopping frustrates and ultimately melts this tetrahedral spin crystal. From analyzing low energy spectra, many-body Chern numbers, entanglement spectra, and modular matrices, we identify the molten state as a chiral spin liquid with gapped semion excitations.

3:06PM H5.00004 Unification of bosonic and fermionic \( \mathbb{Z}_2 \) spin liquids on a rectangular lattice, SHUBHAYU CHATTERJEE, JULIA STEINBERG, SUBIR SACHDEV, Harvard University — Recent theories [1] have postulated the presence of a fractionalized Fermi liquid (FL) in the pseudogap metal phase of cuprates. The FL phase can be described as a spin liquid co-existing with fermionic charge carrying quasiparticles. Underdoped cuprates also show a variety of competing orders, including nematic order which reduces the \( C_4 \) symmetry of the square lattice to \( C_2 \). Motivated by this, we classify mean-field bosonic spin liquids on a rectangular lattice using projective symmetry groups (PSG) [2], and find equivalent descriptions in terms of fermionic partons [3]. In particular, we find a fermionic spin liquid ansatz corresponding to a bosonic \( Z_2 \) spin liquid with favorable mean field energy [4]. The fermionic ansatz might be useful to approach the transition from a FL* to a fermi liquid. [1] Density-wave instabilities of fractionalized Fermi liquids: D. Chowdhury and S. Sachdev, PRB 90, 245136 (2014) [2] Quantum orders and symmetric spin liquids: XG Wen, PRB 65 (16), 165113 (2002) [3] Unification of bosonic and fermionic theories of spin liquids on the kagome lattice: Y-M. Lu, G. Y. Cho, A. Vishwanath, arXiv:1403.0575 [4] Large-N expansion for frustrated quantum antiferromagnets: N. Read and S. Sachdev, PRL 66, 1773 (1991)

3:18PM H5.00005 Coupled wire construction of chiral spin liquids\(^1\), RONNY THOMALE, Univ of Wuerzburg, TOBIAS MENG, TU Dresden, TITUS NEUPERT, PCTS, Princeton University, MARTIN GREITER, Univ of Wuerzburg — We develop a coupled wire construction of chiral spin liquids. The starting point are individual wires of electrons in the Mott regime that are subject to a Zeeman field and Rashba spin-orbit coupling. Suitable spin-flip couplings between the wires yield an Abelian chiral spin liquid state which supports spinon excitations above a bulk gap, and chiral edge states. The approach generalizes to non-Abelian chiral spin liquids at level k with parafermionic edge states.

\(^{1}\) RT is supported by the European Research Council through ERC-StG-336012-TOPOLECTRICS. MG and RT are supported by DFG-SFB 1170.

3:30PM H5.00006 Variational Monte Carlo study of chiral spin liquid in quantum antiferromagnet on the triangular lattice, WENJUN HU, Rice University, SHOUSHU GONG, Florida State University, DONNA SHENG, California State University, Northridge, DONNA SHENG TEAM — We investigate the Heisenberg model with chiral coupling on the triangular lattice by using Gutzwiller projected fermionic states and the variational Monte Carlo technique. As the chiral coupling grows, a gapped spin liquid with non-trivial magnetic fluxes and nonzero chiral order is stabilized. Furthermore, we calculate the topological Chern number and the degeneracy of the ground state, both of which lead us to identify this flux state as the chiral spin liquid with \( C = 1/2 \) fractionalized Chern number. Finally, we add spatial anisotropy in the model to study the effects for the chiral order.

3:42PM H5.00007 Valence-bond-solid domain walls in a 2D quantum magnet\(^1\), HUI SHAO, Beijing Computational Science Research Center, WENAN GUO, Beijing Normal University, ANDERS SANDVIK, Boston University — sing quantum Monte Carlo simulations, we study properties of domain walls in a square-lattice \( S=1/2 \) Heisenberg model with additional interactions which can drive the system from an antiferromagnetic (AFM) ground state to a valence-bond solid (VBS). We study the finite-size scaling of the domain-wall energy at the putative “deconfined” critical AFM-VBS point, which gives access to the critical exponent governing the domain-wall width. This length-scale diverges faster than the correlation length and also is related to the scale of spinon deconfinement. Our results show additional evidence of deconfined quantum criticality and are compatible with critical exponents extracted from finite-size scaling of other quantities.

\(^{1}\) NSFC Grant No. 11175018, NSF Grant No. DMR-1410126

3:54PM H5.00008 Field-induced magnetization jumps and quantum criticality in the 2D J-Q model\(^1\), ADAM IAIZZI, ANDERS SANDVIK, Boston Univ — The J-Q model is a ‘designer hamiltonian’ formed by adding a four spin ‘Q’ term to the standard antiferromagnetic \( S = 1/2 \) Heisenberg model. The Q term drives a quantum phase transition to a valence-bond solid (VBS) state: a non-magnetic state with a pattern of local singlets which breaks lattice symmetries. The elementary excitations of the VBS are triplons, i.e. gapped S=1 quasiparticles. There is considerable interest in the quantum phase transition between the Néel and VBS states as an example of deconfined quantum criticality. Near the phase boundary, triplons deconfine into pairs of bosonic spin-1/2 excitations known as spinons. Using exact diagonalization and the stochastic series expansion method, we study the 2D J-Q model in the presence of an external magnetic field. We use the field to force a nonzero density of magnetic excitations at \( T=0 \) and look for signatures of Bose-Einstein condensation of spinons. At higher magnetic fields, there is a jump in the induced magnetization caused by the onset of an effective attractive interaction between magnons on a ferromagnetic background. We characterize the first order quantum phase transition and determine the minimum value of the coupling ratio \( q \equiv Q/J \) required to produce this jump.

\(^{1}\) Funded by NSF DMR-1410126

4:06PM H5.00009 Chiral phase of a simple two-dimensional spin-1 quantum magnet\(^1\), OLEG STARYKH, University of Utah, ZHENTAO WANG, Rice University, CRISTIAN D. BATISTA, T-Division and CNLS, Los Alamos National Laboratory — We investigate the evolution of the ground state of a simple spin-1 antiferromagnet with easy-axis single-ion anisotropy \( D(S^2)^2 \), with \( D \leq 0 \), on a two-dimensional triangular lattice. The ground state changes from a quantum paramagnet one, at sufficiently large \( |D| \), to a magnetically ordered 120° one at small \( D \sim 0 \). Besides breaking the continuous \( U(1) \) symmetry of global spin rotations along the \( z \)-axis, this non-collinear ordering also breaks the discrete \( Z_2 \) chiral symmetry, which raises the possibility of an intermediate chiral spin liquid state, spontaneously breaking spatial inversion and mirror symmetries. We show that this interesting novel state indeed appears as a result of the condensation of bound \( \langle S_u^a S_m^b - S_u^b S_m^a \rangle \) pairs. The resulting Ising-like nematic state supports a regular pattern of spin currents on the bonds of the triangular lattice. It represents quantum analogue of the classical chiral spin liquid proposed by Villain in 1977.

\(^{1}\) Supported by NSF DMR-1507054
4:18PM H5.00010 Critical scaling corrections in 2D dimerized antiferromagnets\textsuperscript{1}, NUSEN MA, Boston University, Sun Yat-sen University, HUI SHAO, Beijing Computational Science Center, Boston University, DAO-XIN YAO, Sun Yat-sen University, ANDERS SANDVIK, Boston University — 2D dimerized antiferromagnets can be driven through a quantum-critical point by tuning the ratio $\eta = J_2/J_1$ between inter- and intra-dimer couplings. It has been shown [1] that the systems fall into two classes, depending on whether or not a certain bond-inversion symmetry is present in the dimer pattern. The two classes should have the same leading critical exponents but different expo- nents controlling the scaling corrections. We here investigate the scaling corre- cions using quantum Monte Carlo simulations for several different dimerization patterns. We will discuss systematic methods to extract the scaling corrections in the thermodynamic limit.


\textsuperscript{1}Supported by NSF DMR-1410126, NSF-11574404 1275279, and NBRPC-2012CB821400

4:30PM H5.00011 Novel spin liquid with a gapped Fermi surface in the kagome Kondo lattice model. GIA-WEI CHERN, University of Virginia, ZHENTAO WANG, Rice University, KIPTON BARROS, Los Alamos National Laboratory — Geometrical frustration in the Kagome lattice is well known as a source of many exotic phases. Here we study the under-screened Kondo-lattice model (KLM) on the kagome lattice at large electron-spin coupling, a regime in which perturbative approaches such as RKKY are invalid. We employ a recently developed linear-scaling, dynamical sampling method to study the KLM on large kagome lattices. At low temperatures, our simulations uncover an intriguing classical spin liquid phase with short-range correlations. Surprisingly, when $T \to 0$ a wide gap in the electronic spectrum can appear at any filling fraction between 0.5 to 0.63. We characterize this new spin liquid and discuss the origin of spontaneous gap formation.

4:42PM H5.00012 A tensor product state approach to spin-1/2 square J1-J2 antiferromagnetic Heisenberg model: evidence for deconfined quantum criticality\textsuperscript{1}. LING WANG, Beijing Computational Science Research Center, ZHENG-CHENG GU, Perimeter Institute, FRANK VERSTRAËTE, University of Vienna, XIANG-GANG WEN, Massachusetts Institute of Technology — We study this model using the cluster update algorithm for tensor product states (TPSs). We find that the ground state energies at finite sizes and in the thermodynamic limit are in good agreement with the exact diagonalization study. At the largest bond dimension available $D = 9$ and through finite size scaling of the magnetization order near the transition point, we accurately determine the critical point $J_2^c = 0.53(1)J_1$ and the critical exponents $\beta = 0.50(4)$. In the intermediate region we find a paramagnetic ground state without any static valence bond solid (VBS) order, supported by an exponentially decaying spin-spin correlation while a power law decaying dimer-dimer correlation. By fitting a universal scaling function for the spin-spin correlation we find the critical exponents $\nu = 0.68(3)$ and $\eta_2 = 0.34(6)$, which is very close to the observed critical exponents for deconfined quantum critical point (DQCP) in other systems. Thus our numerical results strongly suggest a Landau forbidden phase transition from Neel order to VBS order at $J_2^c = 0.53(1)J_1$.

\textsuperscript{1}This project is supported by the EU Strep project QUEVADIS, the ERC grant QUERG, and the FWF SFB grants FoQuS and ViCoM; and the Institute for Quantum Information and Matter

4:54PM H5.00013 Magnetic fluctuations and dynamics in the vicinity of quantum spin liquids: Cluster dynamical mean-field study of the Kitaev model. JUNKI YOSHITAKE, Dept. of Appl. Phys., Univ. of Tokyo, JOJI NASU, Dept. of Phys., Tokyo Inst. Tech., YUKITOSHI MOTOME, Dept. of Appl. Phys., Univ. of Tokyo — The quantum spin liquid, which does not show any long-range ordering down to the lowest temperature, has attracted broad interest as a new quantum state of matter. Since the ground state of the Kitaev model was shown to be a quantum spin liquid in two dimensions [1], there has been an explosion in both theoretical and experimental studies. Nevertheless, dynamical properties at finite temperatures remain a challenge, despite the relevance to analysis of recent experiments for Ir and Ru compounds. In this contribution, we address this problem by using the cluster dynamical mean-field approximation, which we newly develop on the basis of the Majorana fermion representation. Using the continuous-time quantum Monte Carlo method for the impurity solver, we calculate the magnetic susceptibility, dynamical structure factor, and relaxation time in the nuclear magnetic resonance. We find that these quantities show peculiar temperature dependences in the paramagnetic state when approaching the quantum spin liquid by decreasing temperature, which reflects the fractionalization of quantum spins. We will discuss the results while changing the anisotropy and sign (ferro/antiferro) of the exchange interactions, in comparison with experiments. [1] A. Kitaev, Ann. Phys. 321, 2 (2006).

5:06PM H5.00014 Protection against a spin gap in two-dimensional insulating antiferromagnets with a Chern-Simons term. IMAM MAKHFUZD, PIERRE PUJOL, LPT-IRSAMC and Univ. Paul Sabatier Toulouse France — We propose a mechanism for the protection against spin gaps in doped antiferromagnets. It requires the presence of a Chern-Simons term that can be generated by a coupling between spin and an insulator. We first demonstrate that in the presence of this term the vortex loop excitations of the spin sector behave as anyons with fractional statistics. To generate such a term, the fermions should have a massive Dirac spectrum coupled to the emergent spin field of the spin sector. The Dirac spectrum can be realized by a planar spin configuration arising as the lowest-energy configuration of a square lattice antiferromagnet Hamiltonian involving a Dzyaloshinskii- Moriya interaction. The mass is provided by a combination of dimerization and staggered chemical potential. We finally generated by a coupling between spin and an insulator. We first demonstrate that in the presence of this term the vortex loop excitations of the spin sector behave as anyons with fractional statistics. To generate such a term, the fermions should have a massive Dirac spectrum coupled to the emergent spin field of the spin sector. The Dirac spectrum can be realized by a planar spin configuration arising as the lowest-energy configuration of a square lattice antiferromagnet Hamiltonian involving a Dzyaloshinskii- Moriya interaction. The mass is provided by a combination of dimerization and staggered chemical potential. We finally

5:18PM H5.00015 Interaction-driven fractional quantum Hall state of hard-core bosons on kagome lattice at one-third filling\textsuperscript{1}. D. N. SHENG, California State University, Northridge, S. S. GONG, National High Magnetic Field Lab, W. ZHU, California State University, Northridge — There has been a growing interest in realizing topologically nontrivial states of matter in band insulators, where a quantum Hall effect can appear as an intrinsic property of the band structure. While the on-going progress is under way with a number of directions, the possibility of realizing novel interaction-generated topological phases, without the requirement of a nontrivial invariant encoded in single-particle wavefunction or band structure, can significantly extend the class of topological materials and is thus of great importance. Here, we show an interaction-driven topological phase emerging in an extended Bose-Hubbard model on kagome lattice, where the non-interacting band structure is topological trivial with zero Berry curvature in the Brillouin zone. By means of an unbiased state-of-the-art density-matrix renormalization group technique, we identify that the groundstate in a broad phase emerging in an extended Bose-Hubbard model on kagome lattice, where the non-interacting band structure is topological trivial with zero Berry curvature possibility of realizing novel interaction-generated topological phases, without the requirement of a nontrivial invariant encoded in single-particle wavefunction

\textsuperscript{1}This research is supported by the DOE grants No. DE-FG02-06ER46305, and the NSF grant No. DMR-1408560

Tuesday, March 15, 2016 2:30PM - 5:30PM
Session H6 GMAG DMP: Perpendicular Anisotropy Multi-layers and Hard Magnets 302 - Mazin Almqablah, Western Digital Corporation
2:30PM H6.00001 Electric-field-induced modification in Dzyaloshinskii-Moriya interaction of Co monolayer on Pt(111) , KOHJI NAKAMURA, TORU AKIYAMA, TOMONORI ITO, Mie University, TERUO ONO, Kyoto University, MICHAEL WEINERT, University of Wisconsin - Milwaukee — Magnetism induced by an external electric field (E-field) has received much attention as a potential approach for controlling magnetism at the nano-scale with the promise of ultra-low energy power consumption. Here, the E-field-induced modification of the Dzyaloshinskii-Moriya interaction (DMI) for a prototypical transition-metal thin layer of a Co monolayer on Pt(111) is investigated by first-principles calculations by using the full-potential linearized augmented plane wave method that treats spin-spiral structures in an E-field. With inclusion of the spin-orbit coupling (SOC) by the second variational method for commensurate spin-spiral structures, the DMI constants were estimated from an asymmetric contribution potential approach for controlling magnetism at the nano-scale with the promise of ultra-low energy power consumption. Here, the multilayers/PMN-PT(011) heterostructures composites. Work supported by DOE BES- FG02-04ERU4612.

2:42PM H6.00002 Random Field effects in perpendicular-anisotropy multilayer films , JIAN XU, University of Chicago, DANIEL SILEVITCH, THOMAS ROSENBAUM, California Institute of Technology — With the application of a magnetic field transverse to the magnetic easy axis, randomly-distributed 3D collections of dipole-coupled Ising spins form a realization of the Random-Field Ising Model. Tuning the strength of the site-specific random field, and hence the disorder, via the applied transverse field regulates the domain reversal energetics and hence the macroscopic hysteresis loop. We extend this approach to two dimensions, using sputtered Perpendicular Magnetic Anisotropy (PMA) Co/Pt multilayer thin films. We characterize the coercive fields and hysteresis loops at a series of temperatures and transverse fields.

2:54PM H6.00003 Polarization dependent soft x-ray spectro-microscopy of local spin structures , MACCALLUM ROBERTSON, Center for X-Ray Optics, LBNL, CHRISTOPHER AGOSTINO, National Center for Electron Microscopy, LBNL, MI-YOUNG IM, Center for X-Ray Optics, LBNL, SERGIO MONTOYA, ERIC FULLERTON, Center for Magnetic Recording Research, UCSD, PETER FISCHER, Materials Sciences Division, LBNL. Quantitative information about element-specific contributions to local magnetic spin and orbital moments is readily available by XMCD spectroscopy and images of magnetic domain patterns with a few tens of nanometer spatial resolution. We show that the x-ray spectroscopic analysis of x-ray microscopy images provides quantitative information about local spin structures. We have investigated two prototypical multilayered PMA film systems prepared by sputtering, specifically (Co 0.3 nm/Pt 0.5 nm)x30 and (Fe 0.7nm/Gd 0.4nm)x100 systems. A spectroscopic sequence of full-field magnetic transmission soft x-ray microscopy (MTXM) images covering about 8mm field-of-views with a spatial resolution of about 20nm were recorded across the Co and Fe edges, resp. To modulate the magnetic contrast, two sets of images were obtained with left and right circular polarization. Standard XMCD spectroscopy analysis procedures were applied to retrieve the local spectroscopic behavior. We observe a decrease of the L3/L2 ratio when approaching the domain walls, indicating a non-uniform spin configuration along the vertical profile of a domain, which we will discuss in view of both systems’ magnetic anisotropy. Supported by DOE BES- FG02-04ER4612.

3:06PM H6.00004 Nanoparticulate CoPt Thin Films , YASAMAN BAREKATAIN, GEORGE HADJIPANAYIS, Department of Physics and Astronomy, University of Delaware, MAGNETICS BLAB TEAM — Equiatomic FePt and CoPt alloys are very attractive for application in high density recording media because of the high magnetocrystalline anisotropy K of their fct (111) structure with values exceeding 2MJ/m3. The aim of this study is to fabricate a nanoparticulate CoPt film consisting of CoPt nanoparticles embedded in a matrix. To obtain this we have used co-sputtering of CoPt with different materials M= BN, C, Cu and SiO2. Our first experiments were done on CoPt films with thickness of 200 nm. The as-sputtered films had the fcc structure and a coercivity of 150 Oe. Annealing at 700 °C for 30 min led to an increase in coercivity to 4 kOe. Optimization studies are under way to find the optimum sputtering conditions to obtain a fully tetragonal film with the highest value of coercivity which can then be used in the nanoparticulate composites. Work supported by DOE BES- FG02-04ER4612.

3:18PM H6.00005 Microscopic evidence of strain-mediated magnetoelectric coupling in Co/Pt multilayers/PMN-PT(011) heterostructures , YING SUN, Tsinghua University, WENBO WANG, WEIDA WU, Rutgers University, XIAOLI ZHENG, JIANWANG CAI, Institute of Physics, Chinese Academy of Sciences, YONGGANG ZHAO, Tsinghua University, MING LIU, Xian Jiaotong University — A promising way to control magnetization(M) via an electric field(E-field) is using magnetoelectric(ME) effect in FM/FE heterostructures. We use magnetic(electric) force microscopy(M(e)FM) to study the strain-mediated E-field modulation of M in (Co/Pt)n with perpendicular magnetic anisotropy(PMA) or in-plane anisotropy on PMN-PT(011) substrates. MFM were performed on (Co/Pt)n with an DC E-field applied to PMN-PT. In MeFM, we superimpose an AC modulation on a DC one and utilize lock-in technique to detect weak ME effect. For (Co/Pt)n, with PMA, MFM images show stripe domains with no obvious changes at varied DC E-fields. However, MeFM shows interesting structures and the image contrast reverses sign at opposite strain slopes of the PMN-PT substrate. For sample with in-plane anisotropy, both MFM and MeFM images show dipole-like domains. Interestingly, the MeFM image contrast reverses sign at opposite strain slopes of the substrate. The sign reversal of MeFM contrast indicates that features revealed by MeFM are intrinsic local ME effect. Our MeFM data are consistent with the ferromagnetic resonance results showing that strain-induced anisotropy change will cause part of M switching to the in-plane direction. Possible scenarios will be discussed.

3:30PM H6.00006 Effect of perpendicular magnetic anisotropy and Dzyaloshinskii-Moriya interaction on the enhancement of domain wall creep velocity in Pt/Co thin films by piezolectric strain , PHILIPPA M. SHEPLEY, GAVIN BURNELL, THOMAS A. MOORE, University of Leeds — We investigate piezoelastic strain control of domain wall creep motion in perpendicularly magnetized Pt/Co thin films. Domain wall (DW) motion has potential applications in data storage and spintronics, where the use of voltages rather than magnetic fields to control magnetization reversal could reduce power consumption. Materials with perpendicular magnetic anisotropy (PMA) are of particular interest due to their narrow domain walls and potential for efficient current-induced DW motion. Sputtered Ta/Pt/Co(1)/X films (X= 0.7-8.10 nm, X= Pt, Ir/Pt or Ir) on thin glass substrates were bonded to biaxial piezolectric transducers, to which 150V was applied to produce a tensile out-of-plane strain of 9x10^-4. This reduced the PMA by 10k/J/m3 and increased the DW creep velocity by up to 90%. DW energy can be calculated from the PMA and the Dzyaloshinskii-Moriya interaction (DMI) field. DW creep measurements of DMI field found no change with strain. The change in DW velocity with strain is linear with the change in DW energy for Pt/Co DWs with a mixed Bloch-Neel structure. Pt/Co/Pt films with higher DW velocity changes were found to have purely Bloch DWs. We conclude that the velocity of Bloch DWs is more sensitive to strain-induced changes than that of Bloch-Neel DWs.

1 funded by EPSRC.
3:42PM H6.00007 Thermal Stability of Magnetic States in Circular Thin-Film Nanomagnets with Large Perpendicular Magnetic Anisotropy1, GABRIEL CHAVES-O’FLYNN, New York Univ NYU — The scaling of the energy barrier to magnetization reversal in thin-film nanomagnets with perpendicular magnetization as a function of their lateral size is of great interest and importance for high-density magnetic random access memory devices. Experimental studies of such elements show either a quadratic or linear dependence of the energy barrier on element diameter. I will discuss a theoretical model we developed to determine the micromagnetic configurations that set the energy barrier for thermally activated reversal of a thin disk with perpendicular magnetic anisotropy as a function of disk diameter. We find a critical length in the problem that is set by the exchange and effective perpendicular magnetic anisotropy energies, with the latter including the size dependence of the demagnetization energy. For diameters smaller than this critical length, the reversal occurs by nearly coherent magnetization rotation and the energy barrier scales with the square of the diameter normalized to the critical length (for fixed film thickness), while for larger diameters, the transition state has a domain wall, and the energy barrier depends linearly on the normalized diameter. Simple analytic expressions are derived for these two limiting cases and verified using full micromagnetic simulations with the string method. Further, the effect of an applied field is considered and shown to lead to a plateau in the energy barrier versus diameter dependence at large diameters. Based on these finding I discuss the prospects and material challenges in the scaling of magnetic memory devices based on thin films with strong perpendicular magnetic anisotropy.

1In collaboration with G. Wolf, J. Z. Sun and A. D. Kent. Supported by NSF-DMR-1309202 and in part by Spin Transfer Technologies Inc. and the Nanoelectronics Research Initiative through the Institute for Nanoelectronics Discovery and Exploration.


4:18PM H6.00008 Large electric-field control of perpendicular magnetic anisotropy in strained [Co/Ni] / PZT heterostructures, DANIEL GOPMAN, CINDI DENNIS, P. J. CHEN, NIST - Natl Inst of Stds & Tech, YURY IUNIN, Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow Region, Russia, ROBERT SHULL, NIST - Natl Inst of Stds & Tech — We present [Co/Ni] / PZT heterostructures with Large Perpendicular Magnetic Anisotropy. Chemical-mechanical polishing was used to reduce the roughness of PZT plates to below 2 nm rms, enabling optimal magnetoelectric coupling via the direct interface between PZT and sputtered Co/Ni films with large PMA ($K_{eff} = (95 \pm 5) \text{kJ/m}^3$). We grew the following layer stack: Ta(3)/Pt(2)/[Co(0.15)/Ni(0.6)]$_{5}$/Co(0.15)/Pt(2)/Ta(3); numbers in parentheses indicate thicknesses in nm. Applied electric fields up to $-2 \text{MV/m}$ to the PZT generated 0.05% in-plane compression in the Co/Ni multilayer, enabling a large electric-field reduction of the PMA ($\Delta K_{eff} > 10^4 \text{J/m}^3$) and of the coercive field (35%). Our results demonstrate that: (i) heterostructures combining PZT and [Co/Ni] exhibit larger PMA ($K_{eff} > 10^4 \text{J/m}^3$) than previous magnetoelectric heterostructures based on Co/Pt and CoFeB, enabling thermally stable hybrid magnetoelectric/spintronic devices only tens of nm in diameter and (ii) electric-field control of the PMA is promising for more energy efficient switching of spintronic devices.

4:30PM H6.00009 Properties of easy-plane/ perpendicular magnetic anisotropy bilayers with varied interlayer exchange coupling1, LORENZO FALLARINO2, VOLKER SLUKA, Department of Physics, New York University, New York, NY 10003, USA., BARTEK KARDASZ, MUSTAFA PINARBASI, Spin-Transfer Technologies Inc., Freemont, CA 94538, USA., ANDREW D. KENT, Department of Physics, New York University, New York, NY 10003, USA. — We explore the possibility of an easy-cone ground state in coupled easy plane/easy axis magnetic bilayers. The samples consist of a Co/Ni multilayer with perpendicular magnetic anisotropy and a CoFe layer with easy-plane anisotropy separated by a variable thickness Ru layer. Using ferromagnetic resonance spectroscopy, we characterize the magnetic behavior of the coupled thin films for different Ru thicknesses by determining the resonance fields for both the acoustic and optical FMR modes. In particular, we observe a gap in the resonance field opening up between the two modes in angular-dependent FMR, which is direct evidence for the presence of interlayer coupling. Quantitative comparisons with a theoretical model indicate that by varying the Ru thickness the coupling strength can be tuned continuously from ferromagnetic to the anti-ferromagnetic. These results are consistent with a canted magnetic ground state in zero field, a state of interest for applications in spin-torque devices, such as current tunable spin-torque oscillators.

1Supported by NSF-DMR1309202 and Spin-Transfer Technologies Inc.

2Second affiliation: CIC nanoGUNE, 20018 Donostia-San Sebastian, Basque Country, Spain.

4:42PM H6.00010 Giant magnetic anisotropy of Co, Ru, and Os adatoms on MgO (001) surface, HONGBO WANG, XUEDONG OU, FENGREN FAN, ZHENWEI LI, HUA WU, Fudan Univ — Large magnetic anisotropy energy (MAE) is desirable and critical for nanoscale magnetic devices. Here, using ligand-field level diagrams and density functional calculations, we well explain the very recent discovery [L. G. Rau et al., Science 344, 988 (2014)] that individual Co adatom on MgO (001) surface has a large MAE of more than 60 meV. More importantly, we predict that a giant MAE up to 110 meV could be realized for Ru adatoms on MgO (001), and even more for the Os adatoms (208 meV). This is a joint effect of the special ligand field, orbital multiplet, and significant spin-orbit interaction, in the intermediate-spin state of the Ru or Os adatoms on top of the surface oxygens. The giant MAE could provide a route to atomic scale memory.

4:54PM H6.00011 ABSTRACT WITHDRAWN

5:06PM H6.00012 Perpendicular Magnetic Anisotropy of Tb/Fe and Gd/Fe Multilayers Studied with Torque Magnetometer, ATAUR CHOWDHURY, Physics Department, UAF — Perpendicular magnetic anisotropy (PMA) of multilayers critically depend on the magnetic and structural ordering of the interface. To study the effect of interface on PMA, Tb/Fe and Gd/Fe multilayers with varying Fe (0.8-9.0 nm) and Gd (0.5-2.8 nm) or Tb (0.3-6.3 nm) layer thicknesses were fabricated by planar magnetron sputtering. The magnetometer results of spin orientation clearly reveals that samples with Gd or Tb layer thickness of more than 1.2 nm display no PMA, regardless of the Fe layer thickness. Tb/Fe and Gd/Fe multilayers with thin (<1.2 nm) Tb or Fe layers display large PMA, but no PMA is observed when the Fe layer thickness is increased to 4.0 nm and higher. The bulk magnetization and anisotropy energy constant of the samples are found to increase with increasing Fe layer thickness. Torque measurement also reveals that there are two distinctly different axes of spin alignment at different energy. Tb/Fe and Gd/Fe multilayers with similar composition reveal similar magnetic and structural characteristics, and it may imply that single-ion-anisotropy of rare-earth elements, which is quite large for Tb ions and very small for Gd ions, may not be the dominating cause of PMA in Tb/Fe and Gd/Fe multilayers. A detailed explanation of the results will be provided based on exchange interaction at the interface.

3:06PM H12.0002 Novel spintronic devices for memory and logic: prospects and challenges for room temperature all spin computing. , JIAN-PING WANG, Electrical and Computer Engineering Dept., Univ. of Minnesota — An energy efficient memory and logic device for the post-CMOS era has been the goal of a variety of research fields. The limits of scaling, which we expect to be reached by the year 2025, demand that future advances in computational power will not be realized from ever-shrinking device sizes, but rather by innovative designs and new materials and physics. Magneto-resistive based devices are a promising candidate for future integrated magnetic computation because of its unique non-volatility and functionalities. The application of perpendicular magnetic anisotropy for potential STT-RAM application was demonstrated and later has been intensively investigated by both academia and industry groups, but there is no clear path way how scaling will eventually work for both memory and logic applications. One of main reasons is that there is no demonstrated magnetic structure that could lead to a scaling scheme down to sub 10 nm. Another challenge for the usage of magneto-resistive based devices for logic application is its available switching speed and writing energy. Although a good progress has been made to demonstrate the fast switching of a thermally stable magnetic tunnel junction (MTJ) down to 165 ps, it is still several times slower than its CMOS counterpart. In this talk, I will review the recent progress by my research group and my C-SPIN colleagues, then discuss the opportunities, challenges and some potential path ways for magneto-resistive based devices for memory and logic applications and their integration for room temperature all spin computing system.

3:42PM H12.0003 In Search of New Spintronic Devices Using the Modular Approach1, KEREM YUNUS CAMSARI, Purdue University — There has been enormous progress in the last two decades, effectively combining spintronics and magnetics into a powerful force that is shaping the field of memory devices. At the same time, new materials and phenomena continue to be discovered at a very fast pace, providing an ever-increasing set of building blocks that could be exploited in designing functional devices of the future. Through careful benchmarking against available theory and experiment we recently established a set of “elemental” circuit modules representing a diverse range of materials and phenomena [1], which are continually updated [2]. We will first show how these elemental modules can be integrated seamlessly to model both spintronic transport and nanomechanics, starting from basic spin-valves and extending to complex experimental structures. We will then show how this framework can be used to design transistor-like spintronic devices to provide novel functionality compared to a standard complementary metal oxide semiconductor (CMOS) device. This approach allows us to incorporate the detailed physics of diverse sophisticated phenomena accurately into detailed circuit-level simulations to provide reliable estimates for the switching energy and delay of carefully designed devices.

4:18PM H12.0004 Spin Orbit Transfer Engineering for beyond Spin Transfer Torque memory . , KANG L. WANG, Electrical Engineering Dept., Univ. of California, Los Angeles, CA 90095 — Spin transfer torque memory uses electron current to transfer the spin torque of electrons to switch a magnetic free layer. This talk will address an alternative approach to energy efficient non-volatile spintronics through engineering of spin orbit interaction (SOC) and the use of spin orbit torque (SOT) by the use of electric field to improve further the energy efficiency of switching. I will first discuss the engineering of interface SOC, which results in the electric field control of magnetic moment or magneto-electric (ME) effect. Magnetic memory bits based on this ME effect, referred to as magneto-electric RAM (MeRAM), is shown to have orders of magnitude lower energy dissipation compared with spin transfer torque memory (STTRAM). Likewise, interests in spin Hall as a result of SOC have led to many advances. Recent demonstrations of magnetization switching induced by in-plane current in heavy metal/ferromagnetic heterostructures has been shown to arise from the large SOC. The large SOC is also shown to give rise to the large SOT. Due to the presence of an intrinsic extraordinarily strong SOC and spin-momentum lock, topological insulators (TIs) are expected to be promising candidates for exploring spin-orbit torque (SOT)-related physics. In particular, we will show the magnetization switching in a chromium-doped magnetic TI bilayer heterostructure by charge current. A giant SOT of more than three orders of magnitude larger than those reported in heavy metals is also obtained. This large SOT is shown to come from the spin-momentum locked surface states of TI, which may further lead to innovative low power applications. I will also describe other related physics of SOC at the interface of anti-ferromagnetism/ferromagnetic structure and show the control exchange bias by electric field for high speed memory switching.

The work was in part supported by ERFC-SHINES, NSF, ARO, TANMS, and FAME
Using magnetotransport data and calculations we extract spin parameters in the MoS$_2$ spin valve devices. These findings can open new avenues for exploring spin logic applications. We observe a magnetoresistance effect over a large temperature range up to 300 K and investigate the temperature and bias dependence behavior. We acknowledge the support of the NSF via grant NSF DMR-1506707.
4:06PM H18.00007 Novel valley depolarization dynamics and valley Hall effect of exciton in mono- and bilayer MoS\textsubscript{2}, T. YU, M. W. WU, University of Science and Technology of China, Physics Department — We investigate the valley depolarization dynamics and valley Hall effect of exciton in monolayer and bilayer MoS\textsubscript{2}. For the valley depolarization dynamics, in the monolayer MoS\textsubscript{2}, it is found that in the strong scattering regime, the conventional motional narrowing picture is no longer valid, and a novel valley depolarization channel is opened. For the valley Hall effect of exciton, in both the monolayer and bilayer MoS\textsubscript{2}, with the exciton equally pumped in the K and K’ valleys, the system can evolve into the equilibrium state with the valley polarization parallel to the effective magnetic field due to the exchange interaction. With the drift of this equilibrium state by applied uniaxial strain, the momentum-dependent valley photoluminescence polarization is induced by the exchange interaction, which leads to the valley/photon induced valley Hall current. Specifically, the disorder strength dependence of the valley Hall conductivity is revealed. In the strong scattering regime, the valley Hall conductivity decreases with the increase of the disorder strength; whereas in the weak scattering regime, it saturates to a constant, which can be much larger than the one in Fermi system due to the absence of the Pauli blocking.

4:18PM H18.00008 Spin-orbit coupling and spin relaxation in phosphorene, MARCIN KURPAS, MARTIN GMITRA, JAROSLAV FABIAN, Physics Department, University of Regensburg, 93040 Regensburg, Germany — We employ first principles density functional theory calculations to study intrinsic and extrinsic spin-orbit coupling in monolayer phosphorene. We also extract the spin-mixing amplitudes of the Bloch wave functions to give realistic estimates of the Elliott-Yafet spin relaxation rate. The most remarkable result is the striking anisotropy in both spin-orbit coupling and spin relaxation rates, which could be tested experimentally in spin injection experiments. We also identify spin hot spots in the electronic structure of phosphorene at accidental bands anticrossings. We compare the Elliott-Yafet with Dyakonov-Perel spin relaxation times, obtained from extrinsic couplings in an applied electric field. We also compare the results in phosphorene with those of black phosphorous. This work is supported by the DFG SPP 1538, SFB 689, and by the EU Seventh Framework Programme under Grant Agreement No. 604391 Graphene Flagship.

4:30PM H18.00009 Probing Hole Spins in an InAs/GaAs Quantum Dot Molecule subject to Lateral Electric Fields, XIANGYU MA, Univ of Delaware, GARNETT BRYANT, National Institute of Standards and Technology, MATTHEW DOTY, Univ of Delaware — Quantum dot molecules (QDMs) are structures in which coherent interactions between two or more adjacent quantum dots (QDs) can lead to unique, tunable electronic and spin properties. We explore computationally spin-mixing interactions in the molecular states of single holes confined in vertically-stacked InAs/GaAs self-assembled QDMs. We consider the spin properties of the hole states subject to lateral electric fields both parallel and perpendicular to the molecular stacking axis. We compute the energies of the QDM hole states under various electric and magnetic fields with a combination of full tight binding atomic calculations and approximate atomistic results using eigenstates found at particular fields as a basis to extrapolate to other fields. We observe a relatively large Stark shift in hole states with the application of lateral electric fields, as well as a quenching of the Zeeman splitting. Most importantly, we observe that lateral electric fields induce hole spin mixing with a magnitude that increases with increasing lateral electric field over a moderate range. These results suggest that applied lateral electric fields provide an opportunity to fine-tune and manipulate, in situ, the energy levels and spin properties of single holes confined in QDMs.

4:42PM H18.00010 Spin Dynamics of Tellurium Isoelectricenter Centers Bound Excitons in ZnSe-Te Nanostructures1, VASILIOS DELIGIANNAKIS, The City College of New York of CUNY, SIDDHARTH DHOMKAR, Queens College of CUNY, DANIELA PAGLIERO, The City College of New York of CUNY, HAOJIE JI, Queens College of CUNY, MARIA TAMARGO, The City College of New York of CUNY, IGOR KUSKOVSKY, Queens College of CUNY, CARLOS MERILES, The City College of New York of CUNY — Three-dimensionally confined structures such as quantum dots (QDs) have been of considerable interest due to their ability to closely imitate isolated atoms on mesoscopic length scales. Recently, single impurity states in bulk semiconductors have also attracted attention due to their ability to optimally address quantum states. Here we show results pertaining to the optical and spin properties of Te isoelectronic centers present in type-II sub-monolayer QDs within a ZnSe matrix. Time resolved Kerr rotation (TRKR) measurements were performed using a degenerate pump-and-probe setup. Attempts to probe the QDs by direct optical excitation did not show any results most likely due to the weak oscillator strength of this transition resulting from their type-II nature. Centering the pump and probe pulses around the band edge of ZnSe and performing TRKR vs energy measurements we were able to address the spin dynamics of Te-isoelectronic centers present in the spacer layer. Results show that the *T*2 lifetime experiences a bi-exponential decay and persists up to 1 ns. Further measurements will be done on samples with varying Te concentration, as well as a function of the applied magnetic-field to understand the spin properties of this defect.

5:06PM H18.00011 Modeling of magnetic properties in (Zn,Mn)Te quantum dots1, XIANGYU MA, Univ of Delaware, JAMES PIENTKA, St. Bonaventure University, B. BARMAN, L. SCHWEIDENBACK, A.H. RUSS, Y. TSAI, J.R. MURPHY, A.N. CARTWRIGHT, I. ZUTIC, B.D. MCCOMBE, A. PETROU, SUNY Buffalo, W-C. CHOU, W. C. FAN, National Chiao Tung University, I.R. SELLERS, University of Oklahoma, A.G. PETUKHOV, R. OSZWALDOWSKI, South Dakota School of Mines and Technology — Magnetic polarons in (Zn,Mn)Te quantum dots (QD) show unconventional behavior [1]. These structures exhibit a small red shift of the photoluminescence peak energy in the presence of a magnetic field and they also have a weak dependence of the polaron energy on the external magnetic field. We attribute these properties to a large magnetic field that is proportional to the heavy holes spin density [2]. We have calculated $B_{el}$ using the QD diameter and height as adjustable parameters. Assuming hole localization, this calculation yields values of $B_{el} > 20 T$. The assumption that the hole localization diameter can be smaller than the QD diameter is justified due to alloy and spin disorder scattering [3]. Using the magnetic polaron free energy, we calculate $E_{S+}$ as function of $T$ and $B$ for a variety of $B_{el}$ values. To get a weak dependence of $E_{S+}$ on $T$ and $B$, we used $B_{el}$ an order of magnitude higher than $T$. [1] B. B. Barmann et al., Phys. Rev. B 92, 035430 (2015). [2] J. M. Pientka et al., Phys. Rev. B 92, 155402 (2015). [3] K. V. Kavokin et al., Phys. Rev. B 60, 16499 (1999).

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1U.S. Department of Energy Award No. DE-SC003739

2Supported by DOE DE-SC00004890

3This work was supported by U.S. DOE BES, Award DE-SC00004890, NSF DMR-1305770 and U.S. ONR N000141310754.
5:18PM H18.00013 Gate-tuned spin to charge conversion in semiconducting single-walled carbon nanotubes. EL SHIGEMATSU, HIROSHI NAGANO, Kyoto Univ, SERGEY DUSHENKO, Osaka Univ, YUCHIRO ANDO, Kyoto Univ, TETSUYA TSUDA, SISUUMI KUBABATA, Osaka Univ, TAIHII TAKENOUCHI, Waseda Univ, TAKESHI TANAKA, HIROMICHI KATAURA, AIKU, TERUYA SHIINO, MASASHI SHIRAI,SHI, Kyot Univ — Interconversion of spin and charge current is a hot topic in the molecular spintronics. It was achieved for the first time in a conducting conjugated polymer 1, and shortly followed by spin-charge conversion in graphene. However, control over carrier type has not been shown yet. In this study we focused on single-walled carbon nanotubes (SWNT). Spin injection into semiconductor from metal ferromagnet is challenging due to the presence of Schottky barrier and conductance mismatch problem. To bypass it, we used ionic liquid electric gate and ferrimagnetic insulator. We prepared SWNT layer on top of ferromagnetic iron garnet substrate and observed spin-charge conversion in metallic SWNT. As for a semiconductor SWNT, we applied a top gate using ionic liquid. The drain-source current vs. gate voltage dependence showed tuning of the Fermi level and changing of carrier type. Under gate voltage application we measured electromotive force induced by spin pumping. Detected voltage changed its sign together with carrier type. This is first evidence of spin-charge conversion in carbon nanotubes 2.

2 E. Shigematsu et al., submitted.

Tuesday, March 15, 2016 2:30PM - 5:18PM —
Session H19 GMAG DMP FIAP: Spin-Order and Half-Metallicity of Magnetic Thin Films 318-Chiara Ciccarelli, University of Cambridge

2:30PM H19.00001 Influence of interstitial Mn on spin order and dynamics in the room-temperature ferromagnet Mn$_{1+\delta}$Sb. ALICE TAYLOR, Oak Ridge National Laboratory — Mn$_{1+\delta}$Sb is a well-known, high Curie temperature, ferromagnetic metal. It has particular importance because it, and closely related MnBi, show promise as alternatives to rare-earth-containing permanent magnets, and as magnet-optic media. To exploit these materials useful properties, it is desirable to tune and optimize the magnetic properties 1. To achieve this, the magnetic interactions, and the effects of doping and defects must be understood. In Mn$_{1+\delta}$Sb the magnetic order is highly sensitive to the interstitial Mn ion content, $\delta$, suggesting a route to tune the properties 2. However, detailed theoretical and experimental investigations of the effect of the interstitial ion, Mn$_2$, have been lacking, probably due to a prevailing view in the literature that the Mn$_2$ site is nonmagnetic 3,4. We examine the magnetic state of Mn$_2$, and its influence on the magnetic properties of Mn$_{1+\delta}$Sb. We use a combination of neutron scattering techniques alongside detailed calculations to show that the Mn$_2$ site is in-fact magnetic, and has a dramatic impact on the magnetic dynamics in Mn$_{1+\delta}$Sb. An unusual, broad, intense feature is identified in the magnetic dynamics which cannot be explained by the long-range symmetry of the material. This reveals an area in which current theoretical/modeling techniques limit our ability to understand the magnetic excitations revealed by neutron scattering. This investigation elucidates important aspects of the behavior of Mn$_{1+\delta}$Sb, whilst highlighting requirements for future research to understand the major influence of the interstitial ion on the magnetic properties. 1 A. E. Taylor et al., Phys. Rev. B, 91, 224418 (2015). [2] T. Okita and Y. Makino, J. Phys. Soc. Jpn. 25, 120 (1968). [3] Y. Yamaguchi et al., J. Phys. Soc. Jpn. 45, 846 (1978). [4] W. Reimers et al., J. Phys. Chem. Solids 44, 195 (1983).

3:06PM H19.00002 Magnetic Structure and Dynamics in the Itinerant High-Temperature Ferromagnet MnBi. TRAVIS WILLIAMS, ALICE TAYLOR, ANDREW CHRISTIANSON, STEVEN HAHN, RANDY FISHMAN, MICHAEL MCGUIRE, BRIAN SALES, MARK LUMSDEN, Oak Ridge National Laboratory — The high-temperature ferromagnet MnBi has been receiving much attention as a rare-earth-free permanent magnet to replace more costly rare-earth-containing magnets in applications above room temperature. This is due to MnBi containing earth-free permanent magnet materials, and as magneto-optic media. The samples show very small saturation magnetization, 0.3 emu/g, at room temperature under high magnetic field, 30 kOe. Above room temperature, the magnetization increases with increasing temperature undergoing a magnetic transition at 560°C, similar to an antiferromagnetic-to-paramagnetic transition. The prospect of this material for spintronic applications will be discussed.

3:30PM H19.00003 Electronic and magnetic properties of ferromagnetic interfaces for spin injection applications: metallic and semiconducting cases 1. E. A. ALBANESI, IFIS-CONICET-UNL and FI-UNER, Santa Fe, Argentina, L. MAKINISTIAN, INFAP-CONICET-UNSL, San Luis, Argentina, C. I. ZANDALAZINI, IFIS-CONICET-UNL, Santa Fe, Argentina, R. M. OSZWALDOWSKI, SDSMT, Rapid City, SD, A. G. PETUKHOV, NASA Ames Research Center, Moffett Field, CA 94035 — Robust and reliable operation of spintronic devices is determined by the quality of interfaces between magnetic and nonmagnetic materials. In order to get insights in the tuning of the magnetic properties of such interfaces we present comparative studies of two important cases relevant to applications in spin injection devices. We performed ab-initio calculations of the electronic and magnetic properties, of the ferromagnetic metallic interface of Co$_2$MnAl and gold, and of the interfaces of non-and of magnetic II-VI semiconductors and their quantum wells. In the case of the Heusler alloy Co$_2$MnAl-Au, two structural models are implemented: one with the ferromagnet slab terminated in a pure coherent plane (Co$_2$-t), and the other with it terminated with a plane of MnAl (MnAl-t). The electric in-plane and averaged potential are resolved and analyzed layer by layer through the interface. We predict that both terminations are to be expected to display sensibly different spin injection performances. On the example of magnetic quantum wells of ZnSe/Zn$_{1-x}$Mn$_{1+x}$/Te/ZnSe, we study the variations in the spin resolved density of states, and the potential energy along the junctions.

1We acknowledge financial support from SDSMT (USA), and CONICET, FIUNER, of Argentina

3:30PM H19.00004 Structural and magnetic properties of a prospective spin gapless semiconductor MnCrVAl$^1$. Y HUH, S GILBERT, P KHAREL, Department of Physics, South Dakota State University, Brookings, SD 57007, Y JIN, Department of Physics and Astronomy, University of Nebraska, Lincoln, NE 68588, P LUKASHEV, Department of Physics, University of Northern Iowa, Cedar Falls, IA 50614, DH YOULL, J SELLMYER, Nebraska Center for Materials and Nanoscience, University of Nebraska, Lincoln, NE 68588 — Recently a new class of material, spin gapless semiconductors (SGS), has attracted much attention because of their potential for spintronic devices. We have synthesized a Heusler compound, MnCrVAl, which is theoretically predicted to exhibit SGS by arc melting, rapid quenching and thermal annealing. First principles calculations are employed to describe its structural, electronic and magnetic properties. X-ray diffraction indicates that the rapidly quenched samples crystallize in the disordered cubic structure. The crystal structure is stable against heat treatment up to 650°C. The samples show very small saturation magnetization, 0.3 emu/g, at room temperature under high magnetic field, 30 kOe. Above room temperature, the magnetization increases with increasing temperature undergoing a magnetic transition at 560°C, similar to an antiferromagnetic-to-paramagnetic transition. The prospect of this material for spintronic applications will be discussed.

1This research is supported by SDSL Academic/Scholarly Excellence Fund, and Research/Scholarship Support Fund. Research at UNL is supported by DOE (DE-FG02-04ER46152, synthesis, characterization), NSF (ECCS-1542182, facilities), and NRI.
3:42PM H19.00005 Enhancement of ferromagnetism by Ag doping in Ni-Mn-In-Ag Heusler alloys. SUDIP PANDEY, ABDEL QUETZ, ANIL ARYAL, IGOR DUBENKO, DIPANJAN MAZUMDAR, Southern Illinois University, SHANE STADLER, Louisiana State University, NAUSHAD ALI, Southern Illinois University — The effect of Ag on the structural, magnetic, electronic, and thermoelectric properties of Ni$_{100-x}$Mn$_x$In$_{1-x}$Ag$_x$ ($x=0$, 0.1, 0.2, 0.5, and 1) Heusler alloys was studied. The magnitude of the magnetization change at martensitic transition temperature (T$_M$) decreases with increasing Ag concentration A smaller entropy change ($\Delta S_M$) for the alloys with higher Ag concentration is observed. A shift of T$_M$ by about 25 K to a higher temperature was detected for P = 6.6 kbar with respect to ambient pressure. Large drop of resistivity is observed with the increase of Ag concentration. The magnetoresistance is dramatically suppressed with increasing Ag concentration due to the weakening of the antiferromagnetic interactions in the martensitic phase. The experimental results demonstrate that Ag substitution in Ni$_{100-x}$Mn$_x$In$_{1-x}$Ag$_x$ Heusler alloys suppresses the AFM interactions and enhances the FM interactions in the alloys. The possible mechanisms responsible for the observed behavior are discussed. Acknowledgement: This work was supported by the Office of Basic Energy Sciences, Material Science Division of the U.S. Department of Energy (DOE Grant No. DE-FG02-06ER46291 and DE-FG02-13ER46946).

3:54PM H19.00006 Probing the magnetic structure of Co$_2$Fe$_3$Mn$_{1-x}$Si thin films by XAS/XMCD, ADAM J. HAUSER, JOSHUA PHILLIPS, Department of Physics, The University of Alabama, MIHİR PENDHARKAR, SAJULLI J. PATEL, CHRIST J. PALMSTROM, Materials Department, University of California-Santa Barbara, Santa Barbara, California 93106, USA — We have analyzed the magnetic configuration for highly ordered epitaxial thin films across the Co$_2$Fe$_3$Mn$_{1-x}$Si compositional series ($x = 0$, 0.3, 0.7, 1) by x-ray circular magnetic dichroism (XMCD) and x-ray absorption spectroscopy (XAS). These measurements give the element-specific electronic structure of each film, as well as the spin and orbital moments. We will present our observations at the Co, Mn, and Fe L-edges to explain the significant changes in intermediate stoichiometries as compared with the parent Co$_2$MnSi and Co$_2$FeSi systems.


1Supported by NSF grant ECCS-1402738

4:18PM H19.00008 Large magnetoresistance induced by crystalllographic defects in Fe$_2$TaS$_2$ single crystals, CHIH-WEI CHEN, EMILIA MOROSAN, Rice University, MOROSAN’S GROUP TEAM — The search for the materials that show large magnetoresistance and the mechanisms that induce it remains challenging in both experimental and theoretical aspects. The giant magnetoresistance in one class of materials, ferromagnetic conductors, is generally attributed to the misalignments of magnetic moments, which cause spin disorder scattering. Recently, very large magnetoresistance (>60%) was discovered in the ferromagnetic Fe-intercalated transition metal dichalcogenide, Fe$_{0.28}$TaS$_2$ [Phys. Rev. B 91, 054426 (2015)]. The mechanism that led to this large magnetoresistance was suggested to be due to the deviation of Fe concentration from commensurate values (1/4 or 1/3), which causes magnetic moments misalignments. Here we report a study of Fe$_{0.28}$TaS$_2$ crystals with x close to the commensurate values. Our results qualitatively show that there are crystallographic defects that significantly affect magnetoresistance in Fe$_{0.28}$TaS$_2$. This provides a way to search for large magnetoresistance in more intercalated transition metal dichalcogenides.

1Supported by the Department of Defense PECASE.

4:30PM H19.00009 Development of spin-gapless semiconductor and half metallicity in Ti$_3$MnAl by substitutions for Al, PAVEL LUKASHEV, University of Northern Iowa, SIMEON GILBERT, South Dakota State University, BRADLEY STATEN, NOAHL HURLER, University of Northern Iowa, RYAN FUGLSEBY, PARASHU KHAREL, YUNG HUH, South Dakota State University, SHAH VALLOPPILLY, WENYONG ZHANG, University of Nebraska, Lincoln, K. YANG, Hohai University, DAVID J. SELLMYER, University of Nebraska, Lincoln — In recent years, ever increasing interest in spin-based electronics has resulted in the search for a new class of materials that can provide a high degree of spin polarized electron transport. An ideal candidate would act like insulator for one spin channel and a conductor or semiconductor for the opposite spin channel (e.g., half metal (HM), spin-gapless semiconductor (SGS)). Here, we present the combined computational, theoretical, and experimental study of Ti$_3$MnAl, a Heusler compound with potential application in the field of spintronics. We show that in the ground state this material is metallic, however it becomes a SGS when 50% of Al is substituted with In (e.g., Ti$_3$MnAl$_{0.5}$In$_{0.5}$), and a HM when 50% of Al is substituted with Sn (e.g., Ti$_3$MnAl$_{0.5}$Sn$_{0.5}$). Detailed study of the structural, electronic, and magnetic properties of these materials is presented.

3Financial support: DOE/BES (DE-FG02-04ER46152); NSF NNCI: 1542182; NRI; Academic and Scholarly Excellence Funds, Office of Academic Affairs, SDSU; UNI Faculty Summer Fellowship, Program for Outstanding Innovative Talents in Hohai University.

4:42PM H19.00010 Antiferromagnetic-domain-dependent magnetoresistance in Pt/Fe$_2$Mo$_3$O$_5$ interface, TOSHIYA IDEUE, University of Tokyo, TAKASHI KURUMA, RIKEN Center for Emergent Matter Science (CEMS), SHINTARO ISHIWARA, University of Tokyo, YOSHINORI TOKURA, University of Tokyo, RIKEN Center for Emergent Matter Science (CEMS), UNIVERSITY OF TOKYO TEAM, RIKEN CENTER FOR EMERGENT MATTER SCIENCE (CEMS) TEAM — Interface between nonmagnetic metal and magnetic insulator has been extensively studied, exploiting a variety of new exotic spin transports. Among them, magnetoresistance in Pt/YIG interface attracts intense experimental and theoretical interest. The resistance of Pt layer reflects the magnetization of YIG in spite of the insulating nature of YIG, which has been explained by the spin current across the Pt/YIG interface or the magnetic proximity effect. So far, such anomalous magnetoresistance have been reported only in the interface between nonmagnetic metal and ferrimagnetic insulator. In this work, we have studied the transport properties of Pt on the antiferromagnetic insulator Fe$_2$Mo$_3$O$_5$. Fe$_2$Mo$_3$O$_5$ shows the metamagnetic phase transition under the magnetic field by which we can control the two different antiferromagnetic domains. Interestingly, transverse magnetoresistance in Pt/Fe$_2$Mo$_3$O$_5$ interface shows the distinct behaviors depending on the field cooling process which result in the different antiferromagnetic domains. This implies that the spin transport or proximity effect at the interface is different between two domains and can be probed by the resistance of nonmagnetic Pt.
4:54PM H19.00011 Magnetic properties of Cr$_3$Te$_4$ doped with transition metals: An ab initio study, NABIL AL-AQTASH, The Hashemite University, RENAT SABIRIANOV, University of Nebraska at Omaha — We report density functional theory (DFT) study of the magnetic properties of Cr$_3$Te$_4$ doped with transition metals (TM) (Co, Fe, Ni, V, Mn). TM ions doped in Cr sites, Cr$_{1+x}$TM$_x$(TM)$_{3-x}$Te$_4$ ($x = 0.5$ and $1$). We performed screening of the exchange coupling interaction and magnetization modifications upon the substitution of Cr by 3d-transition metals at various Cr sites in the Cr$_3$Te$_4$ structure. Our calculation show that Cr$_3$Te$_4$ has ferromagnetic coupling and large magnetization (Magnetization per unit cell is 18.24$\mu B$). Magnetocrystalline anisotropy (MAE) of this material is also large (MAE= 1.67MJ/m$^3$). Our calculations show that the increase in interlayer spacing strengthen ferromagnetism of Cr$_3$Te$_4$. Doping with Mn increases Cr$_3$Te$_4$ magnetization, but reduces the exchange coupling energy which means reducing Curie temperature ($T_c$). We find that doping with 3d-TM elements decreases the magnetocrystalline anisotropy energies (MAE) of Cr$_3$Te$_4$.

5:06PM H19.00012 Magnetic properties and stability of the atomic lattice Mn$_n$-$\{2\}$GaC, MARTIN DAHLQVIST, ÅRNI INGASON, Linköping University, Sweden, GUNNAR PÅLSSON, Uppsala University, Sweden, BJÖRN ALLING, IGOR ABRIKOSOV, JOHANNA ROSEN, Linköping University, Sweden — Using first-principles calculations, we predicted the thermodynamically stable magnetic Mn$_n$-$\{2\}$GaC and subsequently synthesized it as a heteroepitaxial thin film. It belongs to a class of atomically laminated compounds with a unique combination of metallic and ceramic properties. They have a common formula $M_{n+1}AX_{2n+1}S_{2n+1}$, where $M$ is an early transition metal, $A$ is a $\text{A}$-group element, and $X$ is carbon or nitrogen. Using density functional theory (DFT) and Heisenberg Monte Carlo (HMC) for a magnetic ground state, several collinear and noncollinear low energy magnetic spin configurations have been identified, some with different symmetries compared to the non-magnetic crystal structure. Around 240 K X-ray diffraction and magnetic measurements display a sharp magnetic long-range order in the lattice in the c-direction coinciding with a sharp magnetic transition. Neutron diffraction measurements displays diffraction peaks consistent with long-ranged antiferromagnetic order with a repetition distance of two structural unit cells (25 1\AA$)$. This is consistent with theoretically predicted structural changes between different, close to degenerate, magnetic ground states, and it is the first unambiguous evidence of long ranged AFM order in MAX phase materials.

Tuesday, March 15, 2016 2:30PM - 5:30PM – Session H21 GMAG DMP: 1D Gapped Antiferromagnets 320 - Vivien Zapf, NHMFL-LANL

3:20PM H21.00001 Spectroscopic Investigation of the Origin of Magnetic Bistability in Molecular Nanomagnets, JORIS VAN SLAGEREN, University of Stuttgart — Molecular nanomagnets (MNMs) are coordination complexes consisting of one or more transition metal and/or f-element ions bridged and surrounded by organic ligands. Some of these can be magnetized in a magnetic field, and remain magnetized after the field is switched off. Because of this, many MNMs have been proposed for magnetic data storage applications, where up to 1000 times higher data densities than currently possible can be obtained. Other MNMs were shown to display quantum coherence, and, as a consequence, are suitable as quantum bits. Quantum bits are the building blocks of a quantum computer, which will be able to carry out calculations that will never be possible with a conventional computer. The magnetic bistability of MNMs originates from the magnetic anisotropy of the magnetic ions, which creates an energy barrier between up and down orientations of the magnetic moment. Currently, most work in the area focuses on complexes of either lanthanide ions or low-coordinate transition metal ions. Synthetic chemical efforts have led to a large number of novel materials, but the rate of improvement has been slow. Therefore a better understanding of the origin of the magnetic anisotropy is clearly necessary. To this end we have applied a wide range of advanced spectroscopic techniques, ranging from different electron spin resonance techniques at frequencies up to the terahertz domain to optical techniques, including luminescence and magnetic circular dichroism spectroscopy. We will discuss two examples, one from the area of lanthanide MNMs [1], one a transition metal MNM (unpublished). [1] Rechkemmer, J.E. Fischer, R. Marx, M. Dörfel, P. Neugebauer, S. Horvath, M. Gysler, T. Brock-Nannestad, W. Frey, M.F. Reid, J. van Slageren*, “Comprehensive Spectroscopic Determination of the Crystal Field Splitting in an Erbium Single-Ion Magnet”, J. Am. Chem. Soc., 137, 13114–13120 (2015).

3:06PM H21.00002 Conditions for the appearance of boundary modes in topological phases of Heisenberg spin ladders, NEIL ROBINSON, Brookhaven Natl Lab, ALEXANDER ATLAND, Universität zu Köln, REINHOLD EGGER, HHU Düsseldorf, NIKLAS GERS, Utrecht University, ROBERT KURNIK, Brookhaven Natl Lab, LEI LI, LMU München, DIRK SCHURICHT, Utrecht University, ALEXEI TSVELIK, Brookhaven Natl Lab, ANDREAS WEICHSELBAUM, LMU München — We consider the problem of delineating the necessary conditions for the appearance of boundary modes in extended SU(2) Heisenberg spin ladders. Specifically, we study Heisenberg ladders with rung exchange, $J_\perp$, and ring exchange, $J_\parallel$, that admit a field theoretic description in terms of Majorana fermions in the continuum limit. In this description there are four Majorana fermions, arranged in a triplet and a singlet. This suggests there are four distinct phases, corresponding to the configurations of the signs of the triplet $m_1$ and singlet $m_2$ magnetization. We label these phases as: Haldane ($m_2 > 0, m_1 < 0$), rung singlet ($m_1 < 0, m_2 > 0$), VBS$_-$ ($m_1, m_2 < 0$) and VBS$_+$ ($m_1, m_2 > 0$). Topologically, we find two of these phases support gapless boundary modes: the Haldane phase (the triplet forms a spin-1/2 degree of freedom at the ends of the ladder) and the VBS$_+$ phase, where all the Majorana fermions have gapless boundary modes. The absence of a gapless boundary mode in the rung singlet phase is surprising; we find that the singlet mode can become gapless if open boundary conditions are replaced with a continuous change in lattice parameters. We suggest a symmetry-allowed modification to the low-energy effective theory which may be responsible for this behavior.

3:18PM H21.00003 The pressure effects on the antiferromagnetic orders in iron-based ladder compounds BaFe$_2$S$_3$, SONGXUE CHI, Quantum Condensed Matter Division, Oak Ridge National Laboratory, YOSHIYA UWATOKO, None, YASUYUKI HIRATA, KENYA OHGUSHI, Institute for Solid State Physics (ISSP), University of Tokyo — The ladder compounds have recently become a new test ground for the studies on Fe-based superconductors. The building block for such materials, the two-leg Fe ladder surrounded by edge-sharing chalcogen tetrahedra, has provided a quasi-one-dimensional channel for the remaining critical issues in this field. Recently, superconductivity was successfully induced by pressure in one of such compounds, BaFe$_2$S$_3$. The knowledge of the pressure effect on its antiferromagnetic order is crucial in understanding the superconductivity in the low-dimensional system. I will present our results of neutron diffraction measurement on the evolution of the magnetic phase under hydraulic pressure in single crystalline BaFe$_2$S$_3$.

3:30PM H21.00004 Neutron scattering study of magnetic structure in triangle spin tube CsCr$_3$F$_7$, MASATO HAGIHALA, ISSP, Univ. of Tokyo, MAXIM AVDEEVE, Bragg Institute, ANSTO, HIROTAKA MANAKA, Kagoshima Univ., TAKESUKE MASUDA, ISSP, Univ. of Tokyo — Triangle spin tube viewed from tube direction is topologically equivalent to kagomé lattice. The rung ($J_\perp$) and inter-tube ($J_\parallel$) interactions on triangle spin tube correspond respectively to the next nearest neighbor and the nearest neighbor interactions on kagomé lattice. In the case of $J_\perp > 0$ (Antiferromagnetic) and $J_\parallel > |J_\perp|$, the ground state is $q = 0, 120^\circ$ structure with $J_\parallel > 0$ or Cubic state that represented multi-$q$ ($q = \pm(1/2, 1/2, 1/2)$ and two symmetric-equivalent vectors) with $J_\parallel < 0$ [1]. CsCr$_3$F$_7$ is a perfect triangle spin tube model with antiferromagnetic intra-tube and rung interactions [2]. Neutron diffraction measurement revealed magnetic long-range order at $T = 1.5 \text{K}$. Contrary to the expectation, the magnetic structure was determined $q = 2\pi((1/2, 1/2, 1/2))$, $120^\circ$ structure by Rietveld refinement. We also confirmed that this structure was stabilized by Dzyaloshinskii –Moriya interaction and small anisotropy that obeyed the three-fold symmetry at Cr sites by calculation. [1] H. Ishikawa et al., JPSJ 83, 043703 (2014). [2] H. Manaka et al., JPSJ 78, 093701 (2009).
3:42PM H21.00005 Dielectric effects at a magnetic Bose-Einstein condensation[1]. KIRILL POVAROV, AARON REICHERT, ERIK WULF, ANDREY ZHULEDEV, Neutron Scattering and Magnetism Group, ETH Zurich, Switzerland — In the presence of magneto-electric coupling one can expect non-trivial dielectric properties at a magnetic quantum phase transition. A “toy model” here is a spin spiral undergoing a field-induced transition into a quantum-disordered phase. In the incommensurate phase the in-plane spin rotational symmetry is protected, making the analogy between the magnetic long-range ordering and BEC exact, but the spin spiral may also host an electric polarization complicating the picture. We have experimentally observed a significant enhancement of the spin tube material Cu$_2$(Cl$_6$)$_2$, $[1]$ to understand if it can be described as a magnetic BEC. We have found that indeed it can. Dielectric spectroscopy results combined with calorimetric measurements, clearly show the absence of polarization fluctuations in the disordered phase down to the very critical point. At the same time the ordered phase shows a huge nonlinearity in dielectric permittivity even for small electric fields. The phase boundary shows beautiful consistency with the 3D BEC universality class. We conclude, that although magneto-electric coupling does not alter the nature of the transition, it gives rise to complex magneto-electric effects in the helium-magnetically ordered phase.


3:54PM H21.00006 Optical spin excitations in quantum spin ladders, GEDIMINAS SIMUTIS, SEVERIAN GVASALIYA, NSM laboratory, ETH Zurich, FAN XIAO, Department of Physics, Durham University, CHRISTOPHER LANDEE, Department of Physics, Clark University, ANDREY ZHULEDEV, NSM laboratory, ETH Zurich — We present a Raman spectroscopy study of magnetic excitations in quantum spin ladders. We start with a strong-rung ladder Cu$_2$(Qnx)(Cl$_6$)$_2$. It has recently attracted attention due to proposal that the ratio of leg to rung exchange can be varied continuously by substituting Br for Cl. We measured the Raman spectra for the hole doping series and report on the scattering from two magnons [1]. We extract the onset and cutoff of the scattering for the whole series and compare it to the estimates from previous bulk measurements as well as numerical calculations. We find that the magnetic spectrum indeed varies continuously as the halogen ions are exchanged. The general behavior is found to be consistent with expectations, however small systematic deviations persist. The difference can potentially be explained by the existence of three-dimensional coupling, however more systematic computational studies are needed to ascertain the origin of the inconsistencies. Having established the analysis using the strong rung case, we then turn our attention to other ladder systems. Unusual magnetic signal is found in a strong leg spin ladder, which is discussed in terms of selection rules and an unexpected energy scale. [1] G. Simutis et al. arXiv:1510.06360

4:06PM H21.00007 ESR modes in a Strong-Leg Ladder in the Tomonaga-Luttinger Liquid Phase[1]. S. ZYVAGIN, HLD-HZDR, D-01328 Dresden, Germany, M. OZEROV, Radboud University, 6525 ED Nijmegen, The Netherlands, M. MAKSY-MENKO, Weizmann Institute of Science, Rehovot 76100, Israel, J. WOSNITZA, HLD-HZDR, D-01328 Dresden, Germany, A. HONECKER, Universit"{e} de Cergy-Pontoise, F-95302 Cergy-Pontoise Cedex, France, C.P. LANDEE, M. TURNBULL, Clark University, Worcester, MA 01060, USA, S.C. FURUYA, T. GIAMARCHI, University of Geneva, CH-1211 Geneva, Switzerland — Magnetic excitations in the strong-leg quantum spin ladder compound (C$_7$H$_{11}$N)$_2$CuBr$_4$ (known as DIMPY) in the field-induced Tomonaga-Luttinger spin liquid phase are studied by means of high-field electron spin resonance (ESR) spectroscopy. The presence of a gapped ESR mode with unusual non-linear frequency-field dependence is revealed experimentally. Using a combination of analytic and exact diagonalization methods, we compute the dynamical structure factor and identify this mode with longitudinal excitations in the antisymmetric channel. We argue that these excitations constitute a fingerprint of the spin dynamics in a strong-leg spin-1/2 Heisenberg antiferromagnetic ladder and owe its ESR observability to the uniform Dzyaloshinskii-Moriya interaction.

[1] This work was partially supported by the DFG and Helmholtz Gemeinschaft (Germany), Swiss SNF under Division II, and ERC synergy UQUAM project. We acknowledge the support of the HLD at HZDR, member of the European Magnetic Field Laboratory (EMFL).

4:18PM H21.00008 Field-induced spontaneous magnon decay in a spin-1/2 coupled two-leg ladder antiferromagnet C9H18N2CuBr4 with small Ising anisotropy, TAO HONG, Quantum Condensed Matter Division, Oak Ridge National Laboratory, Y. QIU, National Institute of Standards and Technology, D. A. TENNANT, Quantum Condensed Matter Division, Oak Ridge National Laboratory, K. COESTER, K. P. SCHMIDT, Lehrstuhl fur Theoretische Physik I, TU Dortmund, F. F. AWWADI, Department of Chemistry, The University of Jordan, M. M. TURNBULL, Carlson School of Chemistry, Clark University — We present a Raman spectroscopy study of magnetic excitations in the strong-leg quantum spin ladder compound (C$_7$H$_{11}$N)$_2$CuBr$_4$ (known as DIMPY) in the field-induced Tomonaga-Luttinger spin liquid phase are studied by means of high-field electron spin resonance (ESR) spectroscopy. The presence of a gapped ESR mode with unusual non-linear frequency-field dependence is revealed experimentally. Using a combination of analytic and exact diagonalization methods, we compute the dynamical structure factor and identify this mode with longitudinal excitations in the antisymmetric channel. We argue that these excitations constitute a fingerprint of the spin dynamics in a strong-leg spin-1/2 Heisenberg antiferromagnetic ladder and owe its ESR observability to the uniform Dzyaloshinskii-Moriya interaction.

4:30PM H21.00009 Local structure of spin Peierls compound TiPO$_4$: $^{47}$Ti and $^{31}$P NMR study[1]. RAIVO STERN$^2$, IVO HEINMAA, ALEXANDER LEITME, ENNO JOON, ALEXANDER TSIRILIN, Natl Inst of Chem Phy & Bio, REINHARD KREMER, MPI Stuttgart, ROBERT GLAUM, Universit"{e} Bonn — TIPO4 structure is made of slightly corrugated TiO2 ribbon chains of edge-sharing TiO6 octahedra. The almost perfect 1D spin TIs+ chains are well separated by PO4 tetrahedra. By magnetic susceptibility and MAS-NMR measurements [1] it was shown that TIPO4 has nonmagnetic singlet ground state with remarkably high Spin-Peierls (SP) transition temperature. The high-T magnetic susceptibility of TIPO4 follows well that of a S=1/2 Heisenberg chain with very strong nearest-neighbor AF spin-exchange coupling constant of J=960K. On cooling TIPO4 shows two successive phase transitions at 111K and 74K, with incommensurate (IC) SP phase between them. We studied local structure and dynamics in TIPO4 single crystal using $^{47}$TiNMR and 31P NMR at 111K and 74K, with temperature range 40K to 300K, and determined the principal values and orientation of the magnetic shift tensors for 31P and 47Ti nuclei. Since 47Ti(5S=5/2 and 5S=7/2, respectively) have quadrupolar moments, we also found the principal axis values and orientations of the electric field gradient (eFG) tensor in SP phase and at 295K. In SP phase the structure contains 2 magnetically inequivalent P sites and only one Ti site. From the T-dependence of the relaxation rate of 31P and 47Ti nuclei we determined activation energy EA = 550 K for spin excitations in SP phase.


[2] Support from ETAQ by PUTF210 and IUT23-3 is acknowledged.

4:42PM H21.00010 Pressure-Induced Order in the Gapped Quantum Magnet DTN, ALEXANDRA MANNIG, JOHANNES MOELLER, ANDREY ZHULEDEV, ETH Zurich, Neutron Scattering and Magnetism Group, Laboratory for Solid State Physics, Zurich, Switzerland, V. OVIDIU GARLEA, CLARINA DELA CRUZ, Oak Ridge National Laboratory, Quantum Condensed Matter Division, Oak Ridge, Tennessee, USA, ZURAB GUGUCHIA, RUSTEM KHASANOV, ELVEZIO MORENZONI, Paul Scherrer Institute, Laboratory for Muon Spin Spectroscopy, Villigen-PSI, Switzerland — We present muon-spin relaxation, neutron diffraction and magnetic susceptibility data under applied hydrostatic pressure on the organometallic salt S = 1 quantum magnet NiCl$_2$·4(SC$_2$NH$_2$)$_2$. The material consists of weakly coupled antiferromagnetic chains and has a spin gap resulting from a large single-ion anisotropy. Our muon spin rotation experiments provide local field dependences as well as magnetic susceptibility measurements and show the potential of low-pressure transitions to be investigated by various techniques.
4:54PM H21.00011 Unusual Magnetic-Pressure Response of an S = 1 Antiferromagnetic Linear-Chain near the D/J ≈ 1 Critical Point.1 , M. K. PEIPRAH, P. A. QUINTERO, J. S. XIA, J. M. PÉREZ, M. W. MEISEL, Dept. of Physics and NHMFL, Univ. of Florida, A. GARCIA, S. E. BROWN, Dept. of Physics, UCLA, J. L. MANSON, Dept. of Chemistry, Eastern Washington Univ. — An S = 1 chain, [Ni(HF)_2(η-C3py)]BF_4 (py = pyridine), has been identified to have nearest-neighbor antiferromagnetic interaction J/K_B = 4.86 K and single-ion anisotropy D/K_B = 4.3 K, while avoiding long-range order to 25 mK. With D/J = 0.88, this system is close to the D/J ≈ 1 gapless quantum critical point between the Haldane and Large-D phases. The magnetization was studied at 50 mK < T < 1 K and with B ≤ 10 T. Using a magnetometer equipped with a pressure cell, the low-field (0.1 T), high temperature (T ≥ 2 K) magnetic susceptibility was studied to 1.47 GPa. These data suggest the response at ambient pressure changes between 0.24 GPa and 0.35 GPa. These studies are being extended by 1H NMR experiments capable of varying the pressure and of spanning from 300 K to below 100K.

1Supported by the NSF via DMR-1202033 (MWM), DMR-1410343 (SEB), DMR-1306158 (JLM), DMR-1461019 (UF Physics REU support for JMP), and DMR-1157490 (NHMFL), and by the State of Florida.


3J-S. Xia et al., arxiv:1409.5971 (2014).

5:06PM H21.00012 High-pressure neutron scattering of Prussian blue analogue magnets, DANIEL PAJEROWSKI, Oak Ridge National Laboratory — Pressure sensitive magnetism is known to be useful in sensors, and while applications tend to use metallic alloys, molecule based magnets (MBMs) have been shown to have large inverse magnetostriuctive (IMS) response. A promising group of MBMs are the Prussian blue analogues (PBAs), in which magnetic ordering can be tuned by external stimuli such as light, electric field, and pressure. Previously, high pressure neutron scattering of nickel hexacyanochromate hydrate has shown direct evidence for isomerization of the cyanide linkage with applied pressure. Other probes have suggested a similar effect in iron hexacyanochromate hydrate, although there has yet to be direct crystallographic evidence. Neutron diffraction is sensitive to organic elements, while even in the presence of metals, and we have performed experiments above 1 GPa to look for linkage isomerism in iron hexacyanochromate. These results are supported by bulk probes and calculations.

5:18PM H21.00013 Changes in the unoccupied electronic structure of the spin crossover molecule [Co(dpzca)]_2, YANG LIU, XIN ZHANG, AXEL ENDERS, PETER DOWBEN, JIAN LUO, JIAN ZHANG, Univ of Nebraska - Lincoln, ALPHA NDIAYE, LBNL, Advanced Light Source — We have investigated the changes in the unoccupied electronic structure of the spin crossover molecule [Co(dpzca)]_2 using X-ray absorption spectroscopy (XAS) and have compared the results with magnetometry (SQUID) measurements. The studies of the variable temperature of the electronic structure of this cobalt complex with symmetric pyrazine imide ligands, (2-pyrazylcarbonyl)-2-pyrazylcyanocarboxamide, i.e. [Co(dpzca)]_2, are consistent with density functional theory (DFT). The temperature dependence of the occupancy of the high-spin state and low-spin state molecular orbital states, the unoccupied ν/ν_2 ratio from XAS and high spin state to low spin state ratio from molecular magnetic susceptibility χ_M/T indicates that the low spin state is not a zero spin state, but simply a lower moment state that would occur below the spin crossover transition of [Co(dpzca)]_2.

Tuesday, March 15, 2016 5:45PM - 6:45PM Session J15 GMAG: GMAG Business Meeting 314 -

5:45PM J15.00001 GMAG BUSINESS MEETING –

Wednesday, March 16, 2016 8:00AM - 11:00AM –

Session K2 DCMP DMP GMAG: Kitaev Spin Liquid Physics in Honeycomb and Related Lattice Materials Ballroom II - Stephen Nagler, Oak Ridge National Lab

8:00AM K2.00001 The magnetic ground state and relationship to Kitaev physics in α-RuCl_3, ARNAB BANERJEE, Quantum Condensed Matter Div., Oak Ridge Nat. Lab., Oak Ridge, TN - 37830. — The 2D Kitaev candidate α-RuCl_3 consists of stacked honeycomb layers weakly coupled by Van der Waals interactions. Here we report the measurements of bulk properties and neutron diffraction in both powder and single crystal samples. Our results show that the full three dimensional magnetic ground state is highly pliable with at least two dominant phases corresponding to two different out-of-plane magnetic orders. They have different Neel temperatures dependent on the stacking of the 2D layers, such as a broad magnetic transition at T_N = 14 K as observed in phase-pure powder samples, or a sharp magnetic transition at a lower T_N = 7 K as observed in homogeneous single crystals with no evidence for stacking faults. The magnetic refinements of the neutron scattering data [1] will be discussed, which in all cases shows the in-plane magnetic ground state is the zigzag phase common in Kitaev related materials including the honeycomb lattice fridates. Inelastic neutron scattering in all cases shows that this material consistently exhibit strong two-dimensional magnetic fluctuations leading to a break-down of the classical spin-wave picture [2]. [1] H.B. Cao, A. Banerjee, J-Q. Yan, C.B. Bridges, M. Lumsden, B.C. Chakoumakos, D.G. Mandrus, D.A. Tennant, S.E. Nagler, Low-temperature crystal and magnetic structure of α-RuCl_3, (manuscript in preparation). [2] A. Banerjee et al., arxiv:1504.08037 (2015).

3Work performed at ORNL is supported by U.S. Dept. of Energy, Office of Basic Energy Sciences and Office of User Facilities Division.

8:36AM K2.00002 How to identify and resolve beyond-geometrical frustration, ITAMAR KIMCHI, Massachusetts Institute of Technology — In this talk, we will discuss recent theoretical developments triggered by the experimental discoveries of iridium oxides α, β, γ-Li_2IrO_3. In these polycrystalline, spin-orbit-coupled J=1/2 moments form 2D and 3D lattices (honeycomb, hyperhoneycomb and stripyhoneycomb) which generalize the 2D honeycomb lattice. Scattering experiments on these compounds have uncovered a peculiar non-coplanar incommensurate magnetic order, involving spirals which counter-rotate across neighboring sites. We discuss the emergence of this magnetic order, and present high-pressure measurements of α-Li_2IrO_3 which indicate strong magnetic frustration. These results are supported by bulk probes and calculations.
9:12AM K2.00003 3D Kitaev spin liquids, MARIA HERMANNS, University of Cologne — The Kitaev honeycomb model has become one of the archetypal spin models exhibiting topological phases of matter, where the magnetic moments fractionalize into Majorana fermions interacting with a $Z_2$ gauge field. In this talk, we discuss generalizations of this model to three-dimensional lattice structures. Our main focus is the metallic state that the emergent Majorana fermions form. In particular, we discuss the relation of the nature of this Majorana metal to the details of the underlying lattice structure. Besides (almost) conventional metals with a Majorana Fermi surface, one also finds various realizations of Dirac semi-metals, where the gapless modes form Fermi lines or even Weyl nodes. We introduce a general classification of these gapless quantum spin liquids using projective symmetry analysis. Furthermore, we briefly outline why these Majorana metals in 3D Kitaev systems provide an even richer variety of Dirac and Weyl phases than possible for electronic matter and comment on possible experimental signatures.

Work done in collaboration with Kevin O’Brien and Simon Trebst.


9:48AM K2.00004 Hyperhoneycomb iridate beta-Li2IrO3 as a platform for Kitaev spin liquid, TOMOHIRO TAKAYAMA, Max Planck Inst — Realization of quantum spin liquid has been a long-sought dream in condensed matter physics, where exotic excitations and unconventional superconductivity upon doping are expected. Honeycomb iridates recently emerged as a possible materialization of Kitaev spin liquid with frustrated “bond – dependent ferromagnetic interaction”. However, the real materials, α-Li2IrO3 and α-Li2Ir2O6, undergo antiferromagnetic ordering likely due to the presence of other dominant magnetic interactions and lattice distortion. We discovered a new form of Li2IrO3, β-Li2IrO3, which comprises a three-dimensional analogue of honeycomb lattice dubbed as “hyperhoneycomb”. Each Ir4+ ion of the hyperhoneycomb lattice has three neighboring like ions rotated by 120° and thus the local structure is identical with 2D honeycomb, indicating that the hyperhoneycomb lattice is a new platform for Kitaev physics. β-Li2IrO3 displays a spiral magnetic order below 38 K, which likely originates from dominance of ferromagnetic Kitaev interaction. We argue that β-Li2IrO3 locates in a close proximity to Kitaev spin liquid. We also discuss the spin liquid behavior observed in a new honeycomb iridate obtained by chemical modulation.

10:24AM K2.00005 Magnetic “three states of matter” in two and three dimensions: a quantum Monte Carlo study of the extended toric codes, YOSHITOMO KAMIYA, RIKEN — Saitama — The possibility of quantum spin liquids, characterized by nontrivial entanglement properties or a topological nonlocal order parameter, has long been debated both theoretically and experimentally. Since candidate systems (e.g., frustrated quantum magnets or 5d transition metal oxides) may host other competing phases including conventional magnetic ordered phases, it is natural to ask what types of global phase diagrams can be anticipated depending on coupling constants, temperature, dimensionality, etc. In this talk, by considering an extension of the Kitaev toric code Hamiltonians by Ising interactions on 2D (square) and 3D (cubic) lattices, I will present thermodynamic phase diagrams featuring magnetic “three states of matter,” namely, quantum spin liquid, paramagnetic, and magnetically ordered phases (analogous to liquid, gas, and solid, respectively, in conventional matter) obtained by unbiased quantum Monte Carlo simulations [YK, Y. Kato, J. Nasu, and Y. Motome, PRB 92, 100403(R) (2015)]. We find that the ordered phase borders on the spin liquid around the exactly solvable point by a discontinuous transition line in 3D, while it grows continuously from the quantum critical point in 2D. In both cases, peculiar proximity effects to the nearby spin liquid phases are observed at high temperature even when the ground state is magnetically ordered. Such proximity effects include flux-shrinking and a tricritical behavior in 3D and a “fractionalization” of the order parameter field that the quantum critical point in 2D, both of which can be detected by measuring critical exponents. (*)

Work done in collaboration with Yasuyuki Kato, Joji Nasu, and Yukitoshi Motome

Wednesday, March 16, 2016 8:00AM - 11:00AM — Session K5 GMAG DMP: Frustrated Magnetism: Spinels 301 - Daniel Khomskii, University of Cologne

8:00AM K5.00001 From Spin Glass to Spin Liquid Ground States in Pyrochlore Molybdates, LUCY CLARK, University of St Andrews — Magnetic pyrochlores continue to generate intense interest due to the wealth of interesting behaviours that they can display as a result of their highly frustrated nature. Here we will present our study of the molybate pyrochlore Lu2Mo2O7, which contains non-magnetic Lu4+ and an antiferromagnetic network of corner-sharing tetrahedra of Mo4+ 4d2 $S = 1$ ions. [1]. Magnetic susceptibility data show that Lu2Mo2O7 enters an unconventional spin glass state at $T_f/16K$ that displays a quadratic dependence of the low temperature magnetic heat capacity, akin to that observed for its well-studied sister compound Y2Mn2O5. [2]. This spin glass transition is also clearly marked in our inelastic (CNCS, SNS) and diffuse elastic magnetic (D7, ILL) neutron scattering data. Furthermore, we will show that it is possible to topochemically substitute the oxide, O2− ions within Lu2Mo2O7 for nitride, N3−, to produce an oxynitride molybdate pyrochlore of composition Lu2Mo2O7N2. Magnetic susceptibility measurements confirm that strong antiferromagnetic correlations persist within the oxynitride, which contains Mo4+ 4d2 $S = 1/2$ ions and is thus a prime candidate to host exotic quantum spin liquid behavior. We will discuss how the enhanced quantum spin fluctuations in Lu2Mo2O7N2 appear to suppress the spin freezing transition observed in its parent oxide and instead support the formation of a gapless spin liquid phase that displays a linear dependence of the low temperature magnetic heat capacity [3]. [1] L. Clark et al., J. Solid State Chem. 203, 199 (2013), [2] H. J. Silverstein et al., Phys. Rev. B 89, 054433 (2014), [3] L. Clark et al., Phys. Rev. Lett. 113, 117201 (2014).

8:36AM K5.00002 Observation of a new incommensurate phase in the spinel MnV2O4, GILBERTO DE LA PENA MUNOZ, SANGJUN LEE, SAMUEL GLEASON, TAYLOR BYRUM, XINYUE FANG, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, SHIH-CHANG WENG, National Synchrotron Radiation Research Center, PETER ABBAMONTE, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign — Using x-ray scattering, we studied the temperature dependence of a large volume of reciprocal space in a MnV2O4 spinel crystal. In addition to the known cubic to tetragonal phase transition at around 56 K, we observed previously unreported incommensurate modulation peaks at delta $q_0$ = 0.33 ± 0.16. We measured the temperature dependence of these modulations and, while they exhibit a shift or splitting in momentum space analogous to that of the structural phase transition, they do so at higher temperature than the Bragg reflections (100K). Our results suggest that MnV2O4 has an additional phase transition that may play a major role in the cause of the V t2g orbital ordering, which is closely related to the cubic to tetragonal transition.

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1 Financial support from the Research Corporation for Science Advancement

9:00AM K5.00004 Effects of Zn doping on the A-Site antiferromagnet spinel CuRh$_2$O$_4$ $^1$. ALEXANDER ZAKJEVSKIL, DALMAU REIG-I-PLESSIS, University of Illinois, Urbana, IL, ALEXANDER THALER, ASHFINA HUQ, Oak Ridge National Laboratory, Oak Ridge, TN, GREGORY MACDOUGALL, University of Illinois, Urbana, IL — A major recent focus of the correlated electron community has been the investigation of 4d and 5d transition metal oxides, which are predicted to have novel phases arising from relativistic spin-orbit coupling. We have recently synthesized and characterized several compounds of the doped spinel series Cu$_{1-x}$Zn$_x$Rh$_2$O$_4$. The parent compound is a normal spinel which undergoes a cubic-tetragonal structural phase transition at $T\sim$850K, and further undergoes a suspected antiferromagnetic transition at $T_N$<22K. We have performed powder x-ray and neutron diffraction, and bulk magnetization measurements on members of the Zn-doping series. Magnetization measurements clearly indicate a monotonic suppression of the Néel temperature with increasing Zn content, to a quantum critical point at $T_N\sim$0.42. X-ray results indicate a change in structure occurring near the same doping. We will present these data and discuss the results within the context of exotic predictions in the literature. Lastly, we will discuss our recent neutron powder diffraction measurements and insights gleaned about the local spin state.

$^1$This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46544.

9:12AM K5.00005 Magnetic Ordering in FeSc$_2$S$_4$ $^1$. K.W. PLUMB, J.R. MOREY, Johns Hopkins University, J.P.C. RUFF, CHESS, Cornell University, J.A. RODRIGUEZ-RIVERA, NIST, T.M. MCQUEEN, S.M. KOOPPAYEH, C.L. BROHOLM, Johns Hopkins University — FeSc$_2$S$_4$ is a cubic spinel where orbitally active Fe$^{2+}$ ions occupy the A-site diamond sublattice. Despite a high spin (S=2) state and Curie Weiss temperature of 45 K thermodynamic measurements show no indication of a phase transition and the material has been proposed as a unique example of a spin-orbital liquid. This ground state might arise from competition between on-site spin-orbit coupling and Kugel-Khomskii exchange. We report neutron scattering measurements on polycrystalline samples of FeSc$_2$S$_4$ which bring this picture into question. They reveal a previously unreported magnetically ordered state below 11 K. No structural distortions are visible with neutron or x-ray scattering. The effect of hydrostatic pressure on the magnetic excitation spectrum was also explored and found to be minimal.

$^1$This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46544.

9:24AM K5.00006 Quantum phase transitions and anomalous Hall effect in a pyrochlore Kondo lattice. SARAH GREFE, Rice University, WENXIN DING, University of California Santa Cruz, QIMIAO SI, Rice University — The metallic variant of the pyrochlore iridates Pr$_2$Ir$_2$O$_7$ has shown characteristics of a possible chiral spin liquid state [PRL 96 087204 (2006), PRL 98, 057203 (2007), Nature 463, 210 (2010)] and quantum criticality [Nat. Mater. 13, 356 (2014)]. An important question surrounding the significant anomalous Hall response observed in Pr$_2$Ir$_2$O$_7$ is the nature of the f-electron local moments, including their Kondo coupling with the conduction d-electrons. The heavy effective mass and related thermodynamic characteristics indicate the involvement of the Kondo effect in this system’s electronic properties. In this work, we study the effects of Kondo coupling on candidate time-reversal-symmetry-breaking spin liquid states on the pyrochlore lattice. Representing the f-moments as slave fermions Kondo coupled to conduction electrons, we study the competition between Kondo-singlet formation and chiral spin correlations and determine the zero-temperature phase diagram. We derive an effective chiral interaction between the local moments and calculate the anomalous Hall response across the quantum phase transition from the Kondo destroyed phase to the Kondo screened phase. We discuss our results’ implications for Pr$_2$Ir$_2$O$_7$ and related frustrated Kondo-lattice systems.

9:36AM K5.00007 Chemical insights into the synthesis and properties of polycrystalline and single crystal iron scandium sulfide (FeSc$_2$S$_4$) $^1$. JENNIFER R. MOREY, KEMP W. PLUMB, SEYED M. KOOPPAYEH, COLLIN L. BROHOLM, TYRELL M. MCQUEEN, Institute for Quantum Matter and Johns Hopkins University — Iron scandium sulfide, FeSc$_2$S$_4$, has recently attracted significant theoretical and experimental interest as a candidate spin-orbital liquid. An AB$_2$X$_4$ spinel, FeSc$_2$S$_4$ (space group Fd-3m, No. 227) features a high degree of frustration associated with the Fe$^{2+}$ ion, which occupies the A-site diamond sublattice and is tetrahedrally coordinated by sulfur. The Fe$^{2+}$ ion is in a high spin (S=2) state, resulting in orbital degeneracy due to a single hole on the $e_g$ orbitals. We report the strides we have made to produce material in powder and single crystal form, and the relationship between the chemical and structural, magnetic, and thermodynamic properties of FeSc$_2$S$_4$.

$^1$This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46544.

9:48AM K5.00008 Weyl Magnon. FEI-YEI LI, Institute of Theoretical Physics, Chinese Academy of Sciences, YAO-DONG LI, Department of Computer Sciences, Fudan Univ, YUE YU, Physics Department, Fudan Univ, YONG BAEK KIM, Physics Department, Univ of Toronto, Ontario; School of Physics, Korea Institute for Advanced Study, LEON BALENTS, Kavli Institute for Theoretical Physics, UCSB, California, GANG CHEN, Physics Department, State Key Laboratory of Surface Physics, Fudan Univ; Perimeter Institute for Theoretical Physics — Conventional magnetic orders in Mott insulators are often believed to be trivial as they are simple product states. In this talk, we argue that this belief is not always right. We study a realistic spin model on the breathing pyrochlore lattice. We find that, although the system has a magnetic ordered ground state, the magnetic excitation is rather nontrivial and supports linear band touchings in its spectrum. This linear band touching is a topological property of the magnon band structure and is thus robust against small perturbation. We thus name this magnon band touching as Weyl magnon. Just like the Weyl fermion, the existence of Weyl magnon suggests the presence of odd-dimensionality. Using neutron scattering, we explore the excitation spectrum of the Fermi arcs and find that the Weyl magnon appears at a finite energy due to the bosonic nature of the magnons. Moreover, the external magnetic field only couples to the spins with a Zeeman term and thus can readily shift the Weyl node position. This provides a way to control the Weyl magnon. Our work will inspire a re-examination of the excitation spectrum of many magnetic ordered systems.
10:00AM K5.00009 Spin Glass Behavior and Field Induced Anisotropic Magnetic Ordering in S = 2 Frustrated Spinel GeFe2O4, TAO ZOU, Michigan State Univ, ZHILING DUN, University of Tennessee, TAO HONG, HUBO CAO, CLARINA DELA CRUZ, Oak Ridge National Lab, MICHAEL GOTTSCHALK, MENGZE ZHU, Michigan State Univ, HAIDONG ZHOU, University of Tennessee, XIAONGLIN KE, Michigan State Univ — We report comprehensive studies of magnetic properties of spinel GeFe2O4 by means of magnetic susceptibility and heat capacity measurements on both polycrystalline and single crystalline samples as well as neutron powder diffraction measurements. We find that this system shows a spin-glass ground state with the transition temperature around T ~ 21 K, in contrast to the static antiferromagnetic order reported in earlier literature. In addition, we reveal a field-induced magnetic ordering, which displays strong magnetic anisotropy character.

10:12AM K5.00010 Orbital degeneracy near the itinerant electron limit in CoV2O4, D. REIG-PLESSIS, D. CASAVANT, University of Illinois, V. O. GARLEA, A. A. ACZEL, M. FEYGENSON, J. NEUEFEIND, Oak Ridge National Lab, H. D. ZHOU, University of Tennessee, S. E. NAGLER, Oak Ridge National Lab, G. J. MACDOUGALL, University of Illinois — Vanadium spinels, AV2O4, have both magnetic frustration and orbital degeneracy on the V3+ sublattice, which lead to strong coupling of the orbital, lattice and spin degrees of freedom. Additionally, upon decreasing the V-V distance, the material is predicted to go from a Mott insulator to a metallic phase. Of all the materials in the AV2O4 series, CoV2O4 is closest to the predicted transition, and it’s debated whether it may be fully described by either localized or itinerant electronics pictures. In all other studied vanadium spinels, there is a cubic to tetragonal transition associated with ordering of the degenerate V^3+ orbitals, consistent with a local orbital picture but, this transition is surprisingly absent from CoV2O4 despite being an insulator with local spins. In this talk we present recent high resolution neutron diffraction and inelastic scattering measurements by our group on powders of CoV2O4. Diffraction data show there is small but clear first order structural transition present which correlates with canting of the V^3+ spins, while inelastic data are well described by a local spinwave picture. We discuss how these results contribute evidence of a local orbital ordering phase in the region near electron itinerancy.

1 This work was sponsored by NSF grant DMR-145526

10:24AM K5.00011 Spin Dynamics and Two-Dimensional Correlations in the FCC Antiferromagnetic Sr2YRuO6, STEVEN DISSELER, J. W. LYNN, NIST Center for Neutron Research, Gaithersburg, Maryland 20899, USA, R. F. JARDIM, Instituto de Física, Universidade de Sao Paulo 05315-970, Brazil, M. S. TORIKACHVILI, Department of Physics, San Diego State University, San Diego, California 92128, USA, E. GR, Institute of Physics “Gleb Wataghin,” University of Campinas - UNICAMP, Campinas, Sao Paulo 13083-859, Brazil — The face-centered cubic lattice structure of YRu3+ with the double perovskite Sr2YRuO6 shows a delicate three dimensional antiferromagnetic (AFM) ground state composed of stacked square AFM layers. We present new inelastic neutron scattering data taken on this state revealing a gapped low-energy excitation band that may be modeled by a simple J1 - J2 interaction scheme allowing quantitative comparison of similar materials. At higher temperatures, the low-energy excitation spectrum is dominated by a quasi-elastic component associated with size fluctuations of two-dimensional AFM clusters that exhibit asymmetric correlations even at low temperatures. Thus, the FCC lattice in general and the double perovskite structure in particular emerge as hosts of both two-dimensional and three-dimensional dynamics resulting from frustration.

10:30AM K5.00012 Unanticipated spin gap measured in the frustrated quasi-FCC d3 double perovskites La2−xAixLiXO6 (X = Ru, Os), DALINI D MAHARAJ, GABRIELE SALA, CASEY A MARJERRISON, JOHN GREEDAN, BRUCE GAULIN, McMaster University, MATTHEW STONE, Spallation Neutron Source, Oak Ridge National Laboratory — There is much current interest in the influence of strong spin-orbit (SO) interactions on exotic ground state selection in new 4d and 5d magnets, particularly involving 4d3+ and 5d6+ ions. Here we consider double perovskites of the form A2BB’O6 which are based on heavy 4d or 5d magnetic ions, where the SO interaction is expected to be significant as it increases as ∼ A2. The double perovskite structure can accommodate a variety of magnetic ions on the B’ site, providing a playground for systematic studies of the exotic ground states stabilized by strong SO coupling. Here, we report inelastic neutron scattering (INS) measurements conducted on the frustrated monclinic magnets, La2LiXO6 (X = Ru, Os), wherein the magnetic moments decorate a quasi face-centered-cubic lattice. Our results show the development of a spin gap in the spin excitation spectrum of size △O6 = 8 meV and △Ru = 2.5 meV concomitant with TN, which is unexpected for orbitally quenched d3 systems. We liken these results to INS results obtained for Ba2YXO6 and La2NaXO6, which were also shown to exhibit spin gaps that correlate with TN. We shall discuss trends observed in these three d3 double perovskite families which correlate strongly SO coupling, spin gap and TN.

10:48AM K5.00013 Raman spectroscopy study of spin-orbital liquid candidate FeSc2S4, STREIT CUNNINGHAM, K.W. PLUMB, Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland, USA, J.R. MOREY, T.M. MCQUEEN, Department of Chemistry, Johns Hopkins University, Baltimore, Maryland, USA, S. KOOPPAYEH, C.L. BROHOLM, NATALIA DRICHKO, Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland, USA — The A-site cubic spinel FeSc2S4, containing Fe2+ ions in a tetrahedral S1 environment, represents a rare candidate of a spin-orbital liquid, where spin and orbital order remain suppressed down to the lowest measurable temperature [1]. We studied phonon spectrum and orbital excitations in FeSc2S4 by Raman spectroscopy on single crystals. At temperatures below 100K we observe widening of sulfur 330 cm−1 T2g and 365 cm−1 A1g phonon modes with an additional weak mode emerging at 400 cm−1. These changes can indicate weak lattice distortions associated with the sulfur sites. Below 100K we also observe orbital excitations at frequencies of approximately 2000 cm−1. We discuss the result in terms of a competition of spin-orbital liquid and a magnetically ordered state. [1] L. Mittelstadt et al., Phys. Rev. B 91 125112 (2015).

1 This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46454.

Wednesday, March 16, 2016 8:00AM - 11:00AM
Session K6 GMAG DMP: Ruthenates 302 - Songxue Chi, Oak Ridge National Laboratory

8:00AM K6.00001 Tuning quantum properties in bilayer ruthenates, XIAONGLIN KE, Michigan State University — The mutual coupling among spin, charge, lattice and orbital degrees of freedom in transition-metal oxide materials often leads to the competition of various types of energetic states. This makes such materials dramatically susceptible to external parameters, giving rise to novel physical properties and rich phase diagrams. In this talk, I shall use a bilayer ruthenate, Ca3Ru2O7, as an example to discuss the emergent phenomena achieved by systematically tuning materials magnetic and electronic properties via chemical doping, magnetic field, and pressure. I shall show that this system provides a rare opportunity to investigate the interplay between correlated metal and Mott insulator. This work was done in collaboration with M. Zhu, T. Tao, S. D. Mahanti, Z. Q. Mao, J. Peng, T. Hong, W. Tian, H. Cao, C. R. dela Cruz, D. Singh, and K. Prokes.
8:36AM K6.00002 Metamagnetism and Nonlinear Susceptibilities in the Bilayer Ruthenate Sr$_3$Ru$_2$O$_7$\textsuperscript{1}. D. PHELAN, Argonne National Labs, B. SHIVARAM, Univ of Virginia, A. VECCHIONE, ROSALBA FITTIPALDI, CNR-SPIN and Dipartimento di Fisica, Salerno, Italy — We report measurements of the third and fifth order nonlinear susceptibilities in the correlated oxide metamagnet, Sr$_3$Ru$_2$O$_7$ for both orientations of the magnetic field, $H$ parallel to the c-axis and in the basal plane. In both geometries we observe peaks in the temperature dependence of the higher order susceptibilities. The position in temperature where the peak in the fifth order susceptibility occurs is at half the temperature where a peak in the third order susceptibility is seen. The latter in turn is at half the temperature where the peak in the linear susceptibility is known to occur. This simple scaling is common to both orientations of the magnetic field. These results will be discussed in the context of similar work with heavy fermion metamagnets\textsuperscript{1}.

\textsuperscript{1}Universality in the Magnetic Response of Metamagnetic Metals“, B.S. Shivaram, D.G. Hinks, and Pradeep Kumar, Phys. Rev. B89, 241107(R), 2014.

8:48AM K6.00003 Structure-magnetism correlation induced by Mn substitution in bilayered perovskite Sr$_3$(Ru$_{1-x}$Mn$_x$)$_2$O$_7$\textsuperscript{1}. QIANG ZHANG, Louisiana State Univ - Baton Rouge, FENG YE, SONGXUE CHI, Oak Ridge National Laboratory, DALGIS MESA, Louisiana State Univ - Baton Rouge, WEI TIAN, Oak Ridge National Laboratory, RONGYING JIN, WARD PLUMMER, JIANGDI ZHANG, Louisiana State Univ - Baton Rouge — Elastic neutron scattering technique was employed to investigate the effect of Mn substitution on the structure, magnetism and their correlation in Sr$_3$(Ru$_{1-x}$Mn$_x$)$_2$O$_7$ ($x=6\%$, $12\%$ and $16\%$) crystals. While parent compound Sr$_3$Ru$_2$O$_7$ is paramagnetic, a small amount of Mn substitution induces an E-type antiferromagnetic order. With the increase of Mn substitution from 6 $\%$ to 16 $\%$, the ordered moment at Ru/Mn site increases significantly with an enhanced $T_N$ from 20 K for $x=6\%$ to 80 K for $x=16\%$, and the in-plane magnetic correlation lengths increase to achieve the maximum for $x=16\%$ as indicated by the resolution-limited width of the $H$-scans through $Q_{AFM} = (0.5, 0, 0)$. Accompanied by the enhancement of $T_N$, the (Ru/Mn)$_{O_6}$ octahedron rotation is found to be suppressed simultaneously, suggesting a correlation between (Ru/Mn)$_{O_6}$ octahedron rotation and magnetism due to Mn substitution. Our findings indicate that Mn substitution on Ru in Sr$_3$Ru$_2$O$_7$ has a significant effect on the microscopic structure and magnetism as well as between them.

\textsuperscript{1}This work is supported by the U.S. Department of Energy under EPSCoR Grant No. DE-SC0012432 with additional support from the Louisiana Board of Regents.

9:00AM K6.00004 Magnetic phase separation in double layer ruthenates Ca$_3$(Ru$_{1-x}$Ti$_x$)$_2$O$_7$, JIN PENG, Nanjing University, JINYU LIU, JIN HU, ZHIQIANG MAO, Tulane University, XIAOSHAN WU, Nanjing University — Ti doping of a small concentration in the double-layered ruthenate Ca$_3$(Ru$_{1-x}$Ti$_x$)$_2$O$_7$ was previously found to induce an unusual magnetic phase transition from a metallic antiferromagnetic state formed from anti-parallel stacking of ferromagnetic bilayers (AFM-b) to a nearest-neighbor antiferromagnetic state (G-AFM) with Mott insulating properties; the critical Ti concentration for the transition is near $x = 0.03$. In this article, we conducted systematic studies on this magnetic transition near the critical composition through detailed magnetization measurements. We found that no intermediate magnetic phases exist between AFM-b and G-AFM states; this is contrasted with manganites where a similar magnetic phase transition takes place through the presence of several intermediate magnetic phases. The AFM-b-to-G-AFM transition in Ca$_3$(Ru$_{1-x}$Ti$_x$)$_2$O$_7$ happens through a phase separation process; the AFM-b and G-AFM phases coexist in the 2-5

9:12AM K6.00005 Field-controlled spin-density-wave order and quantum critically in Sr3Ru2O7, STEPHEN HAYDEN, University of Bristol — The quasi-2D metamagnetic perovskite metal Sr$_3$Ru$_2$O$_7$ has been an enigma for the last decade. The application of a large magnetic field of 8T parallel to the c-axis creates a new phase at low temperatures. This phase shows “electronic nematic” properties in that strong anisotropy its resistivity can be created by tilting the field away from the c-axis. In addition, measurement of transport and thermodynamic properties suggest that the phase is at the centre of a quantum critical region. Here we use neutron scattering to show that the magnetic order parameter, the (Ru/Mn)$_{O_6}$ octahedron rotation and magnetism due to Mn substitution. Our findings indicate that Mn substitution on Ru in Sr$_3$Ru$_2$O$_7$ has a significant effect on the microscopic structure and magnetism as well as between them.

9:48AM K6.00006 Magnetic-field-induced first-order phase transitions in Ca$_3$(Ru$_{1-x}$Fe$_x$)$_2$O$_7$ with unusual irreversible behaviors, MENGZE ZHU, Michigan State Univ, JIN PENG, Nanjing University, CHINA, TAO ZOU, Michigan State Univ, TAO RONG, Oak Ridge National Lab, KAREL PROKES, Helmholtz Zentrum Berlin, Germany, S. D. MAHANTI, Michigan State Univ, ZHIQIANG MAO, Tulane University, XIAOLING KE, Michigan State Univ — Neutron diffraction measurements reveal a magnetic-field-induced incommensurate-commensurate magnetic structure transition in a bilayer ruthenate Ca$_3$(Ru$_{1-x}$Fe$_x$)$_2$O$_7$ ($x = 0.05$). The transition is of first-order in nature, and exhibits intriguing irreversible behaviors at low temperature, i.e. the zero-field incommensurate state before and after field sweeping showing very distinct magnetic ordering wave vectors. The difference in the wavelength of magnetic ordering is strongly temperature dependent, and disappears gradually as temperature raises. This unusual irreversibility in magnetic ordering vector is rarely observed, and in disagreement with phase coexistence phenomena that is commonly seen in other irreversible first-order phase transitions. Nevertheless, our results demonstrate that thermal fluctuations also play an essential role in this unusual behavior.

10:00AM K6.00007 Unconventional Magnetic Domains in Triple-layered Sr$_3$Ru$_2$O$_{10}$\textsuperscript{1}. KAI DING, SEONG JOON LIM, JAE WOOK KIM, Rutgers Univ, GANG CAO, University of Kentucky, SANG WOOK CHEONG, Rutgers Univ, RUTGERS CENTER FOR EMERGENT MATERIALS, CENTER FOR ADVANCED MATERIALS, UNIVERSITY OF KENTUCKY COLLABORATION — A plethora of fascinating phenomena including p-wave superconductivity in Sr$_3$Ru$_2$O$_{10}$ ($n=1$) and hybrid improper ferroelectricity in Ca$_3$Ru$_2$O$_{10}$ ($n=2$) have been observed in Ruddlesden-Popper ruthenates (Ce, Sr)$_x$Ru$_{1+2}$O$_{3n+1}$. The triple-layered Sr$_3$Ru$_2$O$_{10}$ ($n=3$) is believed to have an intriguing complex magnetic state, compared with its neighboring bi-layered meta-magnetic Sr$_3$Ru$_2$O$_{10}$ ($n=2$) and ferromagnetic Sr$_3$Ru$_2$O$_{10}$ ($n=\infty$). The phase competition nature associated with this complexity is considered to be responsible for its novel properties such as coupled anisotropic magnetism and transport, low frequency quantum oscillations and sharp magneto-resistivity steps, which are still not well understood yet. To better understand its microscopic mechanism, we studied the magnetic domain structure on Sr$_3$Ru$_2$O$_{10}$ using low-temperature magnetic force microscopy. The observed unique domain structures in Sr$_3$Ru$_2$O$_{10}$ may shed lights on its microscopic phase competition nature and lead to a deeper understanding on its relations with other layered ruthenates.

\textsuperscript{1}This work is funded by the Gordon and Betty Moore Foundations EPiQS Initiative through Grant GBMF4413 to the Rutgers Center for Emergent Materials.
10:12AM K6.00008 Dynamical mean field study of ferromagnetism and correlation strength in cubic barium ruthenate: results and comparison to strontium and calcium ruthenate. QIANG HAN, Department of Physics, Columbia University, New York, New York 10027, USA; HUNG DANG, Institute for Theoretical Solid State Physics, JARA-FIT and JARA-HPC, RWTH Aachen University, 52056 Aachen, Germany, ANDREW MILLIS, Department of Physics, Columbia University, New York, New York 10027, USA — We present density functional plus dynamical mean fields of cubic BaRuO$_3$ using interaction parameters previously found to be appropriate for the related materials CaRuO$_3$ and SrRuO$_3$. The calculated trends in material properties across this family of compounds are in good agreement with experiment and the results provide insights into the origin of magnetism and the role of the van Hove singularity in the physics of Hunds metals.

10:24AM K6.00009 Ferromagnetic cluster glass state induced by non-magnetic ions in a paramagnetic host. TAKAFUMI D. YAMAMOTO, Department of Physics, Nagoya University, Nagoya 464-8602, RYUJI OKAZAKI, Department of Physics, Faculty of Science and Technology, Noda 278-8510, HIROKI TANIGUCHI, ICHIRO TERASAKI, Department of Physics, Nagoya University, Nagoya 464-8602 — A paramagnetic metal CaRuO$_3$ has been known to show unique impurity effects, where a magnetic ordering is induced by a partial substitution of transition metal ions for Ru. Since this phenomenon occurs regardless of the magnetism of the substituted ions, it must reflect a magnetic instability of this ruthenate. Understanding such physical properties is one of intriguing issues in condensed matter physics.

In this talk, we report an unconventional magnetic state induced by substituting non-magnetic Sc$^{3+}$ ions. We find that the static magnetic susceptibilities of all Sc-substituted samples show ferromagnetic-like features below 40 K, while the Curie-Weiss temperature dramatically changes with increasing $x$. This inconsistency is a sign of non-uniform magnetic system. We propose a phenomenological model and show that the static magnetic properties can be described as a volume average of a paramagnetic component originated from Ru$^{4+}$ ions and a ferromagnetic one driven by Sc substitution [T. D. Yamamoto et al., JPSJ 84, 014708 (2015)]. Furthermore our dynamic magnetic measurements reveal a ferromagnetic cluster glass state embedded in the paramagnetic and metallic host of CaRuO$_3$.

10:36AM K6.00010 Suppression of ferromagnetism and observation of quantum well states in epitaxial thin films of the cubic ruthenate BaRuO$_3$. BULAT BURGANOV, Department of Physics, Cornell University, HANJONG PAIK, Department of Materials Science and Engineering, Cornell University, KYLE SHEN, Department of Physics, Cornell University, DARRELL SCHLOM, Department of Materials Science and Engineering, Cornell University — The pseudocubic perovskite ruthenates ARuO$_3$, where A is alkaline earth metal, are correlated materials where Hund’s coupling drives correlations and leads to a low coherence scale, large renormalization, and formation of local moments. The ferromagnetic BaRuO$_3$ has an ideal cubic structure and a larger bandwidth, compared to its GdFeO$_3$-distorted counterparts, CaRuO$_3$ and SrRuO$_3$. In stark contrast to SrRuO$_3$, which is a Fermi liquid below $T_C$, BaRuO$_3$ exhibits critical fluctuations near $T_C$ that are enhanced under hydrostatic pressure, which suppresses the Fermi liquid coherence scale and $T_C$ and drives a crossover into non-FL regime. Here we use ARPES to characterize the momentum-resolved electronic structure of strained ultrathin BaRuO$_3$ films grown in situ by molecular beam epitaxy. The films on STO (001) are metallic down to 2 u.c. thickness and manifest clearly defined subbands of well-defined quasiparticles which arise due to quantum confinement effects. We observe that the bands are moderately renormalized compared to bare GGA bands and discover that the ferromagnetism can be suppressed in the atomically thin limit. We discuss our results on BaRuO$_3$ in the context of our recent ARPES studies of the other perovskite ruthenates, SrRuO$_3$ and CaRuO$_3$.

10:48AM K6.00011 Antiferromagnetism in Bulk Rutile RuO$_2$. T. BERLIN, Oak Ridge National Laboratory, P. C. SNIJDERS, P. R. C. KENT, T. A. MAIER, Oak Ridge National Laboratory, University of Tennessee, H.-D. ZHOU, University of Tennessee, H.-B. CAO, O. DELAIRE, Y. WANG, Oak Ridge National Laboratory, M. KOEHLER, University of Tennessee, H. H. WEITERING, University of Tennessee, Oak Ridge National Laboratory — While bulk rutile RuO$_2$ has long been considered to be a Pauli paramagnet, we conclude it to host antiferromagnetism based on our combined theoretical and experimental study. This important finding given the large amount of applications of RuO$_2$ in the electrochemical and electronics industry. Furthermore the high onset temperature of the antiferromagnetism around 1000K together with the high electrical conductivity makes RuO$_2$ unique among the ruthenates and among oxide materials in general.

$^1$This work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

Wednesday, March 16, 2016 8:00AM - 11:00AM — Session K11 DMP: GMAG - Electronic Structure and Magnetism in Fe-based Superconductors

8:00AM K11.00001 Orbital-dependent electron correlation effects in iron-based superconductors. MING YI, Univ of California - Berkeley — The iron chalcogenide superconductors constitute arguably one of the most intriguing families of the iron-based high temperature superconductors due to their ability to superconduct at comparable temperatures as the iron pnictides, despite the lack of similarities in their magnetic structures and Fermi surface topologies. In particular, the hole Fermi pockets at the Brillouin zone center poses a challenge to the previous proposal of spin fluctuation mediated pairing via Fermi surface nesting. In this talk, using angle-resolved photoemission spectroscopy measurements, we will present evidence that show that instead of Fermi surface topology, strong electron correlation observed in electron bandwidth is an important ingredient for superconductivity in the iron chalcogenides. Specifically, I will show i) there exists universal strong orbital-selective renormalization effects and proximity to an orbital-selective Mott phase in Fe$_{1+y}$S$_{1-x}$Se$_x$, A$_2$Fe$_2$Se$_2$, and monolayer FeSe film on SrTiO$_3$ [1,2], and ii) in Rb$_{0.5}$Fe$_2$(Se$_{1-x}$S$_x$)$_2$, where sulfur substitution for selenium continuously suppresses superconductivity down to zero, little change occurs in the Fermi surface topology while a substantial reduction of electron correlation is observed in an expansion of the overall bandwidth, implying that electron correlation is one of the key tuning parameters for superconductivity in these materials. [1] M. Yi et al. Phys. Rev. Lett. 110, 067003 (2013). [2] M. Yi et al. Nat. Comm. 6, 7777 (2015). [3] M. Yi et al. arXiv: 1505.06636.

8:36AM K11.00002 Bandwidth-controlled metal-superconductor-insulator phase diagram in iron-chalcogenides. XIAOHAI NIU, SUDI CHEN, JUAN JIANG, ZIRONG YE, TIANLUN YU, YAJUN YAN, XIAOHAI NIU, SUDI CHEN, JUAN JIANG, ZIRONG YE, TIANLUN YU, YAJUN YAN, MIN XU, YU FENG, YAJUN YAN, BINFENG JUN, ZHOU JUN, FUDAN University, DACHUN GU, LILING SUN, Institute of Physics, Chinese Academy of Sciences, QINHUI MAO, HANGDONG WANG, MINHUA FANG, ZEJIANG University, C. J. ZHANG, High Magnetic Field Laboratory, Chinese Academy of Sciences and High-field Technology of China, J. P. HU, Institute of Physics, Chinese Academy of Sciences, ZHE SUN, National Synchrotron Radiation Laboratory, University of Science and Technology of China, DONGLAI FENG, Fudan University — Using angle-resolved photoemission spectroscopy, we studied isovariantly doped K$_x$S$_y$Fe$_z$(S$_{2-y}$S$_{2-z}$)$_{2-z}$S$_x$, Rb$_x$S$_y$Fe$_z$(S$_{2-y}$S$_{2-z}$)$_{2-z}$S$_x$ and (Ti,K)$_x$S$_y$Fe$_z$(S$_{2-y}$S$_{2-z}$)$_{2-z}$S$_x$, in which the superconducting transition temperature decreases with either positive or negative chemical pressures. The bandwidths of Fe 3d bands in the energy window of [0, -0.5]eV in these materials change systematically with doping: with the decreasing of bandwidth, the ground state evolves from a metal to a superconductor, and eventually to an insulator. This systematic study of electronic structures discovered the correlation-driven insulator state by tuning the bandwidth, which is independent with carrier density. The results also indicate that moderate correlation strength is beneficial to enhance superconductivity.
8:48AM K11.00003 ARPES investigation of heavily hole-doped Fe-based superconductor (Ba,K)Fe$_2$As$_2$. XUN SHI, PIERRE RICHARD, PENG ZHANG, AMBROISE VAN ROEKEGHEM, TIAN QIAN, JIANGPING HU, HONG DING, Chinese Academy of Sci (CAS), DELONG FANG, HAIHUI WEN, Nanjing University, NAN XU, MING SHI, Paul Scherrer Institut, TIMUR KIM, MORITZ HOESCH, Diamond Light Source. XIANHUI CHEN, University of Science and Technology of China, PHOTOELECTRON SPECTROSCOPY RESEARCH TEAM, NANNING UNIVERSITY COLLABORATION, PAUL SCHERRER INSTITUT COLLABORATION, DIAMOND LIGHT SOURCE COLLABORATION, UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA COLLABORATION — A Lifshitz transition occurs in the (Ba,K)Fe$_2$As$_2$ family upon K doping and electron pocket are absent in the heavily doped compounds, including KFe$_2$As$_2$. The pairing symmetry is argued to undergoes a phase transition due to the existence of gap node(s) reported in various experiments. In this work we present angle-resolved photoemission spectroscopy and scanning tunneling spectroscopy studies of KFe$_2$As$_2$. We observe a van Hove singularity (vHs) in proximity of the Fermi level ($E_F$), which locates in the middle of the principal axes of the first Brillouin zone. The density-of-states at $E_F$ mainly comes from the vHs whereas it is non-gapped in the superconducting state. Our observation provides natural explanations for many novel behaviors in this material. In particular, it is consistent with our measurements of the gap structure in Ba$_{1-x}$K$_x$Fe$_2$As$_2$. All these results suggest that Cooper pairing is induced by a strong-coupling mechanism.

9:00AM K11.00004 Persistence of Dirac Node near Antiferromagnetic-to-Superconducting Phase Boundary in Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$. HITOSHI TAKITA, NAOYA KISHIMOTO, YOUSUKE NAKASHIMA, Hiroshima University, AKIHIRO INO, MASASHI ARITA, HIROHUMI NAMATAME, MASAKI TANIGUCHI, Hiroshima Synchrotron Radiation Center, YOSHIHIRO AIURA, IZUMI HASE, HIROSHI EI SAKI, KUNIHIRO KIHOU, CHUL-HO LEE, AKIRA IYO, National Institute of Advanced Industrial Science and Technology, MASAMICHI NAKAJIMA, Osaka University, SHIN-ICHI UCHIDA, University of Tokyo, HIROSHIMA UNIVERSITY TEAM, HIROSHIMA SYNCHROTRON RADIATION CENTER TEAM, NATIONAL INSTITUTE OF INDUSTRIAL SCIENCE AND TECHNOLOGY TEAM, OSAKA UNIVERSITY TEAM, UNIVERSITY OF TOKYO TEAM — Since the ground state of iron-pnictides changes from an antiferromagnetic (AF) phase to a superconducting (SC) phase, the evolution of electronic structure has attracted much attention. However, systematic investigation has been hindered by the intricate multiple bands arising from the orbital degree of freedom of iron 3d states. Here we performed a polarization-dependent ARPES study of Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ across the AF-SC phase boundary. The doping dependence of ARPES spectra has shown that the Dirac node reported in the AF phase of BaFe$_2$As$_2$ persists in $x=0.04$ near the AF-SC phase boundary, and that it disappears in the SC phase of $x=0.05$. We parametrized the cone-like dispersion in $x=0.04$. The polarization-dependence of our ARPES spectra is consistent with the view that the Dirac node is protected by Berry phase arising from orbital degree of freedom under the inversion symmetry.

9:12AM K11.00005 Orbital selective correlation reduce in collapse tetragonal phase of CaFe$_2$(As$_{0.935}$P$_{0.065}$)$_2$ and electronic structure reconstruction studied by angle resolved photoemission spectroscopy. LINGKUN ZENG, Chinese Academy of Sci (CAS) — We performed an angle-resolved photoemission spectroscopy (ARPES) study of the CaFe$_2$(As$_{0.935}$P$_{0.065}$)$_2$ in the collapse tetragonal (CT) phase and uncollapse tetragonal (UCT) phase. We find in the CT phase the electronic correlation dramatically reduces respective to UCT phase. Meanwhile, the reduction of correlation in CT phase show an orbital selective effect: correlation in $d_{xy}$ reduces the most, and then $d_{xz/yz}$, while the one in $d_{2z^2-r^2}$ almost keeps the same. In CT phase, almost all bands sink downwards to higher binding energy, leading to the hole like bands around Brillouin zone (BZ) center sink below $E_F$ compared with UCT phase. However, the electron pocket around Brillouin Zone (BZ) corner (M) in UCT phase, forms a large movement down to higher binding energy, resulting in farther away from $d_{xy}$ and closer to $d_{xz}$. We propose the electron filling, namely high spin state in UCT phase to low spin state in CT phase (due to competing between crystal structure field and Hund’s coupling), other than the Fermi surface nesting might be responsible for the absence of magnetic ordering.

9:24AM K11.00006 Effect of directional strain on the phase diagram of Ca(Fe$_{1-x}$Co$_x$)$_2$As$_2$. A. E. BÖHMER, G. DRACHUK, M. A. TANATAR, S. L. BUD’KO, R. PROZOROV, P. C. CANFIELD, Ames Laboratory and Iowa State University — The iron-based superconductor Ca(Fe$_{1-x}$Co$_x$)$_2$As$_2$ is exceptionally sensitive to directional stress with $ab$-plane compression stabilizing and $c$-axis compression destabilizing the orthorhombic antiferromagnetic phase [1]. Due to differential thermal expansion between a sample and a substrate, an effective in-plane compressive strain can be exerted on it upon cooling. We found that this strain induces a phase transition even in overdoped compounds, does not occur in the unstrained state. The induced transition has been characterized by 4-probe resistivity, elastoresistivity (the derivative of resistivity with respect to deformations), polarized light microscopy and Mössbauer spectroscopy. We found a pronounced increase of the resistivity and a divergence of the elastoresistivity coefficients, which is a signature of the tetragonal-to-orthorhombic transition in other iron-based superconductors. The polarized light images directly show the formation of a particularly rich domain pattern below the transition in these samples. This work was supported by the Ames Laboratory, US DOE, under Contract No. DE-AC02-07CH11358. [1] Bud’ko et al., PRB 88,064513 (2013).

9:36AM K11.00007 Quantum fluctuations in iron-pnictide superconductor BaFe$_2$(As$_{1-x}$P$_x$)$_2$. LEI SHU, Z. F. DING, J. ZHANG, C. TAN, K. HUANG, Fudan University, Shanghai, China, L. LIU, S. CHEUNG, J. Y. UEMURA, Columbus University, D. E. MACLAUGLISH, University of Riverside, O. O. BERNAL, California State University, Los Angeles, P.-C. HO, California State University, Fresno, D. HU, Chinese Academy of Sciences, P.C. DAI, Rice University — Muon-spin-relaxation/rotation ($\mu$SR) experiments were performed on single crystals of iron-pnictide superconductors BaFe$_2$(As$_{1-x}$P$_x$)$_2$ ($x=0.28, 0.30$, and $0.33$). Our preliminary results reveal that the static muon relaxation rate from $ZF\mu$SR measurements is temperature independent through $T_c$, suggesting that time reversal symmetry is preserved in the superconducting state. Above $T_c$, the field dependence of muon relaxation rate shows NFL behaviors for optimal composition $x=0.3$. A maximum of zero temperature penetration depth at $x=0.3$ is also observed.

This work was supported by Chinese NSF, grant 1147060, US NSF, grant DMR-1506677 and DMR-1105380.

9:48AM K11.00008 Soft-mode transitions of alkaline-earth 122 pnictides. MICHAEL WIDOM, Carnegie Mellon University, KHANDKER QUADER, Kent State University — A$_2$-122 pnictides (A=Ca, Sr, Ba) exhibit three pressure-driven transitions: a first order enthalpic transition at $P_{H1}$ from the striped AFM orthorhombic (OR) to a tetragonal (T) or a collapsed tetragonal (cT) phase; a transition at $P_{H2}>P_{H1}$ from the metastable OR AFM to a T or cT phase; a Lifshitz transition at $P_{L}$ that causes T to collapse to a cT phase. Transitions at $P_{H1}$ and $P_{L}$ were previously examined through total energy and band structure calculations. Here we address the transition at $P_{H1}$, beyond which the metastable AFM OR state ceases to exist. We show this transition occurs through a loss of elastic stability caused by softening of a shear mode associated with stretching along the c-axis. Simultaneously, magnetism and orthorhombicity approach lifting values with an approximately square-root singularity. Together these suggest a strong magneto-elastic coupling that may be relevant to a further understanding of the A$_2$-122-pnictides under pressure.

This work was supported in part by the DOE under grant DE-SC0014506.


4M. Widom and K. Quader, arXiv:1508.07932
Correlation driven dimensional reduction in a two orbital Hubbard model

10:00AM K11.00009 Correlation driven dimensional reduction in a two orbital Hubbard model

10:00AM Anamitra Mukherjee, University of Tennessee, Knoxville, Tennessee 37996, USA. National Institute of Science Education and Research, India. Nirav Kumar Patel, Adrianna Moreo, Elbio Dagotto, University of Tennessee, Knoxville, Tennessee 37996, USA — We apply a recently developed many-body technique that allows for the incorporation of thermal effects, to a two orbital Hubbard model of relevance for the pnictides. In this Mean Field-Monte Carlo (MF-MC) approach, we first perform a mean field (MF) decomposition of the Hubbard model and then treat the mean field parameters via the standard finite-temperature classical Monte Carlo (MC). We have earlier established [1] that for the one orbital Hubbard model, this MF-MC approach provides remarkable improvement over simple finite-temperature mean field methods and is in good agreement with Determinantal Quantum Monte Carlo results. In this talk we will discuss our MC-MF results applied to the two orbital Hubbard model with degenerate dxz and dyz orbitals for the undoped pnictides [2]. The onsite repulsion strength \(U\) vs. temperature phase diagram is rich and has a narrow window of nematicity above the Neel temperature. Our main result is the discovery of a novel intermediate coupling regime characterized by an unexpected spontaneous dimensional reduction that renders one direction insulating and the other metallic.


Testing The Constrained-Path Quantum Monte Carlo Method Using A One Dimensional Three Orbital Hubbard Model

10:12AM K11.00010 Testing The Constrained-Path Quantum Monte Carlo Method Using A One Dimensional Three Orbital Hubbard Model

10:12AM Guangkun Liu, Uniu of Tennessee, Knoxville and Beijing Normal University, Nitin Kaushal, Univ of Tennessee, Knoxville, Chris Bishop, Shuhua Liang, Univ of Tennessee, Knoxville and ORNL, Shaozhi Li, Steve Johnstone, Univ of Tennessee, Knoxville, Elbio Dagotto, Univ of Tennessee, Knoxville and ORNL — The “sign problem” usually prevents the large scale quantum Monte Carlo simulations of the multi-orbital Hubbard models. Projecting from a variety of initial states constructed via the Hartree-Fock technique, a constrained-path quantum Monte Carlo [1] (CPQMC) simulation has been carried out for the full one-dimensional three-orbital Hubbard model [2] and also for the same model but neglecting the pair-hopping and spin-flip interactions. The corresponding phase diagrams varying electronic density \(n\) and Hubbard \(U\) are constructed. Extensive comparisons with density matrix renormalization group and determinant quantum Monte Carlo results demonstrate that CPQMC is capable of capturing the physics of the orbital-selective Mott phase [2,3]. Our results also suggest that the spin-flip and pair-hopping interactions only have a limited effect on multi-orbital Hubbard model phase diagrams. [1] Guangkun Liu, Zhongbing Huang, and Yongjun Wang, J. Phys.: Condens. Matter 26, 325601(2014) [2] Julian Rincon, Adriana Moreo, Gonzalo Alvarez, and Elbio Dagotto, Phys. Rev. Lett. 112 106405 (2014) [3] Julian Rincon, Adriana Moreo, Gonzalo Alvarez, and Elbio Dagotto, Phys. Rev. B 90 241105(R)(2014)


10:24AM Nitin Kaushal, Guangkun Liu, Chris Bishop, Shuhua Liang, Shaozhi Li, Steve Johnstone, Department of Physics and Astronomy, The University of Tennessee, Knoxville, Elbio Dagotto, Department of Physics and Astronomy, The University of Tennessee, Knoxville and Oak Ridge National Laboratory — Using the Density Matrix Renormalization Group technique, we extensively study a three-orbital Hubbard model in one dimension without pair hopping and spin-flip Hund interactions. The phase diagram varying the electronic density \(n\) and Hubbard \(U\) is constructed and compared against previous results obtained using the full interaction Hamiltonian [1]. Our results suggest that spin-flip and pair hopping terms are not crucially important to address the orbital-selective Mott phase [1]. This analysis paves the way to study multiorbital Hubbard models using techniques such as the Constrained-Path Quantum Monte Carlo (CPQMC) and Determinant Quantum Monte Carlo (DQMC) methods since they perform better, reducing for instance the severity of the “sign problem”, in the absence of pair hopping and spin flip terms in the interaction.


Doping Evolution of Electronic Structure and Superconductivity in FeSe/SrTiO3 Films

10:36AM K11.00012 Doping Evolution of Electronic Structure and Superconductivity in FeSe/SrTiO3 Films

10:36AM Bing Shen, Yong Hu, Defa Liu, Jianwei Hu, School of Physics, Chinese Academy of Sciences, Lili Wang, Xucun Ma, Qikun Xue, State Key Lab of Physics, Tsinghua University, Chuangtian Chen, Zuyan Xu, Technical Institute of Physics, Zhiou, Institute of Physics, Chinese Academy of Sciences — The latest discovery of high temperature superconductivity in FeSe/SrTiO3 film has attracted extensive attention. Our previous ARPES studies on the single-layer and double-layer FeSe/SrTiO3 films from N-phase to S phase by vacuum annealing and get superconducting double-layer FeSe/SrTiO3 films doped and it remains in the semiconducting/insulating state. And our new ARPES results on the FeSe/SrTiO3 films with different layers (1UC, 2UC, 3UC) using potassium deposition, to increase the carrier concentration. As the result, we observed new phases. This systematic study will provide insight in understanding the evolution of electronic states of multiple-layer FeSe film and eventually to the bulk FeSe superconductor.

and MAR16-2015-004498

Electronic structure and lattice dynamics at the interface of single layer FeSe and SrTiO3

10:48AM K11.00013 Electronic structure and lattice dynamics at the interface of single layer FeSe and SrTiO3

10:48AM Towfiq Ahmed, Los Alamos National Laboratory, Alexander Balatsky, Los Alamos National Laboratory — Recent discovery of high-temperature superconductivity with the superconducting energy gap opening at temperatures close to or above the liquid nitrogen boiling point in the single-layer FeSe grown on SrTiO3 has attracted significant interest. It suggests that the interface effects can be utilized to enhance the superconductivity. It has been shown recently that the coupling between the electrons in FeSe and vibrational modes at the interface play an important role. Here we report on a detailed study of electronic structure and lattice dynamics in the single-layer FeSe/SrTiO3 interface by using the state-of-art electronic structure method within the density functional theory. The nature of the vibrational modes at the interface and their coupling to the electronic degrees of freedom are analyzed. In addition, the effect of hole and electron doping in SrTiO3 on the electron-mode coupling strength is also considered.


This work was carried out under the auspices of the National Nuclear Security Administration of the U.S. DOE at LANL under Contract No. DE-AC52-06NA25396, and was supported by the DOE Office of Basic Energy Sciences.

Wednesday, March 16, 2016 8:00AM - 11:00AM –
Session K18 GMAG DMP FIAP: Spin-Hall III 317 - Benjamin Jungfleisch, Argonne National Laboratory
8:00AM K18.00001 Anomalous Hall effect in antiferromagnetic GdPtBi. TAKEHITO SUZUKI, ARAVIND DEVARAKONDA, YU-TING LIU, JOSEPH CHECKELSKY, Massachusetts Inst of Tech-MIT — The Berry phase of the electronic wave function is responsible for a transverse velocity of conducting carriers which results in anomalous Hall conductivity. This effect has been extensively investigated in ferromagnetic systems, but less is known in antiferromagnets. We have synthesized single crystals of GdPtBi, a metallic system which exhibits antiferromagnetic ordering below the transition temperature $T_N = 9$ K. We have investigated the electrical transport and magnetic properties of these crystals and found a distinct anomalous Hall effect response. We will discuss these observations in the context of the known mechanisms for anomalous velocity in ferromagnets and recent models unique to antiferromagnetic systems.

8:12AM K18.00002 Spin transport in antiferromagnetic insulator detected by spin pumping. WEI CAO, YI LI, WILLIAM BAILEY, Columbia Univ — Spin transport in antiferromagnetic insulators has drawn attention recently. Prior work has been done on the spin diffusion length of different antiferromagnetic materials via inverse spin Hall effect. In this work, we measure the spin pumping of Py/Cu/CoO to characterize the absorption of spin current in the CoO layer. The series of Py/Cu/CoO (t) with changing the thickness of CoO layer indicates that there is a Gilbert damping enhancement of 0.001 in saturation at about 2 nm at room temperature. The spin mixing conductance obtained from this experimental series and from Py (t)/Cu/CoO series is $2.4 \text{ nm}^{-2}$ and $3.2 \text{ nm}^{-2}$, respectively. We also measured the spin pumping of the Py/Cu/CoO sample at low temperatures. The Gilbert damping exhibits a positive peak at about 280 K, which is close to the Neel temperature of CoO. Our work shows a finite spin mixing conductance in Py/Cu/CoO and the spin diffusion length of CoO is quite small at room temperature. We also find that its Gilbert damping reaches its maximum value at Neel temperature.

8:24AM K18.00003 Spin current control of damping in YIG/Pt nanowires. CHRISTOPHER SAFRANSKI, IGOR BARSUKOV, HAN KYU LEE, University of California Irvine, TOBIAS SCHNEIDER, Helmholtz-Zentrum Dresden Rossendorf, ALEJANDRO JARA, ANDREW SMITH, University of California Irvine, HOUCHEM CHANG, 3 Colorado State University, YAROSLAV TSEKOVNYAK, University of California Los Angeles, ZHIGZHONG WU, 3 Colorado State University, ILYA KRIVOROTOV, University of California Irvine — Understanding of spin transport at ferromagnet/nanometal interfaces is of great importance for spintronics applications. We report the effect of pure spin currents in YIG(30 nm)/Pt(6 nm) nanowires. The samples show magneto-resistance from two distinct mechanisms: (i) spin Hall magnetoresistance (SMR) and (ii) inverse spin Hall effect (ISHE) along with spin Seebeck current (SSC) induced by Ohmic heating of the Pt layer. Using the SMR and ISHE effects, we measure the spin wave eigenmodes by spin-torque ferromagnetic resonance (ST-FMR). Direct current applied to the Pt layer results in injection of spin Hall current into YIG that acts as damping or anti-damping spin torque depending on the polarity. In addition, Ohmic heating gives rise to a SSC acting as anti-damping regardless of current polarity. ST-FMR reveals current-induced variation of the spin wave mode linewidth that is asymmetric in the bias current and decreases to zero for anti-damping spin Hall current. Near this current, we observe a complex interaction among the spin wave eigenmodes that we assess using micromagnetic simulations. Our results advance understanding of magnetization dynamics driven by pure spin currents.

8:36AM K18.00004 Spin Circuit Representation of Spin Pumping in Topological Insulators. KUNTAL ROY, Purdue University — Earlier we developed spin circuit representation of spin pumping and combined it with the spin circuit representation for the inverse spin Hall effect to show that it reproduces the established results in literature. Here we construct the spin circuit representation of spin pumping in topological insulators. The discovery of spin-polarized surface states in three-dimensional (3D) topological insulators (TIs) with strong spin-orbit coupling is promising for the development of spintronics. There is considerable bulk conduction too in 3D TIs (e.g., Bi$_2$Se$_3$). Spin pumping may serve as an effective way to detect spin-polarized surface states. There is considerable bulk conduction too in 3D TIs (e.g., Bi$_2$Se$_3$). Spin pumping revealed that Rashba-split 2DEG has comparable effects on the magnetization dynamics. From the change of gyromagnetic ratio, we calculated the damping constant saturated at the spin diffusion length of Bi$_2$Se$_3$.

8:48AM K18.00005 Spin pumping from a ferromagnet into a hopping insulator: Role of resonant absorption of magnons. MIKHAIL RAIKH, YUE ZHANG, DMYTRO PESIN, Univ of Utah — Motivated by recent experiments [1,2,3] on spin pumping from a ferromagnet into organic materials in which the charge transport is due to hopping, we study theoretically the generation and propagation of spin current in a hopping insulator. Unlike metals, the spin polarization at the boundary with ferromagnet is created as a result of magnon absorption within localized states and it spreads following the current-currying resistor network (although the charge current is absent). We consider a classic resonant mechanism of the ac absorption in insulators and adapt it to the absorption of magnons. A strong enhancement of pumping efficiency is predicted when the Zeeman splitting of the localized states in external magnetic field is equal to the frequency of ferromagnetic resonance. Under this condition the absorption of a magnon takes place within individual sites. We utilize the spin circuit model for spin orbittorques in topological insulator surface states [2] to develop the equivalent circuit model of spin pumping in topological insulators. Such equivalent circuit model developed here can be utilized to analyze available experimental results and evaluate more complex structures. [1] K. Roy et al., Spin Circuit Representation for Spin Pumping Phenomena, in APS March Meeting, Session Y28.12 (2015). [2] S. Hong, Spin Circuit Model for Spin-Orbit Torque in 2D Channels, in APS March Meeting, Session G52.1 (2015).

9:00AM K18.00006 Detection of topological surface states by spin pumping at room temperature. Y. T. FANCHIANG, C. K. CHENG, M. HONG, Graduate Institute of Applied Physics and Department of Physics, National Taiwan University, Taipei 10617, Taiwan, H. Y. LIN, K. H. CHEN, S. R. YANG, C. N. WU, J. KWO, Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan; S. F. LEE, Institute of Physics, Academia Sinica, Taipei 11529, Taiwan — Spin pumping on heterostructures made of ferromagnetic YIG film and topological insulator Bi$_2$Se$_3$ films has been performed at room temperature. In the presence of topological interface states, spin pumping induced non-equilibrium spin density caused significant resonance field shifts ($H_{|\Delta|}$ shifts) of YIG/Bi$_2$Se$_3$ with respect to bare YIG. The uncommon $H_{|\Delta|}$ shifts correspond to clearly resolved changes of gyromagnetic ratio of YIG. As the Bi$_2$Se$_3$ thickness varied from 4 nm to 20 nm, increasing $H_{|\Delta|}$ shifts were observed, while the enhancement of damping constant saturated at the spin diffusion length of Bi$_2$Se$_3$, suggesting the two parameters were of different origins. Bi$_2$Se$_3$ thickness dependence of spin pumping revealed that Rashba-split 2DEG has comparable effects on the magnetization dynamics. From the change of gyromagnetic ratio, we calculated the imaginary part of spin mixing conductance to be one order of magnitude larger than the real part. Our results showed that with clean and well-defined interface, spin pumping may serve as an effective way to detect spin-polarized surface states.
9:12AM K18.00007 Current-induced spin and orbital magnetizations in tellurium, TAIKI YODA, MOTOAKI HIRAYAMA, TAKEHITO YOKOYAMA, Department of Physics, Tokyo Institute of Technology, SHOJI ISHIBASHI, TAKASHI MIYAKE, Nanosystem Research Institute, AIST, SHUICHI MURAKAMI, Department of Physics, Tokyo Institute of Technology; TIES, Tokyo Institute of Technology — Tellurium has a characteristic helical lattice structure, and lacks mirror and mirror symmetries. Such chiral crystals lead to various novel phenomena. For example, we have shown that spin and orbital magnetisations are induced by an electric current in chiral crystals[1]. In our presentation, we calculate the current-induced spin and orbital magnetization in tellurium by using first-principles calculations. The calculations showed that both spin and orbital magnetizations are induced parallel to the electric current. In tellurium, we found that the orbital magnetization is larger than the spin magnetization by two orders of magnitude. The spin magnetization is induced by the current via the spin-orbit coupling. Therefore, the induced spin magnetization is limited by the size of the spin-orbit coupling. On the other hand, the orbital magnetization is determined by crystal structure without spin-orbit coupling. By using a chiral crystal, a magnetization can be induced by an electric current without ferromagnets and the spin-orbit coupling. [1]Yoda, T. et al. Sci. Rep. 5, 12024

9:24AM K18.00008 Enhanced spin Hall ratios by Al and Hf impurities in Pt thin films1, MINH-HAI NGUYEN, MENGNAN ZHAO, DANIEL C. RALPH, ROBERT A. BUHRMAN, Cornell Univ — The spin Hall effect (SHE) in Pt has been reported to be strong and hence promising for spintronic applications. In the intrinsic SHE mechanism, which has been shown to be dominant in Pt, the spin Hall conductivity is constant, depending only on the band structure of the spin Hall material. The spin Hall ratio \( \theta_{SH} \) is on the other hand, should be proportional to the electrical resistivity \( \rho \) of the spin Hall layer. This suggests the possibility of enhancing the spin Hall ratio by introducing additional diffusive scattering to increase the electrical resistivity of the spin Hall layer. Our previous work has shown that this could be done by increasing the surface scattering by growing thinner Pt films in contact with higher resistivity materials such as Ta. In this talk, we discuss another approach: to introduce impurities of metals with negligible spin orbit torque into the Pt film. Our PtAI and PtHf alloy samples exhibit strong enhancement of the spin Hall torque efficiency with impurity concentration due to increased electrical resistivity.

9:36AM K18.00009 Large Spin Hall Angle in Vanadium Film, TAO WANG, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 USA, XIN FAN, Department of Physics and Astronomy, University of Denver, Denver, CO 80208 USA, WENRUI WANG, Department of Physics, University of Illinois, Urbana, IL 61801 USA, YUNSONG XIE, MUHAMMAD A. WARSI, JUN WU, YUNPENG CHEN, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 USA, VIRGINIA O. LORENZ, Department of Physics, University of Illinois, Urbana, IL 61801 USA, JOHN Q. XIAO, Department of Physics and Astronomy, University of Delaware, Newark, DE 19716 USA — We report on the large spin Hall angle observed in Vanadium film with small grain size and distorted lattice parameter. The spin Hall angle is quantified by measuring current-induced spin-orbit torque in V/CoFeB bilayer using optical spin torque magnetometer based on polar magneto-optical Kerr effect (MOKE). The spin Hall angle as large as \( \theta_{SH} = 0.071 \) has been observed in V/CoFeB bilayer. Structure analysis, using X-ray diffraction (XRD), transmission electron microscopy (TEM) and selected area electron diffraction (SAED), confirms films grown at room temperature have very small grain size and enlarged lattice parameter. The Vanadium films with distorted crystal structure also have high resistivity (>200 \( \mu \)Ω·cm) and long spin diffusion length (16.3 nm) measured via spin pumping experiment. This finding of spin Hall effect enhancement in more disordered structure will provide insights for understanding and exploiting materials with strong spin orbit interaction, especially in high-quality spintronic devices.

9:48AM K18.00010 Spin-orbit torques and charge pumping in crystalline magnets, CHIARA CICARELLI, Univ of Cambridge — In magnetic crystals with an inversion asymmetric unit cell a non-zero global spin-polarization is generated by an electrical current, which acts on the torque on the magnetization exciting magnetic dynamics [1]. This relativistic non-equilibrium spin phenomenon also has a reciprocal effect in which the excitation of magnons results in the pumping of a charge current [2]. The possibility to manipulate/read magnetism with electrical currents is highly relevant for magnetic memories and other spintronic devices. I will start by reviewing our recent research on spin-orbit torques (SOTs) in crystalline magnets, in particular our very recent measurements of the crystalline SOT at room temperature in half-Heusler NiMnSb thin films. With this experiment we are able to fully characterise magnitude and symmetry of the SOTs [3, 4]. I will then talk about the first demonstration of magnonic charge pumping in crystal magnet GaMnAs [2]. In this effect, which is the reciprocal effect of SOTs, the precessing ferromagnet pumps a charge current. Differently from spin pumping, which is commonly used to electrically detect magnetization dynamics, in charge pumping magnons are converted within the ferromagnet into high-frequency currents via the relativistic spin-orbit interaction, without the need of a secondary spin-charge conversion element, such as heavy metals with large spin Hall angle. Reference 1. Chernyshov et al., Nature Physics 5, 656 (2009). 2. Ciccarelli et al., Nature nanotechnology 10, 50 (2014). 3. Fang et al., Nature Nanotechnology 6, 413 (2011). 4. Kurebayashi et al., Nature Nanotechnology 9, 211 (2014).

10:24AM K18.00011 Study on special anisotropy of spin mixing conductance, XIAOLONG FAN, HENGAN ZHOU, Lanzhou University, LI MA, SHIMING ZHOU, Tongji University, DESHENG XUE, Lanzhou University — Spin pumping, a promising technique for generating pure spin current via ferromagnetic resonance (FMR), can pump nonequilibrium magnetization through the interface between normal metal (NM) and ferromagnetic metal or ferromagnetic insulator. The efficiency of spin current injection is determined by spin mixing conductance (SMC). In this work, we systematically investigated the values of the SMC in NM/Pt, Pd, W, Mo)/YIG systems. By using cavity FMR, we found that the SMC has in-plane isotropy but out-of-plane anisotropy. The values of SMC show maximum when magnetization is along film normal. We also used electrical detection of in-plane spin Hall voltage to double check the anisotropy of SMC. We attribute such anisotropy to the interfacial spin orbit coupling.

10:36AM K18.00012 Moderate Positive Spin Hall Angle in Uranium1, MARTA ANGUERA, SIMRAN SINGH, ENRIQUE DEL BARCO, University of Central Florida, ROSS SPRINGELL, University of Bristol, CASEY W. MILLER, Rochester Institute of Technology — We will present results on FMR and voltage measurements of magnetic damping and the inverse spin Hall effect, respectively, in Ni80Fe20/Uranium bilayers. A pure spin current is injected into an Uranium film from the ferromagnetic resonance dynamics of the magnetization of an adjacent Ni80Fe20/permalloy film. The spin current generated is then converted into an electric field by the inverse spin Hall effect. Our results suggest a spin mixing conductance of order 2x10^19 m^-2 and a positive spin Hall angle of 0.004, which are both unexpected based on trends in d-electron systems. These results support the idea that materials with unfilled f-electron orbitals may require additional exploration for spin physics.

1Supported in part by Samsung Electronics

1Work at UCF was supported by NSF-ECCS grant 1402990. Work at RIT was supported by NSF-ECCS Grant 1515677.

10:48AM K18.00013 Thickness dependence of inverse spin Hall effect in Au and W studied using YIG-based spin pumping, KENG-YUAN MENG, JACK BRANGHAM, JAMES GALLAGHER, SISHENG YU, SHANE WHITE, WILLIAM RUANE, ROHAN ADUR, CHRIS HAMMEL, FENGYUAN YANG, The Ohio State University — Yttrium iron garnet (YIG) is an excellent material for generating pure spin currents due to its narrow ferromagnetic resonance (FMR) linewidth and low damping. High quality YIG thin films are deposited by off-axis magnetron sputtering, followed by in-situ deposition of Au and W layers of varying thicknesses. Using the inverse spin-Hall effect (ISHE) in the Au and W layers, we study FMR-driven spin pumping from YIG thin films (16nm) into each metal at thicknesses of 2-50nm. Gilbert damping of these bilayers are obtained with variable frequency FMR measurements. Spin transport parameters, including the spin diffusion length in metal, spin mixing conductance at the interfaces and spin Hall angles, are also determined.
8:12AM K19.00002 Magnetism and Mn Clustering in (In, Mn)Sb Magnetic Semiconductors, \(^1\), BRUCE WESSELS, JINDONG LIU, MICAH HANSON, JOHN PETERS, Northwestern University — Magnetic semiconductors doped with transition metal elements such as (In,Mn)Sb and (Ga,Mn)Sb are considered ideal systems for spintronic devices such as magnetic junction transistors. The magnetic behavior of these semiconductors is largely influenced by magnetic atom distribution, electronic structure, and chemical state. The Mn distribution and phase composition in (In, Mn)Sb films grown by metal-organic vapor phase epitaxy (MOVPE) were determined using X-ray photoelectron spectroscopy (XPS). From XPS the spin-orbit splitting energy of the Mn 2p core level was found to increase with increasing Mn concentration, which is attributed to atomic-scale clusters that are ferromagnetic or ferrimagnetic. The magnetic properties in conjunction with XPS analysis indicate that atomic-scale Mn clusters could be responsible for the high-temperature magnetism of greater than 400 K in (In,Mn)Sb. These results demonstrate the potential of modifying the magnetic properties of (In,Mn)Sb films by controlling Mn concentration or phase composition.

1This work was supported by the NSF under grant DMR-1305666.

8:24AM K19.00003 Electronic structure near the Fermi level in the ferromagnetic semiconductor GaMnAs studied by ultrafast time-resolved light-induced reflectivity measurements, \(^1\), TOMOKI ISHII, TADASHI KAWAZOE, Univ of Tokyo, YUSUKE HASHimoto, Radboud Univ Nijmegen, HIROshi TERADA, IRIYA MUNETa, MOTOICHI OHTsu, MASAKI TANAKA, SHINOBU OHYA, Univ of Tokyo — The determination of the Fermi level \((E_F)\) position is important to understand the origin of the ferromagnetism in ferromagnetic semiconductor GaMnAs. The recent transient reflectivity (TR) spectroscopy measurement, which is potentially sensitive to the absorption edges, indicated that the \(E_F\) exists in the valence band \([1]\). However, the pump fluence in this study is rather high, and the accumulation of photo-carriers can shift the absorption edges. Thus, the definition of both the band gap and \(E_F\) is obscure. Here, we have performed TR spectroscopy measurements on GaMnAs films with the pump fluence carefully controlled to suppress the accumulation of photo-carriers. The energy resolution of the TR spectrum was improved to 0.5 meV. The data shows light-controlled change in reflectivity spectra which is attributed to the band-gap renormalization and band filling. We have reproduced the observed TR spectra using the Kramers-Kronig relation and found the Mn-induced electronic states near the \(E_F\) in the band gap. \([3]\) T. de Boer et al., Phys. Rev. B 85, 033202 (2012).

1This work was partially supported by Grants-in-Aids for Scientific Research including Specially Promoted Research and Project for Developing Innovation Systems of MEXT.

8:36AM K19.00004 High Field Magnetic Circular Dichroism in Ferromagnetic InMnSb and InMnAs, \(^1\), M. A. MEEKER, B. A. MAGILL, G. A. KHODAPARAST, Virginia Tech, D. SAHA, C. J. STANTON, University of Florida, S. MCGILL, NHMF, Florida, B. W. WESSELS, Northwestern Univ. — An understanding of the fundamental interactions in narrow gap ferromagnetic semiconductors such as InMnAs and InMnSb has been developed primarily from static magnetization and electrical transport measurements. In this study, to provide a better understanding of the conduction and valence bands through the sp-d exchange interactions, we have performed magnetic circular dichroism measurements (MCD) on MOVPE grown InMnAs and InMnSb. In our samples, the Mn content varies from 2% to 10.7% and all the samples have Curie temperatures above 300 K. The samples were photo-excited using a Quartz Tungsten Halogen lamp with energies ranging between 0.92-1.45 eV, and in magnetic fields up to 31 T. The temperatures ranged from 15-190 K. Comparison of the observed MCD with theoretical calculations provides a direct method to probe the band structure including the temperature dependence of the spin-orbit split-off bandgap and g-factors, as well as a means to estimate the sp-d coupling constants.

1Supported by the AFOSR through grant FA9550-14-1-0376, NSF-Career Award DMR-0846834 , NSF-DMR-60035274 , NSF-DMR-1305666, NSF MRI program (DMR-1229217).

8:48AM K19.00005 Spin-dependent transport properties of a GaMnAs-based vertical spin-metal-oxide-semiconductor field-effect transistor structure, \(^1\), TOSHIKI KANAKI, HIROKATSU ASAHARA, SHINOBU OHYA, MASAACKI TANAKA, The University of Tokyo — Spin metal-oxide semiconductor field-effect transistors (spin MOSFETs) \([1]\) are one of the most promising devices for the post-scaling era. In previous studies on spin MOSFETs\([2,3]\), the drain-source current was controlled by the gate-source voltage and magnetization configuration of the source and drain; however, the magnetoresistance (MR) ratios \((0.1\% \text{ to } 0.005\%)\) were too small to be put into practical applications, and thus spin MOSFET with a high MR ratio is strongly required. Here, we study a GaMnAs-based vertical spin-MOSFET structure. We successfully modulate the drain-source current \(I_{DS}\) by \(0.5 \pm 0.5\%\) with a gate-source voltage of \(-10.8 \pm 10.8\) V and also modulate \(I_{DS}\) by up to 60% with changing the magnetization configuration of the GaMnAs source/drain at 3.5 K. The MR ratio is more than two orders of magnitude higher than that obtained in the previous studies on spin MOSFETs\([2,3]\). \([1]\) S. Sugahara and M. Tanaka, APL 84, 2307 (2004). \([2]\) R. Nakane et al., JJAP 49, 113001 (2010). \([3]\) T. Sasaki et al., Phys. Rev. Appl. 2, 034005 (2014). \([4]\) T. Kanaki et al., submitted; arXiv:1510.07497.

1This work is supported by Grants-in-Aid for Scientific Research including the Specially Promoted Research and the Project for Developing Innovation Systems of MEXT.
9:00AM K19.00006 Ferromagnetism in Silicon Single Crystals with Positively Charged Vacancy Clusters

YU LIU, Helmholtz Zentrum Dresden-Rossendorf, XINGHONG ZHANG, QUAN YUAN, JIECAI HAN, Harbin Institute of Technology, SHENGQIANG ZHOU, Helmholtz Zentrum Dresden-Rossendorf, BO SONG, Harbin Institute of Technology — Defect-induced ferromagnetism provides an alternative for organic and semiconductor spintronics. Here, we investigated the magnetism in Silicon after neutron irradiation and try to correlate the observed magnetism to particular defects in Si. Commercially available p-type Si single crystal wafer is cut into pieces for performing neutron irradiations. The magnetic impurities are ruled out as they can not be detected by secondary ion mass spectroscopy. With positron annihilation lifetime spectroscopy, the positron trapping center corresponding to lifetime 375 ps is assigned to a kind of stable vacancy clusters of hexagonal rings (V6) and its concentration is enhanced by increasing neutron doses. After irradiation, the samples still show strong diamagnetism. The weak ferromagnetic signal in Si after irradiation enhances and then weakens with increasing irradiation doses. The saturation magnetization at room temperature is almost the same as that at 5 K. The X-ray magnetic circular dichroism further provides the direct evidence that Silicon is the origin of this ferromagnetism. Using first-principles calculations, it is found that positively charged V6 brings the spin polarization and the defects have coupling with each other.

1The work is financially supported by the Helmholtz Postdoc Programme (Initiative and Networking Fund, PD-146).

9:12AM K19.00007 Microscopic understanding of spin current probed by shot noise

TOMONORI ARAKAWA, Department of Physics, Graduate School of Science, Osaka University, 560-0043, Toyonaka, Osaka — The spin currents is one of key issue in the spintronics field and the generation and detection of those have been intensively studied by using various materials. The analysis of experiments, however, relies on phenomenological parameters such as spin relaxation length and spin flip time. The microscopic nature of the spin current such as energy distribution and energy relaxation mechanism, has not yet well understood. To establish a better microscopic understanding of spin currents, I focused on the shot noise measurement which is well established technique in the field of mesoscopic physics [Y. M. Blanter and M. B. ötter, Phys. Rep. 336, 1 (2000)]. Although there are many theoretically works about shot noise in the presence of spin currents, for example detection of spin accumulation [J. Meair, P. Stano, and P. Jacquod, Phys. Rev. B 84 (2011)], estimation of spin flip currents, and so on, these predictions have never been experimentally confirmed. In this context, we reported the first experimental detection of shot noise in the presence of spin accumulation in a (GaMn)As/AlGaAs/heterostructure based lateral spin valve device [T. Arakawa et al., Phys. Rev. Lett. 114, 016601 (2015)]. Together with this result, we found however that the effective temperature of the spin current drastically increases due to the spin injection process. This heating of electron system could be a big problem to realize future spin current devices by using quantum coherence, because the effective temperature rise directly related to the destruction of the coherence of the spin current. Therefore, then we focused on the mechanism of this heating and the energy relaxation in a diffuse channel. By measuring current noise and the DC offset voltage in the usual non-local spin valve signal as a function of the spin diffusion channel length, we clarified that the electron-electron interaction length, which is the characteristic length for the relaxation of the electron system, is much longer than the spin relaxation length. In other words, the spin currents in such a semiconducting material can be strongly out of equilibrium.

In this invited talk, I will present a series of experimental work on the spin current in a (GaMn)As/AlGaAs/heterostructure barrier/FeGaAs based lateral spin valve device, mainly probed by the current noise measurement. Finally I hope I will mention about our future plan to cool down the effective temperature of the spin current by using superconductivity.

This work was partially supported by JSPS KAKENHI Grant Numbers 26220711, 25887037, 25103003, and 15K17680.

9:48AM K19.00008 Physical Properties of Fe-doped Ba(Mn$_{1-x}$Fe$_x$)$_2$Sb$_2$ Single Crystals

ZHENYU DIAO, JIANNENG LI, AHMAD US SALEHEEN, TAPAS SAMANTA, W.ADAM PHELAN, SHANE STADLER, RONGYING JIN. Department of Physics and Astronomy, Louisiana State University — BaMn$_2$Sb$_2$ forms the ThCr$_2$Si$_2$-type crystal structure and has the magnetic semiconducting ground state. In attempt to alter its ground-state properties, Mn is partially substituted by Fe resulting in Ba(Mn$_{1-x}$Fe$_x$)$_2$Sb$_2$. While the doped system remains the same structure for $x \leq 0.5$, its electrical and thermal conductivity decreases with increasing $x$, suggesting that doping-induced disorder plays an important role. Magnetically, we find that, with increasing $x$, the magnetic transition temperature $T_M$ decreases (from 700 K for $x = 0$ to 500 K for $x = 0.5$) but magnetic susceptibility increases above and below $T_M$. These and low-temperature magnetization anisotropy suggest the canted-antiferromagnetic configuration with net magnetic moment in BaMn$_2$Sb$_2$. The antiferromagnetic interaction is gradually suppressed upon Fe doping, leading to the enhanced ferromagnetic component in Ba(Mn$_{1-x}$Fe$_x$)$_2$Sb$_2$.

10:00AM K19.00009 Magnetic Coupling in FeBi$_2$Se$_4$ and FeSb$_2$Se$_4$ from first principles

LOGAN WILLIAMS, EMMANOUIL KIOUPAKIS, JUAN LOPEZ, PIERRE FERDINAND P. PÔDEU, University of Michigan — Spintronic devices offer benefits in power efficiency and size reduction over current electronics, but require the development of semiconductor materials with favorable magnetic properties. Specifically, a high ferromagnetic-to-paramagnetic Curie transition temperature is required for spintronics operation at room temperature. FeBi$_2$Se$_4$ and FeSb$_2$Se$_4$ are two n and p-type magnetic semiconductors, respectively, with Curie transition temperatures of 450 K. We employ first-principles calculations based on density functional theory to examine the magnetic coupling mechanisms in these materials. Our results indicate that antisite defects of Fe upon the Bi/Sb sites are crucial to the ferromagnetic coupling of the Fe magnetic moments in the crystals. This research was supported by the National Science Foundation CAREER award through Grant No. DMR-1254314. Computational Resources were provided by the DOE NERSC facility.

10:12AM K19.00010 Strain fields and electronic structure of CrN

TOMAS ROJAS, SERGIO E. ULLOA, Ohio University — Chromium nitride (CrN) has a promising future for its resistance to corrosion and hardness, and very interesting magnetic and electronic properties. CrN presents a phase transition in which the crystal structure, magnetic ordering and electronic properties change at a (Neé) temperature ~ 280 K. Thin films from different labs exhibit different conductance behavior at low temperature. We study the unusual electronic and magnetic properties of thin layers. For that purpose we develop a tight binding Hamiltonian based on the Slater-Koster approach, and estimate the interaction between the Cr-3d and N-2p orbitals, by analyzing the band structure and comparing it with ab initio calculations performed using the LSDA+U method [1]. These calculations show the system to behave as a semiconductor below the Neé temperature. Based on our model we calculate the effective masses and analyze the effect of strain fields in the electronic structure in order to understand the electronic behavior near the phase transition. [1] A. Herwadkar and W. Lambrecht, Phys. Rev. B 79(3), 035125 (2009).
10:24AM K19.00011 Observation of the room-temperature local ferromagnetism and its nanoscale growth in the ferromagnetic semiconductor GeFe. Y. K. WAKABAYASHI, S. SAKAMOTO, The Univ. of Tokyo, Y. TAKEDA, JAE, K. ISHICAMI, Y. TAKAHASHI, Y. SAIKOH, The Univ. of Tokyo, H. YAMAGAMI, JAE, A. FUJIMORI, M. TANAKA, S. OHYA, The Univ. of Tokyo — Group IV-based ferromagnetic semiconductor GeFe is expected to be efficient spin injectors and detectors in group IV-based semiconductor devices, because it can be epitaxially grown on Si and Ge substrates [1,2] and the TC can be increased up to 210 K by annealing [3]; however, detailed microscopic understanding of the ferromagnetism is lacking. In this study, we have investigated the local magnetic properties of the GeFe films, using soft X-ray magnetic circular dichroism. We found that nanoscale local ferromagnetic regions formed in the high Fe-content regions exist even at room temperature, well above the Curie temperature of 20 - 100 K. We also observed the intriguing nanoscale growth process of the local ferromagnetic regions in which they expand as temperature decreases, followed by a transition of the entire film into a ferromagnetic state at the Curie temperature [4]. References [1] Y. Ban, Y. Wakabayashi et al., AIP Adv. 4, 097108 (2014). [2] Y. K. Wakabayashi et al., Phys. Rev. B, 90, 205209 (2014). [3] Y. K. Wakabayashi et al., J. Appl. Phys. 116, 173906 (2014). [4] Y. K. Wakabayashi et al., arXiv:1502.00118 (2015).

3This work was partly supported by Giant-in-Aids for Scientific Research including Specially Promoted Research, Project for Developing Innovation Systems of MEXT, and First program of JSPS.

10:36AM K19.00012 Magnon-drag and thermomagnetic transport properties of Ca doped YIG. YUANHUA ZHENG, BIN HE, The Ohio State University - Columbus, XI CHEN, JIANSHI ZHOU, University of Texas at Austin, LI SHI, ROBERTO MYERS, JOSEPH HEREMANS, The Ohio State University - Columbus — Yttrium-iron garnet (YIG) is an insulating ferromagnet commonly used to study various spin transport phenomena: in conjunction with a Pt film, it generates the well-known spin-Seebeck effect [1]. Because of the close relationship between the spin-Seebeck effect and the magnon-drag charge Seebeck effect [2], we investigate the thermoelectric transport properties of an electrically conducting bulk YIG crystal doped p-type with Ca. A large and sharp change in the thermopower of Ca-YIG near the Curie temperature has been observed, which is potentially explained by the magnon-drag model. We present the temperature dependence of electrical conductivity, magneto-thermopower, and Hall coefficient of Ca-YIG. Photo-excitation of the carriers from the valence band into the Ca level results in photodetector properties and photo-Seebeck effects as well. [1] Jin et al., Phys. Rev. B 92, 054436 (2015) [2] Lucassen et al., Appl. Phys. Lett. 99 262506 (2011)

1Acknowledgement: ARO MURI W911NF-14-1-0016

10:48AM K19.00013 Infrared Kerr measurements on ferromagnetic silicon and silicon carbide. JUNGRYEOL SEO, ALOK Mukherjee, MUMTAZ MURAT ARIK, JOHN CERNE, Department of Physics, University at Buffalo, Buffalo, NY, USA, YU LIU, SHENQIANG ZHOU, ROMAN BITTGER, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany, BO SONG, Harbin Institute of Technology, Nangang, Harbin, Heilongjiang, China, GANG WANG, Institute of Physics, Chinese Academy of Sciences, Haidian, Beijing, China — We measure the infrared (100-1000 meV) Kerr angle in ferromagnetic silicon and silicon carbide. The samples were either neutron irradiated or aluminum doped to induce ferromagnetic behavior. The samples are studied in the 10-300K temperature range at magnetic fields up to 7T. We also explore the dependence of the magneto-optical signal on samples with different irradiation exposure levels. This study provides new information on the optical, magnetic, and electronic properties of these materials. Work supported by NSF-DMR1410599 and the Helmholtz Postdoctoral Program PD-146.

Wednesday, March 16, 2016 11:15AM - 2:15PM –
Session L5 GMAG DMP: Frustrated Magnetism: Artificial Spin Ice 301 - Jayasimha Atulasimha, Virginia Commonwealth University

11:15AM L5.00001 Nearest neighbor correlations in perpendicular artificial spin ice arrays in the presence of an applied field. SUSAN KEMPINGER, ROBERT FRALEIGH, PAUL LAMMERT, VINCENT CRESPI, NITIN SAMARTH, Pennsylvania State University, PETER SCHIFFER, University of Illinois — By studying the field dependent magnetization switching process in perpendicular artificial spin ice arrays, we hope to gain insight in to the dynamical properties of interacting spin systems. To this end, we have used diffraction-limited Kerr imaging to study lithographically patterned arrays of single domain, nanoscale islands of Co/Pt multilayers. We can tune the interaction strength and introduce geometric frustration in to the patterned systems by changing the lattice spacing and geometry of the arrays. Using MOKE microscopy we are able to optically resolve, spatially isolate, and extract the switching field of each island in an array in the presence of an external field. These switching fields allow us to calculate the magnetization and nearest neighbor spin-spin correlation throughout a hysteresis loop. These quantities help us determine the effect of increased interactions and geometric frustration on the switching process of dipole coupled arrays. Funded by DOE.

11:27AM L5.00002 Dimensionality Reduction in Artificial Spin Ice1. IAN GILBERT2, YUYANG LAO, ISAAC CARRASQUILLO, University of Illinois at Urbana-Champaign, LIAM O’BRIEN2, JUSTIN WATTS, MICHAEL MANN, CHRIS LEIGHTON, University of Minnesota, ANDREAS SCHOLL, Lawrence Berkeley National Laboratory, CRISTIANO NISOLI, Los Alamos National Laboratory, PETER SCHIFFER, University of Illinois at Urbana-Champaign — Over the past ten years, square and hexagonal arrays of single-domain nanomagnets, known as artificial spin ice, have been used to study the microscopic properties of geometric frustration. Here we describe the fabrication of a new type of artificial spin ice, the tetris lattice. The ground state configuration of the nanomagnets’ moments was determined with photoemission electron microscopy. This lattice is designed such that its vertices (small clusters of nanomagnets) cannot simultaneously achieve their ground state. As a consequence, the lattice decomposes into alternating ordered and disordered one-dimensional bands of moments. The disordered bands can be described by a thermal one-dimensional Ising model, underscoring the emergent dimensionality reduction found in this lattice.

1This work was primarily supported by the US DOE. Work at UMN was supported by NSF MRSEC.

2Present affiliation: National Institute of Standards and Technology

3Also University of Cambridge

11:39AM L5.00003 DC Magnetization and FMR results of Fibonacci Distortions on the Honeycomb Artificial Spin Ice. JUSTIN WOODS, BARRY FARMER, TODD HASTINGS, JUSTIN VISAK, LANCE DE LONG, Univ of Kentucky — Nanofabrication techniques allow magnetic thin films to be lithographically-patterned into arrays of interacting macro-spins that can be designed to study emergent physical properties. Here we discuss the effects of continuous symmetry breaking on the equilibrium and dynamic magnetic properties of frustrated magnetic metamaterials. We have patterned five Permalloy (Ni_{80}Fe_{20}) samples of distorted Kagome ASI arrays that are generated by repeated application of a substitution algorithm. This algorithm employs an aperiodic Fibonacci sequence of binary digits that can be mapped into short (d_1) and long (d_2) distances. This distorts film segment lengths while the width (nominally 70 nm) and thickness (25 nm) remain constant. Additionally, the coordination of each three-fold Kagome vertex is continuously modified via these distortions. Micromagnetic simulations predict the Fibonacci distortions causes jamming of Dirac String propagation. We report DC magnetization and FMR dispersion for different magnitudes of distortion, and compare these results to simulation. Research at University of Kentucky supported by U.S. National Science Foundation grant no. DMR-1506979.
In artificial ferroic systems, novel functionality is engineered through the combination of structured ferroic materials and the control of the interactions between the different components. We will present two classes of these systems, beginning with hybrid mesoscopic structures incorporating two different ferromagnetic layers whose static and dynamic behaviour result from the mutual imprint of the magnetic domain configurations. Here we have demonstrated a new vortex core reversal mechanism, which occurs when it is displaced across domain boundaries with a magnetic field. We will then describe our progress on artificial spin ice, consisting of arrays of dipolar-coupled nanomagnets arranged in frustrated geometries. We have employed photomission and electron microscopy techniques to fabricate artificial spin ice networks and to study how these magnetic nanostructures change upon application of an external magnetic field. We have also created artificial spin ice with fluctuating magnetic moments and observed the evolution of magnetic configurations with time. This has provided a means to study relaxation processes with a controlled route to the lowest-energy state. Recently, we have demonstrated with muon spin relaxation that these magnetic metamaterials can support thermodynamic phase transitions, and future directions include the incorporation of novel magnetic materials such as ultrathin magnetic films, the investigation of 3D structures, as well as the implementation of x-ray resonant magnetic scattering to study magnetic correlations in smaller nanomagnets and at faster timescales.

We examine square and kagome artificial spin ice networks for colloids confined in arrays of double-well traps. Unlike magnetic artificial spin ices, colloidal and vortex artificial spin ice realizations allow creation of doping sites through double occupation of individual traps. We find that doping and kagome ice geometries produces opposite effects. For square ice, doping creates local excitations in the ground state configuration that produce a local melting effect as the temperature is raised. In contrast, the kagome ice ground state can absorb the doping charge without generating non-ground-state excitations, while at elevated temperatures the hopping of individual colloids is suppressed near the doping sites. These results indicate that in the square ice, doping adds degeneracy to the ordered ground state and creates local weak spots, while in the kagome ice, which has a highly degenerate ground state, doping locally decreases the degeneracy and creates local hard regions.

We analyze an anisotropic magnetoresistance (AMR) model. Supported by the US Department of Energy. Work at the University of Minnesota was supported by Seagate Technology, NSF MRSEC, and a Marie Curie International Outgoing Fellowship within the 7th European Community Framework Programme.

Spin wave band structure of artificial square ices, Elio Iacocca, University of Colorado - Boulder, Co, USA; Chalmers University of Technology, Sweden, Sebastian Gliga, ETH, Switzerland; PSI, Switzerland, Robert Stamps, University of Glasgow, UK, Olle Heinonen, Argonne National Laboratory, IL, USA — Artificial square spin ices are structures composed of magnetic elements located on the sites of a geometrically frustrated, two-dimensional square lattice. Using a semi-analytical approach, we show that square spin ices exhibit a rich spin wave band structure that is tunable both by external magnetic fields and the magnetic state of individual elements. Internal degrees of freedom can give rise to equilibrium states with bent magnetization at the edges of each element, leading to characteristic excitations; in the presence of magnetostatic interactions these form separate bands analogous to impurity bands in semiconductors. Full-scale micromagnetic simulations corroborate our semi-analytical approach. This study shows that the magnon spectra, and therefore group and phase velocities and band gap, can be manipulated by external fields, temperature, or more sophisticated techniques such as using spin torque on individual elements, and suggesting that artificial square spin ices can be used as metamaterials for spin waves. Our results close the gap between the research fields of artificial spin ices and magnonics.

Artificial spinices are nanostructured two-dimensional arrays of ferromagnetic elements, in which frustrated interactions lead to unusual collective magnetic behavior. Here we report a room-temperature magnetoresistance study of connected permalloy (Ni$_8$Fe$_{12}$) kagome artificial spin ice networks, wherein the direction of the applied in-plane magnetic field is systematically varied. We measure both the longitudinal and transverse magnetoresistance in these structures, and we find certain transport geometries of the network show strong angular sensitivity — even small variations in the applied field angle lead to dramatic changes of the magnetoresistance response. We also investigate the magnetization reversal of the networks using magnetic force microscopy (MFM), demonstrating avalanche behavior in the magnetization reversal. The magnetoresistance features are analyzed using an anisotropic magnetoresistance (AMR) model. Supported by the US Department of Energy. Work at the University of Minnesota was supported by Seagate Technology, NSF MRSEC, and a Marie Curie International Outgoing Fellowship within the 7th European Community Framework Programme.
1:27PM L5.00010 Nanomagnetic field-driven thermal mobility of emergent monopoles in artificial spin ice. SOPHIE MORLEY, MARK C. ROSAMOND, University of Leeds, DIEGO ALBA VENERO, ISIS, ALES HRABEC, Université Paris Sud, JOSE MARIA PORRO, ISIS, MI-YOUNG NC, XIONG, LBNL and DGIST, PETER FISCHER, UC Santa Cruz, SEAN LANGRIDGE, ISIS, CHRISTOPHER H. MARROWS, University of Leeds — Artificial spin ices are nanomagnetic islands confined in 2D and their size means they can be considered as single domain and Ising-like. In the square geometry, each vertex has four nanomagnets which can point either in or out. The lowest energy arrangement consists of two-in and two-out and obeys the so-called ‘ice-rule’. It is possible to construct an ordered state by tiling such vertices, above which it is possible to have ice-rule-violating excitations known as emergent magnetic monopoles. It is their propagation which has been imaged with a transmission X-ray microscope and, due to a novel on-membrane heater, elevated temperatures applied up to 700 K. Square ice arrays were fabricated on a SiN membrane, the CoFeB islands were 80x250 nm, 10nm thick and had lattice spacings in the 350-500nm. Increased avalanche length and faster string velocities were observed for both stronger interaction and increased temperature. We have also been able to define a magnetic mobility in our systems and observed increased mobility in more interacting systems or elevated temperature. The largest change in the magnetic mobility was found for the most strongly interacting array, increasing by 1.7±0.7mm²A⁻¹s⁻¹ for ∆T ≈ 30 K.

1:39PM L5.00011 Macroscopic Artificial Magnetic Honeycomb Lattice of Thermally Controlled Ultra-Small Bonds. BROCK SUMMERS, ASHTUSH DAHAL, Univ of Missouri - Columbia, LISA DEBEER-SCHITT, Oak ridge National Lab, JAGATH GUNASEKERA, DEEPAK SINGH, Univ of Missouri - Columbia — The two-dimensional artificial magnetic honeycomb lattice system is evolving into a new research arena to explore a plethora of novel magnetism that are predicted to occur as functions of temperature and magnetic field: a long-range spin ice, spin liquid, an entropy-driven magnetic charge-ordered state involving topological vortex pairs and a spin-order due to the spin chirality. We have created macroscopic samples of artificial magnetic honeycomb lattices of Cobalt and Permalloy having connected ultra-small elements (bonds), with length scales of sub-10 nm to 30 nm, which have been fabricated previously. The equivalent energy of the resulting systems is 10-100 K and is thus amenable to both temperature- and field-dependent exploration of novel magnetic phenomena. We have performed detailed magnetic and small angle neutron scattering measurements (SANS) on the newly fabricated honeycomb lattice of Permalloy that show the thermal character of the system. Furthermore, the experimental data reveals the onset of magnetic ordered regimes in temperature that are consistent with the predicted novel phase diagram in artificial honeycomb lattice. Research is supported by U.S. Department of Energy, Office of Basic Energy Sciences under Grant No. DE-SC0014461.

1:51PM L5.00012 Real time dynamic behavior of vertex frustrated artificial spin ice. YUYANG LAO, JOSEPH SKLENAR, University of Illinois at Urbana-Champaign, IAN GILBERT, National Institute of Standards and Technology, ISAAC CARRASQUILO, University of Illinois at Urbana-Champaign, ANDREAS SCHOLL, ANTHONY YOUNG, Lawrence Berkeley National Laboratory, CRISTIANO NISOLI, Los Alamos National Laboratory, PETER SCHIFFER, University of Illinois at Urbana-Champaign — Artificial spin ice systems comprise two dimensional arrays of nanoscale single domain ferromagnets designed to have frustrated interactions among the moments. By decimating islands from the common square artificial spin ice, one can design lattices with so-called ‘vertex frustration’. In such lattices, the geometry prevents all vertices from occupying local ground states simultaneously. Using Photoemission Electron Microscopy (PEEM), we access the real time thermally induced dynamics of the moment behavior in those lattices. Operating at a proper temperature, the moment direction of each island fluctuates with a sufficiently slow frequency that it can be resolvable by acquiring successive PEEM images. We can extract information regarding the collective excitations of the moments and understand how they reflect the frustration of lattice. Supported by the US Department of Energy, Office of Basic Energy Sciences, Materials Science and Engineering Division under grant no. DE-SC0010778. The work of C.N. was carried out under the auspices of the US Department of Energy at LANL under contract no. DE-AC52-06NA253962. The ALS is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the US Department of Energy under contract no. DE-AC02-05CH11231.

2:03PM L5.00013 Monte Carlo simulations of kagome lattices with magnetic dipolar interactions. MARTIN PLUMER, Memorial University Newfoundland, MARK HOLDEN, University of Waterloo, ANDREW WAY, Memorial University of Newfoundland, IVAN SAÏKA-VOÏDOV, Memorial University Newfoundland, BYRON SOUTHERN, University of Manitoba — Monte Carlo simulations of classical spins on the two-dimensional kagome lattice with only dipolar interaction are presented [1]. In addition to revealing the sixfold-degenerate ground state, the nature of the finite-temperature phase transition to long-range magnetic order is discussed. Low-temperature states consisting of mixtures of degenerate ground-state configurations separated by domain walls can be explained as a result of competing exchange-like and shape-anisotropy-like terms in the dipolar coupling. Fluctuations between pairs of degenerate spin configurations are found to persist well into the ordered state as the temperature is lowered until locking in to a low-energy state. Results suggest that the system undergoes a continuous phase transition at T* ≈ 0.43 in agreement with previous MC simulations [2] but the nature of the ordering process differs [3]. Preliminary results which extend this analysis to the 3D fcc ABC-stacked kagome systems will be presented [4].


Wednesday, March 16, 2016 11:15AM - 2:15PM
Session L6 GMAG DMP FIAP: Spin-Transport Phenomena: Oscillators and Spin-Injections I
302 - Lihui Bai, University of Manitoba

11:15AM L6.00001 Mutual synchronization of two spin transfer oscillators coupled through their self-emitted microwave currents. CROS, R. LEBRUN, Unit Mixte CNRS/Thales, Univ. Paris-Sud, Univ. Paris-Saclay, Palaiseau, France, S. TSUNEJI, Spintronic Research Center, AIST, Tsukuba, Japan, P. BORTOLOTTI, Unit Mixte CNRS/Thales, Univ. Paris-Sud, Univ. Paris-Saclay, Palaiseau, France, H. KUBOTA, Spintronic Research Center, AIST, Tsukuba, Japan, M. ROMERA, Unit Mixte CNRS/Thales, Univ. Paris-Sud, Univ. Paris-Saclay, Palaiseau, France, K. YAKUSHIJI, A. FUKUSHIMA, Spintronic Research Center, AIST, Tsukuba, Japan, J. GROLLIER, Unit Mixte CNRS/Thales, Univ. Paris-Sud, Univ. Paris-Saclay, Palaiseau, France, S. TSUNEJI, Spintronic Research Center, AIST, Tsukuba, Japan, J. GROLLIER, Unit Mixte CNRS/Thales, Univ. Paris-Sud, Univ. Paris-Saclay, Palaiseau, France, S. YUASA, Spintronic Research Center, AIST, Tsukuba, Japan, UNIT MIXTE DE PHYSIQUE CNRS/THALES COLLABORATION, SPINTRONICS RESEARCH CENTER, AIST COLLABORATION — Here, we demonstrate the mutual synchronization of two vortex STOs through electrical coupling. We describe how in using a delay line, we can optimize the locking range of the synchronization. We also evidence that the coupling efficiency is tuned by the nonlinear parameters of STOs but also more originally through the ratio between the two components of spin transfer torques. This represents a definite advantage of our vortex-STOs for their future implementation in large arrays of synchronized STOs. We find that the linewidth of the two synchronized STOs decreases by a factor 2 and the output power increases by factor 4 (~1.6 W) compared to non-interacting STOs. These results provide a solid basis towards the efficient synchronization of multiple STOs. EU FP7 grant (MOSAIC No. ICT-FP7-317950 is acknowledged.

3This work was supported by the European Commission FP7-ICT-2011 contract No. 317950 MOSAIC, ERC grant 307144 MUSTANG, VR, SSF, and the Knut and Alice Wallenberg Foundation.

11:39AM L6.00003 Theory of mode coupling in spin torque oscillators coupled to a thermal bath of magnons, YAN ZHOU, University of Hong Kong, SHULEI ZHANG, University of Missouri, DONG LI, Hong Kong Baptist University, OLLE HEINONEN, Argonne National Lab and Northwestern University — Recently, numerous experimental investigations have shown that the dynamics of a single spin torque oscillator (STO) exhibits complex behavior stemming from interactions between two or more modes of the oscillator. Examples are the observed mode-hopping and mode coexistence. There has been some initial work indicating how the theory for a single-mode (macro-spin) spin torque oscillator should be generalized to include several modes and the interactions between them. In this work, we rigorously derive such a theory starting with the generalized Landau-Lifshitz-Gilbert equation in the presence of the current-driven spin transfer torques. We will first show, in general, that how a linear mode coupling would arise through the coupling of the system to a thermal bath of magnons, which implies that the manifold of orbits and fixed points may shift with temperature. We then apply our theory to two experimentally interesting systems: 1) a STO patterned into nano-pillar with circular or elliptical cross-sections and 2) a nano-contact STO. For both cases, we found that in order to get mode coupling, it would be necessary to have either a finite in-plane component of the external field or an Oersted field. We will also discuss the temperature dependence of the linear mode coupling.

1Y. Zhou acknowledges the support by the Seed Funding Program for Basic Research from the University of Hong Kong, and University Grants Committee of Hong Kong (Contract No. AoE/P-04/08).

2S. Zhang was supported by NSF Grants DMR-1406568.

3Work by O.Heinonen was supported by the U.S. Department of Energy.

11:51AM L6.00004 Nonlocal spin-transfer with low-resistance AlO$_x$ spin injection interface and ohmic spin absorption interface, YUNJIAO CAI, CHUAN QIN, SHUHAN CHEN, YI JI, Univ of Delaware — Mesoscopic nonlocal spin valves are fabricated for the purpose of spin-transfer with pure spin current. The device consists of a 300 nm wide Py (NiFe alloy) spin injector (F1), an 80 nm wide Py spin detector (F2) and an 80 nm wide Cu channel. The thickness of F1, F2, and Cu is 15 nm, 3 nm, and 110 nm, respectively. A 3 nm layer of low-resistance AlO$_x$ is placed at the F1/Cu interface to mitigate the spin resistance mismatch between Py and Cu and to provide substantial injection spin polarization. The F1 injector and the F1/AlO$_x$/Cu interface are robust enough to sustain a d.c. injection current up to 6 mA. The F2/Cu interface remains ohmic to facilitate an efficient absorption of the pure spin current from the Cu channel into the F2. A nanoscale magnetic domain in F2 underneath the F2/Cu interface can be reversibly switched between 5 K and 150 K via spin-transfer by the pure spin current. The critical injection current for the reversal at 100 K is 1.5 mA, which is significantly lower than those in previous studies for nonlocal spin-transfer.

12:03PM L6.00005 Spin current valve effect in normal metal/magnetic insulator/normal metal sandwiches, JUNXUE LI, YADONG XU, MOHAMMED ALDOSARY, CHI TANG, ZHISHENG LIN, UC Riverside, SHUFENG ZHANG, University of Arizona, ROGER LAKE, JING SHI, UC Riverside, SHINES COLLABORATION — Pure spin current is generated in two common ways. One makes use of the spin Hall effect in normal metals (NM), the other utilizes spin waves with the quasi-particle excitations called magnons. A popular material for the latter is yttrium iron garnet (YIG), a magnetic insulator (MI). Here we demonstrate in NM/MI/NM sandwiches that these two types of spin current are interconvertible, which allows transmitting an electrical signal across the MI, predicted as the magnon-mediated current drag phenomenon. We show experimentally that the spin current can be switched on or off by controlling the MI. We then apply our theory to two experimentally interesting systems: 1) a STO patterned into nano-pillar with circular or elliptical cross-sections and 2) a nano-contact STO. For both cases, we found that in order to get mode coupling, it would be necessary to have either a finite in-plane component of the external field or an Oersted field. We will also discuss the temperature dependence of the linear mode coupling.

1As part of the SHINES, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award SC0012670.

2The first two authors contributed equally.

12:15PM L6.00006 Comparison of spin transfer mechanisms in three terminal spin-torque-oscillators, EMILIE JUE, WILLIAM RIPPARD, MATTHEW PUFALL, ERIC R. EVARTS, NIST - Boulder, QUANTUM ELECTROMAGNETICS DIVISION TEAM — The manipulation of magnetization by electric current is one of the most active field of spintronics due to its interests for memory and logic applications. This control can be achieved through the transfer of angular momentum via a spin polarized current (the mechanism of spin-transfer torque - STT) or through a direct transfer of angular momentum from the crystal lattice through the spin-orbit interaction (the mechanism of spin-orbit torque - SOT). Over the past years, SOT gained a lot of attention especially for the new possibilities that it offers for data storage application. However, the quantification and the comparison of both mechanisms' efficiencies remains uncertain. In this work, we compare for the first time the STT and SOT efficiencies in individual devices. For this, we created 3-terminal spin-torque oscillators (STO) composed of spin-valves (SV) on top of a Pt wires. The devices can be excited either by STT or by SOT depending on whether the current is applied through the SV or through the Pt wire. By varying the Pt width and the dimensions of the SV, we tune the SOT and STT and compare their efficiencies. We will discuss the complexity of such a structure and the differences in the magnetization dynamics induced by the different excitation mechanisms.
12:27PM L6.00007 Characterization of perpendicular STT-MRAM by spin torque ferromagnetic resonance\(^1\) CHENG C. SHA, LIU YANG, HAN KYU LEE, IGOR BARUSKOV, JIEYI ZHANG, ILYA KIVOROTOV. University of California, Irvine — We describe a method for simple quantitative measurement of magnetic anisotropy and Gilbert damping of the MTJ free layer in individual perpendicular STT-MRAM devices by spin torque ferromagnetic resonance (ST-FMR) with magnetic field modulation. We first show the dependence of ST-FMR spectra of an STT-MRAM element on out-of-plane magnetic field. In these spectra, resonances arising from excitation of the quasi-uniform and higher order spin wave eigenmodes of the free layer as well as acoustic mode of the synthetic antiferromagnet (SAF) are clearly seen. The quasi-uniform mode frequency at zero field gives magnetic anisotropy field of the free layer. Then we show dependence of the quasi-uniform mode linewidth on frequency is linear over a range of frequencies but deviates from linearity in the low and high frequency regimes. Comparison to ST-FMR spectrums reveals that the high frequency line broadening is linked to the SAF mode softening near the SAF spin flop transition at 5 K. In the low field regime, the SAF mode frequency approaches that of the quasi-uniform mode, and resonant coupling of the modes leads to the line broadening. A linear fit to the linewidth data outside of the high and low field regimes gives the Gilbert damping parameter of the free layer.

\(^1\)This work was supported by the Samsung Global MRAM Innovation Program.


12:51PM L6.00009 First-principles theory of current-induced spin torques in noncollinear antiferromagnets ALLAN MACDONALD, HUA CHEN, The University of Texas at Austin, YIMING WU, Peking University, YASUFUMI ARAKI, Tohoku University — We propose a new theoretical approach for calculating current induced torques in hybrid systems containing magnetic and heavy metal thin films. The theory is based on ab-initio density functional theory (DFT) and appeals explicitly to the local-spin-density approximation for exchange and correlation. Because the effective magnetic field from exchange and correlation is everywhere parallel to the spin-density in the ferromagnet, it does not contribute to the current-induced torque, which is due entirely to spin-orbit coupling near heterojunctions involving heavy metals. The theoretical picture can be combined with any theory of the electronic steady state produced by electrochemical potential gradients, and involves response of the single-particle density matrix that is partially diagonal and partially off-diagonal in an unperturbed eigenstate representation. The theory is formulated using the basis of Wannier functions and can be readily interfacing with existing DFT codes. This approach predicts strong current-induced torques due to either antiferromagnetic or non-magnetic heavy metal layers. As an illustration, we use it to calculate specifically the spin torque in a ferromagnet induced by an adjacent noncollinear antiferromagnet (Mn3Ir).

1:03PM L6.00010 Spin Torque Generated by the Spin Hall Effect in Ferromagnets JOSEPH GIBBONS, Department of Physics, Cornell University, ROBERT BUHRMAN, School of Applied and Engineering Physics, Cornell University, DANIEL RALPH, Department of Physics, Cornell University — Ferromagnetic materials exhibit the anomalous Hall effect, the generation of a transverse charge current due to spin-orbit coupling. The anomalous Hall effect is closely related to the spin Hall effect, and hence this transverse charge current is expected to be accompanied by a strong transverse spin current, whose direction can be manipulated by rotating the magnetic moment. We measure the torque from this spin current generated by Gd-doped Fe and acting on an in-plane magnetized free layer. We use the harmonic measurement technique, applying a current to an in-plane pinned ferromagnet/spacer/in-plane free ferromagnet stack and measuring the second harmonic Hall voltage. We report the angular dependence of the spin torque for a variety of initial exchange bias directions, and as the spin torque changes with an external magnetic field.

1:15PM L6.00011 Enhanced spin orbit torques by oxygen incorporation in tungsten films TIMOTHY PHUNG, KAI-UWE DEMASIUS, WEIFENG ZHANG, BRIAN P. HUGHES, SIEH-HUN YANG, ANDREW KELLOCK, WEI HAN, AAKASH PUSHP, STUART S. P. PARKIN, IBM Almaden Res Ctr — Spin orbit torques are generated by the conversion of charge to spin currents in non-magnetic materials. The origin of these torques is of considerable debate. One of the most interesting materials is metallic tungsten for which large spin orbit torques have been found in thin films that are stabilized in the A15 (\(\beta\)-phase) structure. Here we report, using spin transfer torque ferromagnetic resonance, large spin Hall angles of up to \(\sim 0.5\) by incorporating oxygen into tungsten films. Whilst the incorporation of oxygen into the tungsten leads to significant changes in its microstructure and electrical resistivity, the large spin Hall angles measured are found to be remarkably insensitive to the oxygen doping level (12-44%). This invariance of the spin Hall angle with the bulk W(0) properties for higher oxygen concentrations suggests that the spin orbit torques in this system may actually be partly intrinsic in origin, and induced by scattering of the electrons at the W(O) |CoFeB interface rather than from the interior of the W(O) film. Our results show an intriguing novel path towards enhanced spin orbit torques.

1:27PM L6.00012 Optically Detected Ferromagnetic Resonance in Metallic Ferromagnets Via Off-Resonant Detection of Nitrogen Vacancy Centers in Diamond MICHAEL R. PAGE, VIDYA P. BHALLAMUDI, JOE SCHULZE, CAROLA M. PURSER, SERGEI MANIULOV, CHRISTOPHER WOLFE, JACK T. BRANCHAM, FENGJUAN YANG, P. CHRIS HAMMEL. The Ohio State University Department of Physics — We report optical detection of ferromagnetic resonance in thin film metallic ferromagnets using a recently discovered approach employing nitrogen vacancy centers in diamond. While conventional optically detected magnetic resonance measures magnetic fields through their impact on the magnetic resonance frequency of the nitrogen vacancy center, we measure a change in the nitrogen vacancy center photoluminescence at the ferromagnets resonance condition without need to work at the NV resonance frequency. This measurement technique allows sensitive, local detection of ferromagnetic resonance and can enable the study of magnetic dynamics at the nanoscale in a wide range of materials. While this measurement protocol was first reported in the study of ferromagnetic resonance in YIG, here we demonstrate the measurement in commonly used metallic ferromagnets to establish the generality of the technique and open the possibility of measuring nanoscale patterned devices and magnetic textures based on metallic ferromagnets of both commercial and scientific interest.
1:39PM L6.00013 Phase-resolved ferromagnetic resonance detection using heterodyning. SE-UNGHA YOON, ROBERT D. McMICHAIL, National Institute of Standards and Technology — We have developed a new phase-resolved ferromagnetic (FMR) detection method using a heterodyne method. Phase resolution is important to determine the characteristics of spin transfer torques in magnetization dynamics under microwave excitation [1]. Specifically, field-like torques and damping-like torques result in magnetization precession with different phases. In this method, we drive spin precession in a Permalloy thin film using microwaves. The resulting precession is detected using 1550 nm laser light, that is modulated at a frequency slightly shifted with respect to the driving frequency. In the reflected light, beating of the spin precession and the light modulation produces an oscillating Kerr rotation signal with a phase equal to the precession phase plus a phase due to the path length difference between the excitation microwave and the optical signal. This detection method eliminates the need for field modulation and allows detection at higher frequencies where the 1/f noise floor is reduced. [1] M. Weiler, J. M. Shaw, H. T. Nembach, and T. J. Silva, Phys. Rev. Lett. 113, 157204 (2014).

1:51PM L6.00014 Anomalous Hall Effect in a Kagome Ferromagnet1, LINDA YE, CHRISTINA WICKER, TAKEHITO SUZUKI, JOSEPH CHECKELSKY, Massachusetts Inst of Tech-MIT, JOSEPH CHECKELSKY TEAM — Theferromagnetic kagome lattice is theoretically known to possess topological band structures [1,2]. We have synthesized large single crystals of a kagome ferromagnet Fe3Sn2 which orders ferromagnetically well above room temperature [3].We have studied the electrical and magnetic properties of these crystals over a broad temperature and magnetic field range.Both the scaling relation of anomalous Hall effect and anisotropic magnetic susceptibility show that the ferromagnetism of Fe3Sn2 is unconventional.We discuss these results in the context of magnetism in kagome systems and relevance to the predicted topological properties in this class of compounds. [1]Phys. Rev. B 87 144101 (2013) [2]Phys. Rev. Lett. 106 236802 (2011) [3]J. Phys: Cond. Mat. 21 452202 (2009)

2:03PM L6.00015 Interaction and multiband effects in the intrinsic spin-Hall effect of an interacting multiorbital metal, NOYA A ARAKAWA, RIKEN CEMS — The spin-Hall effect is a spin-current version of the usual-Hall effect, and its potential for application may be great. For the efficient utilization utilizing the spin-Hall effect, an understanding of interaction effects may be helpful because the interaction effects sometimes become remarkable in transport phenomena (e.g., fractional-quantum-Hall effect). However, a lot of theoretical studies neglected the interaction effects, and the interaction effects in the spin-Hall effect had been little understood. To improve this situation, I developed a general formalism for the intrinsic spin-Hall effect including the interaction effects and multiband effects by using the linear-response theory with approximations appropriate for an interacting multiorbital metal (see arXiv:1510.03988). In this talk, I explain how the electron-electron interaction modifies the spin-Hall conductivity and show several new and remarkable interactions effects, new mechanisms of the damping dependence and a crossover of the damping dependence in a clean system and a temperature-dependent correction due to the spin-Coulomb drag. I also show guidelines useful for general formulations of other transport phenomena including the interaction effects and multiband effects.


11:15AM L18.00001 Tabletop soft x-ray magnetic circular dichroism measurements using circularly polarized high harmonic sources, T FAN, R KNUT, C HERNINDEZ-GARCA, D HICKSTEIN, D ZUSIN, C GENTRY, F DOLLAR, C MANCUSO, C HOGLE, J ELLIS, K DORNEY, JILA - University of Colorado, D LEGUT, Charles University, K CARVA, P OPPENEEER, Department of Physics - Uppsala University, O SHPYRKO, E FULLERTON, University of California at San Diego, O KFIR, O COHEN, Physics Department - Technion, D MILOSEVIC, University of Sarajevo, A BECKER, A JARON BECKER, T POPMINTCHEV, M MURNANE, H KAPTEYN, P GRYCHTOL, JILA - University of Colorado — X-ray magnetic circular dichroism (XMCD) allows for the extraction of the orbital and spin contributions to the magnetization and its interaction with phononic and electronic degrees of freedom on fs time and nm length scales, with element-specificity. However, to date, circular soft x-ray beams were restricted to large-scale x-ray facilities. These facilities have great advantages of high peak and average powers, but have limited access and temporal resolution. In this work, we present the first direct tabletop approach for generating bright circularly polarized light exceeding 100 eV. This makes it possible to implement XMCD on the tabletop for the first time, allowing not only the 3d ferromagnets, but also the 4f rare earth materials with element-specificity. We demonstrate the stability, circularity and brightness of our high harmonic source by extracting the magneto-optical coefficients near the N edge of Gd (145 eV), as well as at the M edges of Fe (52eV), for an out-of-plane magnetized Gd/Fe multilayer sample thus enabling ultrafast studies of magnetization dynamics.

11:27AM L18.00002 Localization of Fe d-states in Ni-Fe-Cu alloys and implications for ultrafast demagnetization, TOM SILVA, NIST, Boulder, CO, USA, RONNY KNUT, JILA, Boulder, CO, USA, ERNA DELCZEG-CZIRJAK, Uppsala University, Uppsala, Sweden, JUSTIN SHAW, HANS NEMBACH, JILA, Boulder, CO, USA, PATRIK GRYCHTOL, DMITRIY ZUSIN, CHRISTIAN GENTRY, EMRAH TURGUT, HENRY KAPTEYN, MARGARET MURNANE, JILA, Boulder, CO, USA, DARIO ARENA, University of South Florida, Tampa, FL, USA, OLLE ERIKSSON, OLOF KARIS, Uppsala University, Uppsala, Sweden — Ni_{x}Fe_{1-x}Cu (Py) and Py-Cu exhibit intriguing ultrafast demagnetization behavior, where the Ni magnetic moment shows a delayed response relative to the Fe. To unravel the mechanism responsible for this behavior, we have studied Py-Cu alloys for a wide range of Cu concentrations using X-ray magnetic circular dichroism (XMCD). The magnetic moments of Fe and Ni are found to respond very differently to Cu alloying: Fe becomes a strong ferromagnet in Py, with the magnetic moment largely unaffected by Cu alloying. In contrast, the Ni magnetic moment decreases continuously with increasing Cu concentration. Ab-initio calculations corroborate these results and we discuss the electronic structure in the framework of virtual bound states (VBSS). Fe exhibits VBSS in the minority band that lie approximately 1 eV above the Fermi level in pure Py, and which move closer to the Fermi level upon Cu alloying. A strong interaction between the VBSs and electrons above the Fermi level enhances the formation of magnons at Fe sites. This mechanism is consistent with a demagnetization delay between Fe and Ni, as found experimentally.

11:39AM L18.00003 Time Resolved X-ray Magnetic Circular Dichroism at the Linac Coherent Light Source3, W SCHLIEDE, J HIGLEY, E JAL, G DAKOFSKI, E YUAN, J MACARTHUR, A LUTMAN, K HIRSCH, P GRANITZKA, Z CHEN, G COSLOVICH, M HOFFMAN, A MITRA, A REID, P HART, H DUHR, HUH, SLAC - Natl Accelerator Lab, E ARENHOLZ, P SHAFER, P DENNES, J JOSEPH, Lawrence Berkeley Natl Lab, L GUYADER, Helmholtz-Zentrum Berlin, Germany, A TSUKAMOTO, Nihon University, Chiba, Japan — We demonstrate ultrafast time resolved X-ray Magnetic Circular Dichroism on optically switchable GdFeCo thin film samples. This method extends the element specificity of time resolved x-ray absorption spectroscopy to characterize the evolution of electron spin and orbital angular momenta. These measurements were enabled by a recent upgrade at the Linac Coherent Light Source (LCLS) to generate circularly polarized x-rays. Additionally these measurements were enhanced by new detection systems that benefit all x-ray absorption spectroscopy experiments performed in transmission. Consequently static XMCD data are in excellent agreement with similar measurements at synchrotron light sources. The LCLS is an x-ray free electron laser user facility accessible via a peer-reviewed proposal process.  

1 The research is supported by DMR-1213139.
2 This research has been supported by the Director, Office of Science, Office of Basic Energy Sciences under Contract No. DE-AC02-76SF00515.
3 Acknowledgement: The Linac Coherent Light Source (LCLS), SLAC National Accelerator Laboratory, is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Contract No. DE-AC02-76SF00515.
11:51AM L18.00004 Spin pumping in electrodynamically coupled magnon-photon systems1, LIHUI BAI, Department of Physics and Astronomy, University of Manitoba, Winnipeg, Canada R3T 2N2 — The electronics industry is quickly approaching the limitation of Moore’s Law due to Joule heating in high density-integrated devices. To achieve new higher-speed devices and reduce energy consumption, researchers are turning to spintronics where the intrinsic spin, rather than the charge of electrons, is used to carry information in devices. Advances in spintronics have led to the discovery of giant magnetoresistance (GMR), spin transfer torque etc. Another subject, cavity electrodynamics, promises a completely new quantum algorithm by studying the properties of a single electron interacting with photons inside of a cavity. By merging both spintronics and cavity electrodynamics, a new cutting edge field called Cavity Spintronics is forming, which draws on the advantages of both subjects to develop new spintronics devices utilizing light-matter interaction. In this work, we use electrical detection, in combination with microwave transmission, to investigate both resonant and nonresonant magnon-photon coupling in a microwave cavity at room temperature. Spin pumping in a dynamically coupled magnon-photon system is found to be distinctly different from previous experiments. Characteristic coupling features such as modes anticrossing, linewidth evolution, peculiar line shape, and resonance broadening are systematically measured and consistently analyzed by a theoretical model set on the foundation of classical electrodynamic coupling. Our experimental and theoretical approach paves the way for pursuing microwave coherent manipulation of pure spin current via the combination of spin pumping and magnon-photon coupling.

1 Co-authored with M. Harder, C.-M. Hu from University of Manitoba, Y. P. Chen, J. Q. Xiao from University of Delaware, and X. Fan from University of Denver

12:27PM L18.00005 Ultrafast magnetization dynamics in heterogeneous granular FePt media , PATRICK GRANITZKA, ALEXANDER REID, EMMANUELLE JAL, TIAMIN LIU, SLAC – National Accelerator Laboratory, WILLIAM SCHLOTTER, SLAC – Linac Coherent Light Source, PADRAIC SHAFER, LBNL, VIRAT METHA, OLAV HELLWIG, HGST, YUKIKO TAHAHASHI, National Institute for Materials Science, Japan , ERIC FULLERTON, UCSF, Center for Magnetic Recording Research, JOACHIM STOHR, HERMANN DURR, SLAC – National Accelerator Laboratory — Granular FePt in the L10 phase is a key material for future magnetic data storage devices, supporting stable magnetic domains less than 10 nm in diameter. To switch the magnetization of magnetically hard materials like FePt, new writing techniques are needed such as Heat Assisted Magnetic Recording (HAMR). However, it is not known how HAMR works on the fundamental length and time scales of magnetization in FePt. Here we investigate the nanoscale aspects of magnetization dynamics in FePt HAMR with fs X-ray pulses from the Linac Coherent Light Source at Stanford using resonant X-ray diffraction. We show that while many spins display switching in a magnetic field following a fs optical excitation. The remaining spins do not switch. Surprisingly the ratio of spins that switch to spins that do not, stays constant over a large fluence range. Furthermore we observe that the spin reservoir which displays heat assisted magnetic recording is quenched homogeneously over the size distribution of grains, while the spins that do not follow the field display a length-scale dependent quenching.

12:39PM L18.00006 A simple and effective theory for all-optical helicity-dependent spin switching1, GUOPING ZHANG, Department of Physics, Indiana State University, Terre Haute, IN 47809, USA, YIHUA BAI, Office of Information Technology, Indiana State University, USA, THOMAS F GEORGE, University of Missouri-St. Louis — All-optical helicity-dependent spin switching (AOS) represents a new frontier in magnetic recording technology, where a single ultrafast laser pulse, without any assistance from an external magnetic field, can permanently switch spin within a few hundred femtoseconds. By contrast, the existing theory does rely on an artificial magnetic field to switch spins. Here we develop a microscopic spin switch theory, free of any artificial field, and demonstrate unambiguously that both circularly and linearly polarized lights can switch spins faithfully. Our theory is based on the Hookean theory, but includes two new elements: spin-orbit coupling and exchange interaction. We predict that left (right) circularly polarized light only flips (flops) spin, a symmetry constraint that strongly favors ferrimagnetic orderings over ferromagnetic ones, with the allowable exchange interaction within 10 meV, consistent with all prior theories. The effect of the laser amplitude is highly nonlinear: if it is too weak, AOS does not occur, but if too strong, the spin cant; a compromise between them produces a narrow spin reversal window as observed experimentally. We envision that our model can be easily extended to describe spin frustrated systems and multiferroics, where the light-spin interaction

1 Supported by the U.S. Department of Energy under Contract No. DE-FG02-06ER46304 and the National Energy Research Scientific Computing Center

12:51PM L18.00007 A fast time-dependent density functional theory method for the simulation of ultrafast demagnetization induced by laser , ZHANGHUI CHEN, LIN-WANG WANG, Lawrence Berkeley Nati Lab, MAGNETIC PROJECT TEAM — We present a fast real-time time-dependent density functional theory method to investigate the ultrafast spin dynamics induced by laser. The Hamiltonian considers non-collinear magnetic moment, spin-orbital coupling and electron-laser interaction. An accelerated method with leapfrog prediction of charge matrix is used to solve the time-evolving equation. The investigation of Ni bulk found that the spin demagnetization consists of one time-lag stage and one fast demagnetization stage followed by one slow demagnetization stage. The time-lag and fast stages are mainly affected by the spin-electron interaction and their interactions with photons while the slow stage is affected by phonon-related interaction. Demagnetization appears only when spin-orbital coupling effect is considered. We further demonstrated how to manipulate the spin dynamics by changing laser fluence, duration and wavelength.

1:03PM L18.00008 A comparative study of laser-induced demagnetization dynamics in Fe, Co, and Ni, MAITHREYI GOPALAKRISHNAN, CHRISTIAN GENTRY, DMITRIY ZUSIN, PATRIK GRYCHTOL, RONNY KNUT, JILAR, University of Colorado Boulder, JUSTIN SHAW, HANS NEMBACH, Electromagnetics Division, NIST, Boulder, STEFAN MATHIAS, Department of Physics, Georg-August-Universitat Gottingen, MARTIN AESCHLIMANN, Department of Physics, University of Kaiserslautern, PETER OPPENEER, Department of Physics and Astronomy, Uppsala University, CLAUS SCHNEIDER, Peter Grunberg Institut, Forschungszentrum Julich, HENRY KAPTEYN, MARGARET MURNANE, JILAR, University of Colorado Boulder — Even twenty years after the discovery of ultrafast demagnetization of ferromagnetic materials induced by a femtosecond laser pulse there is still an ongoing debate about the mechanisms that drive the process. Surprisingly, a comprehensive study that compares demagnetization dynamics in different materials on equal footing is lacking. Yet, the scientific community would greatly benefit from such study. We fill this gap by performing a systematic comparison of ultrafast demagnetization behavior in Iron, Cobalt and Nickel, the simplest itinerant ferromagnets, under a wide range of pump fluences. In this experiment, we utilize a tabletop broadband extreme ultraviolet source to probe magnetization dynamics at the M2,3 absorption edges of these three elements using the transverse magneto-optical Kerr effect. The obtained data can be used to inform theory and, thereby, assist in resolving the remaining questions about the micro- and macroscopic mechanisms behind ultrafast laser-induced magnetization dynamics in materials.
1:15PM L18.00009 Ultrafast demagnetization, spin-dependent Seebeck effect, and thermal spin transfer torque in Pt/TbFe/Cu and Pt/TbFe/Cu/Fe thin films. JOHANNES KIMLING, University of Illinois, BIRGIT HEbler, University of Augsburg, JUDITH KIMLING, University of Illinois, MANFRED ALBRECHT, University of Augsburg, DAVID G. CAHILL, University of Illinois — We investigate diffusive spin currents in Pt(20nm)/TbFe(10nm)/Cu(100nm) and Pt(20 nm)/TbFe(10 nm)/Cu(100nm)/Fe(3nm) stacks using time-resolved magneto-optic Kerr effect (TRMOKE) and time-domain thermoreflectance measurements. Our experiments are based on two hypothesis: (1) fast changes of magnetization due to laser excitation are transferred into spin accumulation, e.g., via electron-magnon scattering; the generated spin accumulation drives a diffusive spin current into adjacent normal metal layers; (2) electronic thermal transport through the ferromagnetic layer injects a spin current into adjacent normal metal layers, based on the spin-dependent Seebeck effect. [1] We excite the Pt layer with ps-laser pulses. Resulting diffusive spin currents generate nonequilibrium magnetization in the Cu layer (sample I) and induce a precession of the magnetization of the Fe layer via spin transfer torque (sample II). Both responses are probed using TRMOKE. Prior experiments used [Co(0.2mm)/Pt(0.4mm)]Co(0.2nm) instead of TbFe. [1] The ferrimagnetic TbFe layer introduces two major modifications: (1) slow demagnetization behavior, and (2) large thermal resistance. Hence, thermal spin transfer torques can be observed on significantly longer time scales. [1] G.-M. Choi, C.-H. Moon, B.-C. Min, K.-J. Lee, and D. G. Cahill, Nature Physics 11, 576 (2015).

1:39PM L18.00011 Ultrafast Study of Dynamic Interfacial Exchange Coupling in Ferromagnet/Oxide/Semiconductor Heterostructures, YU-SHENG OU, YI-HSIN CHIU, The Ohio State University, NICHOLAS HARMON, The University of Iowa, PATRICK ODENTHAL, University of California, Riverside, MATTHEW SHEFFIELD, MICHAEL CHILCOTE, ROLAND KAWAKAMI, The Ohio State University, MICHAEL FLATT, The University of Iowa, EZEKIEL JOHNSTON-HALPERIN, The Ohio State University — Time-resolved Kerr/Faraday rotation (TRKR/TRFR) is employed to study GaAs spin dynamics in the regime of strong and dynamic exchange coupling to an adjacent MgO/Fe layer. This study reveals a dramatic, resonant suppression in the inhomogeneous spin lifetime (T*) in the GaAs layer. Further investigation of the magnetization dynamics of the neighboring Fe layer, also using TRKR/TRFR, reveals not only the expected Kittel-dispersion but also additional lower frequency modes with very short lifetime (65 ps) that are not easily observed with conventional ferromagnetic resonance (FMR) techniques. These results suggest the intriguing possibility of resonant dynamic spin transfer between the GaAs and Fe spin systems. We discuss the potential for this work to establish GaAs spin dynamics as an efficient detector of spin dissipation and transport in the regime of dynamically-driven spin injection in ferromagnet/semiconductor heterostructures.

1:51PM L18.00012 Heisenberg vs. Stoner: Ultrafast magnon generation and exchange renormalization in the course of laser-induced demagnetization, DMITRIY ZUSIN, EMRAH TURGUT, PATRIK GRYCH-TOL, RONNY KNUT, JILA, University of Colorado - Boulder, DOMINIK LEGUT, Department of Condensed Matter Physics, Charles University, Prague, JUSTIN SHAW, HANS NEMBACH, THOMAS SILVA, Electromagnetics Division, NIST, BOSTAN, STEFAN MATHIAS, MARTIN AESCHLIMANN, Department of Physics, University of Kaiserslautern and Research Center OPTIMAS, CLAUS SCHNEIDER, Peter-Gruben-Institut, Forschungszentrum Julich, KAREL CARVA, PETER OPPENHEIER, Department of Physics and Astronomy, Uppsala University, HENRY KAPTEYN, MARGARET MURNANE, JILA, University of Colorado - Boulder — In this work, we access the microscopic mechanisms responsible for the ultrafast magnetization dynamics of ferromagnets following a femtosecond laser excitation. Using a tabletop high-harmonic source of extreme ultraviolet light, we perform magneto-optical pump-probe spectroscopic studies across the M_{2,3} absorption edge of Cobalt with time, energy and angle resolution. This novel approach allows us to extract the time-dependent resonant magneto-optical properties of the Cobalt sample. In combination with ab-initio calculations of the density of states and the magneto-optical response, this gives us direct access to ultrafast dynamics of the bond structure. A comparison of our theoretical simulations with the experimental measurements suggests a variety of demagnetization mechanisms, which include ultrafast magnon excitations, enhanced electron temperature and transient renormalization of exchange splitting.

2:03PM L18.00013 Studies of Ultrafast Demagnetization in Ferromagnetic Metal Alloys using TDDFT, PETER ELLIOTT, KEVIN KRIEGER, JOHN KAY DEWHURST, SANGEETA SHARMA, E.K.U. GROSS, Max Planck Institute of Microstructure Physics — Time dependent density functional theory (TDDFT) has recently[1,2] been applied to study magnetization dynamics in periodic systems. In particular it was found for short intense pulses, a significant source of demagnetization is spin-flips mediated by the spin-orbit interaction. In this work, we perform TDDFT simulations for the case of bulk Heusler compounds under the same conditions, and find a similar loss of the global magnetic moment can occur. Furthermore, we also see local spin-density fluctuations following the loss of the global moment in agreement with the experiments. Here we study the impact of spin-orbit mediated demagnetization in certain cases. Additionally we will analyze the spin-current densities to better understand the various processes at work. [1] Laser induced ultrafast demagnetization: an ab-initio perspective, K. Krieger, J.K. Dewhurst, P. Elliott, S. Sharma, E.K.U. Gross, J. Chem. Theory and Comput. 11, 4870 (2015). [2] Demonstration of Optimal Control of Laser Induced Spin-Orbit Mediated Ultrafast Demagnetization, P. Elliott, K. Krieger, J. K. Dewhurst, S. Sharma, E. K. U. Gross, submitted (2015).
11:15AM L19.00001 Engineering a spin-orbital magnetic insulator by tailoring iridate-based superlattices. JOBU MATSUNO, RIKEN Center for Emergent Matter Science — In 5d Ir oxides with an interplay of spin-orbit coupling and electron correlations, we have tailored a spin-orbital magnetic insulator out of a semimetal SrIrO$_3$ by tuning the structure through superlattices [(SrIrO$_3$)$_n$ + SrIrO$_3$] ($n = 1, 2, 3, 4$, and $\infty$) grown on SrTiO$_3$ (001) substrates. We observed the systematic decrease of the magnetic ordering temperature and the resistivity as a function of $n$. The transition from the semimetal to the insulator is found to be closely linked to the appearance of magnetism at $n \geq 3$. Long range magnetic ordering was realized even in the $n = 1$ single layer superlattice, implying that the design and realization of novel electronic phases is feasible at the level of a single atomic layer in complex Ir oxides. We also report the fabrication of (111)-oriented superlattice structures with alternating 2nm-layers ($n = 1, 2, 3$) of Ca$_{12}$Sr$_7$Re$_2$O$_{30}$ perovskite and two layers of SrTiO$_3$ perovskite on SrTiO$_3$(111) substrates. In the case of $n = 1$ bilayer films, the Ir sublattice is a buckled honeycomb, where a topological state may be anticipated. The ground states of the superlattice films were found to be magnetic insulators, which may suggest the importance of electronic correlations in Ir perovskites in addition to the much discussed topological effects.

11:51AM L19.00002 Novel magnetic and electronic states in manganite-iridate heterostructures. JOHN NICHOLS, SHINBUHM LEE, JON PETRIE, TRICIA MEYER, XIANG GAO, ERJIA GUO, Oak Ridge National Laboratory, JOHN FREELAND, Argonne National Laboratory, DI YI, JIAN LIU, University of Tennessee, DANIEL HASKEL, Argonne National Laboratory, THOMAS ZAC WARD, GYULA ERES, VALERIA LAUTER, MICHAEL R. FITZSIMMONS, HO NYUNG LEE, Oak Ridge National Laboratory — Strong correlation between spin, charge, lattice, and orbital order parameters has proven to give rise to exotic physical phenomena, while epitaxial design of materials with strong interfacial coupling is an efficient technique to tune such parameters. Although there have been numerous studies of interfaces between 3d-3d and 4d-3d compounds, only few studies reported work on 3d and 5d materials and there has been no report on strong interfacial coupling in such systems. We have synthesized high quality [(AMnO$_3$)$_m$/(SrIrO$_3$)$_n$] ($A = Sr, La$) heterostructures by pulsed laser epitaxy on SrTiO$_3$ (001) substrates and have observed interesting novel magnetic and electronic ground states, which are highly sensitive to the degree of dimensional confinement in the heterostructures. Based on studies with x-ray diffraction, SQUID, dc-transport, x-ray circular dichroism, and polarized neutron reflectometry measurements, we will report intriguing magnetic and transport properties that provide the first evidence of strong interfacial coupling between 5d and 3d materials.

12:03PM L19.00003 Strain control of magnetic structure in Sr$_3$Ir$_2$O$_7$. CHOONG H. KIM, IBS-CCES & Seoul Nat'i Univ. — We have studied from first principles the structural, electronic, and magnetic properties of the layered-perovskite iridates Sr$_3$Ir$_2$O$_7$ as a function of epitaxial strain. In Sr$_3$Ir$_2$O$_7$, bilayer iridates, an easy c-axis collinear antiferromagnetic structure have been reported, a significant contrast to single layer Sr$_2$IrO$_4$ with in-plane canted moments. This behavior is understood by competition among intra- and interlayer bond-directional pseudospin interactions. From our first-principles calculations, we show that these two energy scales are controllable via strain to drive spin-flop transition.

12:15PM L19.00004 Realization of a Ferroelectric-Domain-Wall Tunnel Junction. JACOBO SANTA-MARIA, G. SANCHEZ-SANTOLINO, J. TORNOS, D. HERNANDEZ-MARTIN, J. I. BELTRAN, M. CABERO, A. PEREZ-MUOZ, Z. SEFRIOUI, C. LEON, M. VARELA, GFMC Univ Complutense. 28040 Madrid, S. JENNYCOOK, Department of Materials Science & Engineering, National University of Singapore, Singapore 117575. — Incorporating ferroelectric domain walls as an active part of electronic devices holds the promise of interesting new functionalities. Here we form a ferroelectric BaTiO$_3$ tunnel barrier just 4.4-nanometer thick, with ferromagnetic La$_{0.7}$Sr$_{0.3}$MnO$_3$ electrodes, containing a head-to-head domain wall within its thickness. A confined electron gas is formed at the domain wall, stabilized by oxygen vacancies, which controls the tunneling transport of the magnetic quantum states. Resonant tunneling assisted by the discrete levels of the ferroelectric quantum well gives rise to strong quantum oscillations of the tunneling conductance. Our engineered, highly constrained, domain wall provides a major step forward towards the new concept “The Wall is the Device”, exploiting the electronic properties of domain walls for ferroelectric tunnel barriers with new functionalities.

12:27PM L19.00005 Tailoring magneto-electro-resistance in La$_{0.7}$Sr$_{0.3}$MnO$_3$/BaTiO$_3$multiferroic tunnel junctions. MARIONA CABERO, A.M. PEREZ-MUOZ, D. HERNANDEZ-MARTIN, Z. SEFRIOUI, M. VARELA, C. LEON, J. SANTAMARIA, GFMC Univ Complutense. 28040 Madrid, S. VALENCIA, Helmholtz-Zentrum Berlin fr Materialen & Energie, Albert-Einstein-Strasse 15, 12489 Berlin, Germany, R. ABRUDAN,1 Helmholtz-Zentrum Berlin fr Materialen & Energie, Albert-Einstein-Strasse 15, 12489 Berlin, S. J. PENNYCOOK, Department of Materials Science & Engineering, National University of Singapore, Singapore 117575. — Controlling and manipulating the electronic states of oxide interfaces using external stimuli has become a major direction towards oxide-based electronics. Here, we present a study of the transport properties of multiferroic La$_{0.7}$Sr$_{0.3}$MnO$_3$/BaTiO$_3$ (LSMO/BTO) ferromagnetic/ferroelectric heterostructures. Multiferroic tunnel junctions (MTJ’s) have been obtained introducing an ultrathin La$_x$/Sr$_{1-x}$capped layer between the ferromagnetic barrier and the top ferromagnetic electrode. The LSMO introduces an asymmetry in the screening of polarization charges at both interfaces, which yields ferroelectric barrier values in excess of 105 % and triggers an inversion of the sign of the tunneling magnetoresistance controlled ferroelectric switching. We will discuss these results in the light of the generation and transport of oxygen vacancies. Work at UCM supported by MINECO MAT2014-52405-C02-01 and ERC Starting Investigator Grant #239739 STEMOX. MCM acknowledges financial support from MICINN through grant MAT2012-38045-C04-04.

12:39PM L19.00006 DFT+$U$ study of electronic structure and Curie temperature of A$_2$BReO$_6$ ($A=$Sr, Ca and $B=$Cr, Fe). ALEX LEE, CHRIS MARIANETTI, Applied Physics and Applied Math, Columbia University — Re-based double perovskites (DPs) have attracted much attention due to their high Curie temperature ($T_c$) and colossal magnetic resistance with large potential for spintronic applications. Here we investigate the magnetic and electronic properties of the Re-based DPs A$_2$BReO$_6$ ($A=$Sr, Ca and $B=$Cr, Fe) using density functional theory + $U$ (DFT+$U$) calculations. While nonmagnetic Ca$_2$CrReO$_6$ and Ca$_2$FeReO$_6$ (monoclinic) are insulating within GGA+$U$, tetragonal Sr$_2$CrReO$_6$ ($a^0c^0d^0$) and Sr$_2$FeReO$_6$ ($a^0a^0c^-$) remain metallic. We show that both on-site interaction $U$ and octahedral tilting are critical to obtain the insulating phases. The $a^0a^0c^-$-phase of Sr$_2$FeReO$_6$ is most stable and insulating with nonzero $U$, suggesting that the high quality Sr$_2$CrReO$_6$ film on STO substrate can be a semiconductor as reported in recent experiments. We explain that the insulator-to-metal transition (MIT) of Ca$_2$FeReO$_6$ at 140K is predominantly due to a structural phase transition which drives the insulating state. Curie temperatures of Re-based DPs are calculated using the classical Monte Carlo simulations based on the Heisenberg model.
12:51PM L19.00007 Magnetism and Nanoscale Structural and Compositional Irregularities in MBE-grown La$_2$MnNiO$_6$ on SrTiO$_3$(001), SCOTT CHAMBERS, YINGGE DU, TIMOTHY DROUBAY, PETER SUSHKO, STEVEN SPURGEON, ARUN DEVARAJ, MARK BOWDEN, V SHUTTHURANDAN, Pacific Northwest Natl Lab, TORGNY GUSTAFFSON, Rutgers University — Double perovskites (La$_2$BB'O$_6$) are a fascinating class of oxides with considerable potential for applications requiring ferromagnetic and semiconducting properties. We have investigated MBE-grown La$_2$MnNiO$_6$ and have found that despite the fact that Mn and Ni are present as $4+ (d^5, t^2_g, e^0)$ and $3+ (d^6, t^6_g, e^2)$ respectively, and exhibit suitable XMCD signatures, the volume-averaged moment per formula unit is considerably less than 5 Bohr magnetons. Our electron energy loss spectroscopy (STEM-EELS) and atom probe tomography (APT) results to date reveal that there is considerable disorder in the B-site sublattice for as-deposited films, despite excellent volume-averaged stoichiometry. While air annealing results in substantial ordering, the moment remains low due to the nucleation of NiO inclusions with needle-like shapes revealed only by APT. First principles modeling suggests that even though the double perovskite is quite stable if nucleated in excess O, the presence of O vacancies facilitates structural disorder. In this talk, we will present our latest results on this fascinating material.

1:03PM L19.00008 Magnetism, Chemical Ordering, and Defects in Epitaxial Double Perovskite La$_2$MnNiO$_6$ Thin Films, TIM DROUBAY, STEVEN SPURGEON, YINGGE DU, ARUN DEVARAJ, Pacific Northwest National Laboratory, STEVE HEALD, Advanced Photon Source, Argonne National Laboratory, PETER SUSHKO, Pacific Northwest National Laboratory, TORGNY GUSTAFFSON, Rutgers University, DAVID KEAVNEY, Advanced Photon Source, Argonne National Laboratory, SCOTT CHAMBERS, Pacific Northwest National Laboratory — Oxide double perovskites (A$_2$BB'O$_6$) exhibit an interesting variety of electronic and magnetic properties such as half-metallicity and high temperature ferromagnetism holding promise for potential technological applications. We have investigated La$_2$MnNiO$_6$/SrTiO$_3$ grown using molecular beam epitaxy and have found different proportions of two ferromagnetic phase transitions (~130K and ~290K) and various saturation magnetization values (~4.6$\mu_B$/f.u.) dependent upon post-growth annealing. Contrary to previous reports, neither the increase in the saturation magnetization nor the Curie temperature(s) after annealing can be accounted for by the increase in magnetic order of the surface layer. However, an increase in magnetic moment can be ascribed to the exchange interaction between magnetic Yb and Fe ions. Here we report an x-ray magnetic circular dichroism (XMCD) study of (0001) Hexagonal YbFeO$_3$ thin films deposited on (111) yttria-stabilized zirconia substrates with pulsed laser deposition. XMCD spectra for the Fe $L_{2,3}$ edges and Yb $M_{5,6}$ edge were measured with the magnetic field applied parallel to the x-ray propagation direction and 20 degree away from the film normal at beamline 4ID-C of the APS at ANL. Field dependence of the XMCD spectra show that Fe and Yb each has a ferromagnetic ordering at around 6.7 K but with opposite orientations in between. The saturation magnetic moment for Fe is determined by the sum rules to be 0.07$\mu_B$/f.u. We will describe these results in light of first principles calculations which suggest that local deviations from the ideal stoichiometry facilitate the formation of the NIO phase and structural disorder in the double perovskite phase.

1:15PM L19.00009 Half-metallic ferromagnetism on surfaces of insulating and antiferromagnetic LaFeO$_3$ thin films, ROHAN MISHRA, Washington University in St. Louis, YOUNG-MIN KIM, Korea Basic Science Institute, QIAN HE, Oak Ridge National Laboratory, SEONG-KEUN KIM, Korea Institute of Science & Technology, SEOHYOUNG CHANG, ANAND BHATTACHARYA, Argonne National Laboratory, SOKRATES T. PANTELIDES, Vanderbilt University, Oak Ridge National Laboratory, ALBINA BORISEVICH, Oak Ridge National Laboratory — The surfaces of perovskite transition metal oxides have correlated electrons show novel electronic and magnetic phenomena. In this work, we combine scanning transmission electron microscopy imaging and electron energy loss spectroscopy (EELS) with density functional theory (DFT) calculations to study the surface of (LaFeO$_3$)$_{1/3}$/(SrFeO$_3$)$_{1/3}$ heterostructure thin films. Using EELS, we observe a reduction in the oxidation state of Fe on moving from the bulk to the surface over a length of ~5 unit cells. Simultaneously acquired STEM images allow us to map the associated changes in their structure, such as cation displacements and changes in oxygen polyhedral tilts. DFT calculations coupled with the STEM results show that by reducing the surface layer of a LaFeO$_3$ film such that the surface is terminated with FeO$_6$ tetrahedra instead of the FeO$_8$ octahedra as present in the bulk, it is possible to stabilize an exotic ferromagnetic phase where the surface layer displays a half-metallic ferromagnetic behavior, while the bulk remains antiferromagnetic and insulating, similar to the surface of topological insulators. The calculations also predict that the magnetism and conductivity at the surface can be controlled by the partial pressure of oxygen.

1:27PM L19.00010 X-ray Magnetic circular dichroism study of hexagonal YbFeO$_3$ thin films, XIAO WANG, Bryn Mawr College, KISHAN SINHA, XIAOSHAN XU, University of Nebraska-Lincoln, YAOHUA LIU, Oak Ridge National Laboratory, DAVID KEAVNEY, Argonne National Laboratory, X.M. CHENG, Bryn Mawr College — Multiferroic materials exhibit multiple ferroic orders simultaneously and thus have potential applications in information technology, sensing, and actuation. Hexagonal YbFeO$_3$ is a promising candidate for a multiferroic material with room temperature ferromagnetism because of the expected enhanced Fe moment and higher transition temperature due to the exchange interaction between magnetic Yb and Fe ions. Here we report an x-ray magnetic circular dichroism (XMCD) study of (0001) Hexagonal YbFeO$_3$ thin films deposited on (111) yttria-stabilized zirconia substrates via pulsed laser deposition. XMCD spectra for the Fe $L_{2,3}$ edges and Yb $M_{5,6}$ edge were measured with the magnetic field applied parallel to the x-ray propagation direction and 20 degree away from the film normal at beamline 4ID-C of the APS at ANL. Field dependence of the XMCD spectra show that Fe and Yb each has a ferromagnetic ordering at around 6.7 K but with opposite orientations in between. The saturation magnetic moment for Fe is determined by the sum rules to be 0.07$\mu_B$/f.u. cation at around 6.7 K, about 4 times larger than that in Hexagonal LuFeO$_3$.

1:39PM L19.00011 MAGNETO-OPTIC ENHANCEMENT IN NANO-SCALE IR GARNET FILMS, ASHIM CHAKRAVARTY, MIGUEL LEVY, Physics Department, Michigan Technological University, 49931, USA — This work addresses dimensionality-induced magnetoeffect inclusions in liquid-phase-epitaxy magnetic garnet thin films. It is found that the Faraday rotation (FR) per unit length, ASHIM CHAKRAVARTY, MIGUEL LEVY, Physics Department, Michigan Technological University, 49931, USA — This work addresses dimensionality-induced magnetoeffect inclusions in liquid-phase-epitaxy magnetic garnet thin films. It is found that the Faraday rotation (FR) per unit length evinces a marked and steady enhancement as the film thickness is reduced approximately below 100 nm in Bi$_2$O$_3$Gd$_2$Lu$_2$Fe$_2$O$_{12}$, although it remains constant in the micron- and most of the sub-micron-regime. The reported specific FR change in such reduced dimensions is due to size-dependent modifications in diamagnetic transition processes in the garnet film. These processes correspond to the electronic transitions from the singlet $S^g$ ground state to spin-orbit split excited states of the Fe$^{2+}$ ions in the garnet. A measurable reduction in the corresponding ferrimagnetic resonance linewidths is found, thus pointing to an increase in electronic relaxation times and larger fixed excitations at reduced thicknesses than in the bulk. These changes together with a shift in vibrational frequency of the Bi-O bonds in the garnet at reduced thicknesses result in magneto-optical enhancement in ultra-thin garnet films.

1:51PM L19.00012 Enhancement of Magnetization in Y$_3$Fe$_2$O$_{12}$ Epitaxial Thin Films, JACK T. BRANGHAM, JAMES C. GALLAGHER, ANGELA S. YANG, SHANE P. WHITE, ROHAN ADUR, WILLAM T. RUANE, BRYAN D. ESSER, MICHAEL R. PAGE, P. CHRIS HAMMEL, Ohio State Univ - Columbus, DAVID W. MCCOMB, Center for Electron Microscopy and Analysis, Dept of Materials Science and Engineering, The Ohio State University, Columbus, OH 43212, FENGYUAN YANG, Ohio State Univ - Columbus — The ability to generate pure spin currents has applications in telecommunications, radar, and spin-based logic. Y$_3$Fe$_2$O$_{12}$ (YIG) is one of the best materials for dynamic generation of spin currents due to its low damping, narrow ferromagnetic resonance (FMR) linewidth, and insulating behavior. We grow stoichiometric, high quality, epitaxial YIG thin films with thicknesses ranging from 4 to 250 nm on Gd$_3$Ga$_2$O$_{12}$ by off-axis magnetron sputtering and characterize the YIG films by various techniques. The temperature dependence of the saturation magnetization was independently measured by in-plane vibrating sample magnetometry, out-of-plane magnetic shape anisotropy, and angular-dependent FMR absorption from 10 K to the Curie temperature of 530 K. The room temperature saturation magnetization was also measured with frequency dependent FMR. All measurements show a magnetization enhancement of 15% or greater when compared to reported magnetization values of bulk YIG crystals. We speculate this is due to suppression of the long wavelength magnons due to the finite size of the films.
2:03PM L19.00013 Strain induced structural, electronic, and magnetic properties of SrFeO$_2$ and BaFeO$_2$. WEIDONG LUN, XIAOLE ZHANG, Shanghai Jiao Tong University, China — The structural, electronic and magnetic properties of SrFeO$_2$ and BaFeO$_2$ under tensile strains are studied using first-principles density-functional theory calculations. Strain-induced Jahn-Teller-like behaviors involving the cooperative displacements of oxygen atoms are predicted in both compounds. Lattice dynamical properties are also investigated and the strain-induced imaginary phonon modes are consistent with the Jahn-Teller-like distortion. The usual Jahn-Teller instability of degenerate energy levels does not contribute to the interesting phenomena. Besides the structural and electronic properties, a transition of magnetic orderings from G-type anti-ferromagnetic phase to C-type anti-ferromagnetic phase is predicted in both compounds, which originates from the combined effects of the lattice-orbital coupling and the spin-orbital coupling due to exchange interaction between orthogonal Fe 3d orbitals.

We acknowledge funding support from the National Natural Science Foundation of China.

Wednesday, March 16, 2016 11:15AM - 2:03PM — Session L33 DMP GMG: Kitaev Physics in Honeycomb Iridates 336 - George Jackeli, University of Stuttgart

11:15AM L33.00001 Evidence for coexisting magnetic order in frustrated three-dimensional honeycomb iridates Li$_2$IrO$_3$. NICHOLAS BREZNAY, ALEJANDRO RUIZ, ALEX FRANO, JAMES ANALYTIS, University of California, Berkeley — The search for unconventional magnetism has found a fertile hunting ground in 5d iridium oxide (iridate) materials. The competition between coulomb, spin-orbit, and crystal field energy scales in honeycomb iridates leads to a quantum magnetic system with localized spin-1/2 moments communicating through spin-anisotropic Kitaev exchange interactions. Although early and ongoing work has focused on layered two-dimensional honeycomb compounds such as Na$_3$IrO$_3$ and a 4d analog, RuCl$_3$, recently discovered polytypes of Li$_2$IrO$_3$ take on three-dimensional honeycomb structures. Bulk thermodynamic studies, as well as recent resonant x-ray diffraction and absorption spectroscopy experiments, have uncovered a rich phase diagram for these three-dimensional honeycomb iridates. Low temperature incommensurate and commensurate magnetic orders can be stabilized by tuning the applied magnetic field, displaying a delicate coexistence that signals highly frustrated magnetism.

11:27AM L33.00002 Vacancies in a 3D-Kitaev model on hyper-honeycomb lattice. G J SREEJITH, Max Planck Institute for Physics of Complex Systems, Dresden, SUBHRO BHATTACHARJEE, International Centre for Theoretical Sciences, Bangalore, RODERICH MOESSNER, Max Planck Institute for Physics of Complex Systems, Dresden — We study the properties of isolated single and pairs of vacancies in an exactly solvable Kitaev model on a three dimensional hyper-honeycomb lattice. We show that each vacancy in the lattice is associated with a low energy spin like degree of freedom, similar to the case of previously studied honeycomb model. We calculate the contribution from these vacancy spin-moments to the low field magnetization response to a z-directed field. Isolated vacancies in the gapped phase act as free spins. In the gapless phase, these spins interact with the surrounding spin-liquid suppressing the low-field magnetization to $\frac{1}{\ln(1/t)}$. Pair of vacancies have a sublattice-dependent, anisotropic, spin-liquid mediated interaction with each other. In the gapless phase, interaction between vacancies in the same (opposite) sublattice enhances (suppresses) the low-field magnetization, indicating a ferromagnetic (anti-ferromagnetic) nature. We also show that, unlike vacancies in the honeycomb lattice, the vacancies here do not bind a flux at low-energies.

11:39AM L33.00003 Spin-Peierls instability of three-dimensional Kitaev spin liquids with Majorana Fermi surface. MARIA HERMANNS, SIMON TREBST, ACHIM ROSCH, University of Cologne — The Kitaev honeycomb model is one of the paradigmatic examples of a frustrated spin system exhibiting a quantum spin liquid ground state. The emergent low-energy degrees of freedom are fermions that can form various different (semi-)metallic states. Three-dimensional variants of this model can, in particular, harbor gapless quantum spin liquids with a Majorana Fermi surface. In this talk, we discuss Fermi surface instabilities arising from additional spin exchange terms (such as a Heisenberg coupling), which induce interactions between the emergent Majorana fermion degrees of freedom. We show that independent of the details of the interactions, the Majorana Fermi surface is always unstable. Generically, the system spontaneously dimerizes at exponentially small temperatures and forms a quantum spin liquid with nodal lines. Depending on the microscopic details, further symmetries of the system may be broken at this transition. These spin-Peierls instabilities of a 3D spin liquid are closely related to BCS instabilities of fermions.


11:51AM L33.00004 Kitaev physics in three dimensional honeycomb iridates. YONG-BAEK KIM, Univ of Toronto — It has been realized that Mott insulators with strong spin-orbit coupling may allow strongly bond-dependent exchange interactions between local moments. Such interactions may lead to magnetic frustration and possible quantum spin liquid phases. This is in contrast to usual frustrated magnets, where the magnetic frustration comes from the geometry of the underlying lattice structure. Hence, it offers a new avenue to generate exotic phases of matter. Recently, two different Kitaev exchange interactions have been discovered and it has been suggested that the magnetic exchange interactions contain the so-called Kitaev interactions, which depends on bond directions. In particular, the local moments of Ir ions in IrO$_2$ and Ir$_2$IrO$_3$ reside on the three-dimensional hyper-honeycomb and stripy-honeycomb lattices. The Kitaev model is exactly solvable on these lattices as well as the two-dimensional honeycomb lattice and the ground state is a quantum spin liquid with gapless excitations. We discuss recent progress in theoretical understanding of magnetic exchange interactions, possible presence of quantum spin liquid phases, and unusual magnetic order in IrO$_2$ and Ir$_2$IrO$_3$. These theoretical results are used to make connections to recent experimental data.

12:03PM L33.00005 Detecting Semimetal Surface Modes in Kitaev Spin Liquids. BRENT PERREAULT, University of Minnesota, JOHANNES KNOLLE, Cavendish Laboratory, NATALIA B. PERKINS, F. J. BURNELL, University of Minnesota — Raman scattering is a useful probe for Kitaev-type spin liquids because it couples only to the dispersing (and potentially gapless) fermionic degrees of freedom in these systems. I will discuss Raman scattering in Kitaev spin liquids on the 3D hyperhoneycomb (H-O) lattice, where these fermionic degrees of freedom realize topologically non-trivial band structures with protected gapless surface states. I will describe Raman signatures both of bulk 3D samples, and thin-film samples of these materials, where the resonant Raman response can detect the protected surface modes.
Phys. Rev. 112:39PM L33.00006 Large Band Gap of alpha-RuCl₃ Probed by Photoemission and Inverse Photoemission Spectroscopy SOBIN SINN, CHOONG HYUN KIM, LUKE SANDILANDS, IBS-CCES, Seoul National University, KYUNG-DONG LEE, CHOONGJAE WON, IBS-CCES, Inha University, JE SEOP OH, IBS-CCES, Seoul National University, MOONSUP HAN, YOUNG JIN CHANG, University of Seoul, NAMJUNG HUR, Inha University, HITOSHI SATO, Hiroshima Synchrotron Radiation Center, BYEONG-GYU PARK, Pohang Accelerator Laboratory, CHANGYOUNG KIM, HYEONG-DO KIM, TAE WON NOH, IBS-CCES, Seoul National University — The Kitaev honeycomb lattice model has attracted great attention because of its possibility to stabilize a quantum spin liquid ground state. Recently, it was proposed that alpha-RuCl₃ is its material realization and the first 4d relativistic Mott insulator from an optical spectrum and LDA+U+SO calculations. Here, we present photoemission and inverse photoemission spectra of alpha-RuCl₃. The observed band gap is about 1.8 eV, which suggests that the previously assigned optical gap of 0.3 eV is misinterpreted, and that the strong peak at about 1.2 eV in the optical spectrum may be associated with an actual optical gap. Assuming a strong excitonic effect of 0.6 eV in the optical spectrum, all the structures except for the peak at 0.3 eV are consistent with our electronic spectra. When compared with LDA+U+SO calculations, the value of U should be considerably larger than the previous one, which implies that the spin-orbit coupling is not a necessary ingredient for the insulating mechanism of alpha-RuCl₃. We also present angle-resolved photoemission spectra to be compared with LDA+U+SO and LDA+DMFT calculations.

12:51PM L33.00007 Ab-initio study on crystal structure of alpha-RuCl₃ HAE-YOUNG KEE, HEUNG-SIK KIM, Univ of Toronto — alpha-RuCl₃ was recently proposed as a candidate system for materialization of Kitaev model, but precise structural information of the compound has remained elusive. For the clarification of the full three-dimensional crystal structure of alpha-RuCl₃, we performed ab-initio electronic structure calculations including effects of spin-orbit coupling (SOC) and electron correlations. We found that SOC prevents dimerization between Ru atoms, and keeps the system close to honeycomb lattice. The ground state crystal structure has monoclinic C2/m-type layer stacking, but trigonal P3121-and orthorhombic Cmcm-type stacking orders are comparable to the C2/m structure in energy, so that stacking faults can be easily introduced. The electronic structure and the J_eff=1/2 pseudospin exchange interactions and possible magnetic states in alpha-RuCl₃ will be presented.

1:03PM L33.00008 Nanoscale structural and electronic characterization of alpha-RuCl₃ layered compound MAXIM ZIATDINOV, ARTEM MAKSOV, ARNAB BANERJEE, WU ZHOU, TOM BERLIN, JIAQIANG YAN, STEPHEN NAGLER, Oak Ridge National Laboratory, DAVID MANDRUS, University of Tennessee, ARTHUR BADDORF, SERGEI KALININ, Oak Ridge National Laboratory — The exceptional interplay of spin-orbit effects, Coulomb interaction, and electron-lattice coupling is expected to produce an elaborate phase space of alpha-RuCl₃ layered compound, which to date remains largely unexplored. Here we employ a combination of scanning transmission electron microscopy (STEM) and scanning tunneling microscopy (STM) for detailed evaluation of the system’s microscopic structural and electronic orders with a sub-nanometer precision. The STM and STEM measurements are further supported by neutron scattering, X-Ray diffraction, density functional theory (DFT), and multivariate statistical analysis. Our results show a trigonal distortion of Cl octahedral ligand cage along the C3 axis in each RuCl₃ layer. The lattice distortion is limited mainly to the Cl subsystem leaving the Ru honeycomb lattice nearly intact. The STM topographic and spectroscopic characterization reveals an intra unit cell electronic symmetry breaking in a spin-orbit coupled Mott insulating phase on the Cl-terminated surface of alpha-RuCl₃. The associated long-range charge order (CO) pattern is linked to a surface component of Cl cage distortion. We finally discuss a fine structure of CO and its potential relation to variations of average unit cell geometries found in multivariate analysis of STEM data.

1The research was sponsored by the U.S. Department of Energy

1Current Affiliation : Florida A and M University

1:15PM L33.00009 Probing Spin Excitations Using Magneto-Raman Spectroscopy K. THIRUNAVUKKARASU, Z. LU, National High Magnetic Field Laboratory, Tallahassee, FL, J. SIMPSON, Department of Physics, Towson University, MD, A. WALKER, National Institute of Standards and Technology, Gaithersburg MD, J. SEARS, Y.-J. KIM, Department of Physics, University of Toronto, Canada, K. BURCH, Department of Physics, Boston College, MA, D. SMIRNOV, National High Magnetic Field Laboratory, Tallahassee, FL — The presence of a 2D quantum spin liquid state was recently suggested for the spin-orbit coupled Mott insulator alpha-RuCl₃ with a honeycomb lattice.[Phys. Rev. 90, 041112 (2014)] Optical spectroscopy, Raman scattering, specific heat as well as magnetic susceptibility measurements on alpha-RuCl₃ identified elementary excitations due to electronic correlations and spin-orbit coupling.[arXiv:1503.07593, Phys. Rev. Letters 114, 147201 (2015), and Phys. Rev. 91, 144420 (2015)] These observations appear to be consistent with theoretical expectations for Heisenberg-Kitaev model for QSL.[Phys. Rev. 91, 241110 (2015)] The underlying mechanism for the unconventional magnetism in alpha-RuCl₃ was further investigated by probing the effect of external magnetic field on the Raman spectroscopic signatures. Raman scattering experiments were performed at temperatures down to 5 K and magnetic fields up to 10 T. The intensity of strongest Ru-K₃ phonon was found to decrease with increasing magnetic field strength suggesting the presence of strong magnetic interactions. The experimental observations and its implications will be presented.

1:27PM L33.00010 Phase diagram and quantum order by disorder in the Kitaev honeycomb magnet IOANNIS ROUSOCHATZAKIS, Univ of Minn - Minneapolis, JOHANNES REUTHER, Dahlem Center for Complex Quantum Systems of Berlin, Helmholz-Zentrum Berlin für Materialien und Energie, 14195 Berlin, Germany

1 NSF DMR-1511768; Freie Univ. Berlin Excellence Cluster Quantum Matter (EXC 2094/1-1170); DFG-SFB 1143, DFG-SPP 1666, and BMBF.

1:51PM L33.00012 Order by disorder in Kitaev-Heisenberg models on the honeycomb lattice
, NATALIA PERKINS, YURIY SIZYUK, SAMUEL DUCHARTRAN, Univ of Minnesota, Minneapolis, PETER WOELFLIE, Institute for Condensed Matter Theory and Institute for Nanotechnology, Karlsruhe Institute of Technology — Recent diffuse magnetic x-ray scattering data in Na2IrO3 [1] clearly determined the spin orientation in this zigzag state and showed that, unexpectedly, it is along the 44.3 degrees direction with respect to a axis, which is approximately half way between the cubic a and b axes. This experiment provides an important check of the validity of any model proposed to describe the magnetic properties of Na2IrO3 as the model should correctly predict not only the type of the magnetic order but also its orientation in space. We propose that order by disorder mechanism in quantum J1-K1-J2-K2-J3 model [2] gives the experimentally observed direction along cubic face diagonals. Our findings are based on both the calculation of the contribution of thermal fluctuations of quantum spins into free energy obtained by Hubbard-Stratonovich transformation and the zero-point correction to the ground state energy due to quantum spin fluctuations obtained by the spin-wave expansion at zero temperature. [1] S. H. Chun et al, Nature Physics10,1038 (2015). [2] Y. Sizyuk, C. Price, P. Woelfle, and N. B. Perkins, JPhys. Rev. B 90, 155126 (2014).

Wednesday, March 16, 2016 2:30PM - 5:18PM –
Session P5 GMAG DMP FIAP: Spins in Two Dimensions: Graphene, 2DEGs and Quantum Wells
301 - Hanan Dery, University of Rochester

2:30PM P5.00001 Homoeptaxial graphene tunnel barriers for spin transport , ADAM FRIEDMAN, Naval Research Laboratory — Tunnel barriers are key elements for both charge-and spin-based electronics, offering devices with reduced power consumption and new paradigms for information processing. Such devices require mating dissimilar materials, raising issues of heteroepitaxy, interface stability, and electronic states that severely complicate fabrication and compromise performance. Graphene is the perfect tunnel barrier. It is an insulator out-of-plane, possesses a defect-free, linear habit, and is impervious to interdiffusion. Nonetheless, true tunneling between two stacked graphene layers is not possible in environmental conditions (magnetic field, temperature, etc.) usable for electronics applications. However, two stacked graphene layers can be decoupled using chemical functionalization. We demonstrate successful tunneling, charge, and spin transport with a fluorinated graphene tunnel barrier on a graphene channel. We show that while spin transport stops short of room temperature, spin polarization efficiency values are the highest of any graphene spin devices. We also demonstrate that hydrogenation of graphene can also be used to create a tunnel barrier. We begin with a four-layer stack of graphene and hydrogenate the top few layers to decouple them from the graphene transport channel beneath. We demonstrate successful tunneling by measuring non-linear IV curves and a weakly temperature dependent zero-bias resistance. We demonstrate lateral transport of spin currents in non-local spin-valve structures and determine spin lifetimes with the non-local Hanle effect to be commensurate with previous studies. The measured spin polarization efficiencies for hydrogenated graphene are higher than most oxide tunnel barriers on graphene, but not as high as with fluorinated graphene tunnel barriers. However, here we show that spin transport persists up to room temperature. Our results for the hydrogenated graphene tunnel barriers are compared with fluorinated tunnel barriers and we discuss the possibility that magnetic moments in the graphene tunnel barriers affect the spin transport of our devices.


3:18PM P5.00003 Spintronics with Graphene and van der Waals heterostructures , SAROJ DASH, M.VENKATA KAMALAKAR, ANDR DANKERT, Chalmers University of Technology, QUANTUM DEVICE PHYSICS LABORATORY TEAM — Two-dimensional (2D) atomic crystals provide a large class of materials proposed to be important for nanoelectronics and spintronic. Here we present two important advancements in graphene spintronics by employing 2D materials and heterostructures. Graphene is considered to be an ideal material for spin transport due to the high mobility and long spin lifetime of the carriers. We realized spin transport over a long distance of 16 m and spin lifetimes up to 1.2 ns in large area CVD graphene on SiO2/Si substrate at room temperature [1]. Subsequently, using the h-BN tunnel barrier/graphene van der Waals heterostructure, we observe an enhancement in the spin tunnel polarization [2], and a negative spin signal for thicker h-BN barriers. These findings open a platform for exploring novel spin functionalities in 2D crystal heterostructures and understanding the basic science that control their behavior. [1] M. V. Kamalakar et al., Long Distance Spin Communication in Chemical Vapor Deposited Graphene, Nature Communications 6, 6766 (2015). [2] M. V. Kamalakar et al., Enhanced Tunnel Spin Injection into Graphene using Hexagonal Boron Nitride; Scientific Reports 4, 61464 (2014).

3:42PM P5.00005 Stoner-like theory of Magnetism in Silicon MOSFETs1. DENIS GOLOSOV, Bar-Ilan University — We consider quasi-two-dimensional gas of electrons in a typical Si-MOSFET, assuming contact repulsive interaction between electrons. Magnetisation and susceptibility are evaluated within the mean-field approach. The finite thickness of inversion layer results in an interaction-induced electron wave function change, not found in both purely two-dimensional and three-dimensional (bulk) cases. Taking this self-consistent change into account leads to an increased susceptibility and ultimately to a ferromagnetic transition deep in the high-density metallic regime. We further find that in the paramagnetic state, magnetisation increases sublinearly with increasing in-plane magnetic field. In the opposite limit of low carrier densities, the effects of long-range interaction become important and can be included phenomenologically via bandwidth renormalisation. Our treatment then suggests that with decreasing density, the metal-insulator transition is preceded by a ferromagnetic instability. We discuss the validity of our mean-field scheme, and relate the results to the available experimental data.

1Supported by Israeli Absorption Ministry

3:54PM P5.00006 Rashba scattering in the dilute limit, JOEL HUTCHINSON, JOSEPH MACIEJKO, University of Alberta — In two-dimensional (2D) noncentrosymmetric crystals, the spin degeneracy of the electronic band structure may be lifted by Rashba spin-orbit coupling. The resulting spin-split dispersion is responsible for the spin Hall effect and has desirable applications to spintronics. This spin-split dispersion is described in terms of two distinct helicity bands, but below a threshold energy, electrons are confined to one of these. At the bottom of this lower band, the density of states exhibits a van Hove singularity. This is the relevant regime for a dilute spin-orbit coupled 2D electron gas, which has been shown to host a variety of exotic phases in the presence of electron-electron interactions. In this talk we investigate scattering of Rashba electrons off a circular potential barrier in this dilute limit, which is relevant both for impurity scattering in the noninteracting limit as well as for short-range two-particle scattering in the interacting problem. The S matrix and scattering cross section are determined, and it is found that scattering becomes effectively one-dimensional at the band bottom.

4:06PM P5.00007 Edge spin accumulation in a two-dimensional electron gas with two subbands1, ALEXANDER KHAETSKII, State Univ of NY - Buffalo, J. CARLOS EGUES, Instituto de Fisica de Sao Carlos, Brazil — We have studied the edge spin accumulation in 2D electron gas due to the intrinsic mechanism of spin-orbit interaction for the case of a two-subband structure. This study is strongly motivated by recent experiments [1] which observed the spin accumulation near the edges of a high mobility 2D electron system in a bilayer symmetric GaAs structure in contrast to zero effect in a single-layer configuration. Our theoretical explanation is based on the Rashba-like spin-orbit interaction which arises as a result of the coupling between two subband states of opposite parities in a symmetric quantum well [2]. Following the method developed in [3], we have calculated the edge spin density in a quasi-ballistic regime, and explained the experimental results, in particular, a large magnitude of the edge spin density. We showed that one can easily proceed from the regime of strong spin accumulation to the regime of weak one. It opens up a possibility to construct an interesting new spintronic device.

1Supported by FAPESP (Brazil)

4:18PM P5.00008 Dynamical spin injection into a two-dimensional electron gas in an AlGaAs/GaAs structure, KENRO OHTOMO, YUICHIRO ANDO, TERUYA SHINJO, Kyoto University, TETSUYA UEMURA, Hokkaido University, MASASHI SHIRAISHI, Kyoto University — A two-dimensional electron system in a GaAs-based heterostructure is the attractive platform for spintronics since it has high mobility and spin-orbit interaction can be modulated by the gate voltage. Thus, it is a possible platform to realize electric gate-controlled spin transistor. However, room-temperature spin transport through GaAs-based heterostructure has yet to be shown. We report first spin transport through the quantum well at GaAs/AlGaAs interface at room temperature. We used spin pumping under ferromagnetic resonance to inject spins from the NiFe/Fe2O3 to the GaAs/AlGaAs quantum well. Generated spin current propagated through the 1 μm channel and was detected using spin-charge conversion inverse spin Hall effect in the Pt electrode. In agreement with spin pumping theory, polarity of the spin transport signal was reversed together with magnetization of the NiFe/Fe2O3. This first demonstration of spin transport through a quantum well at a semiconductor heterostructure interface at room temperature opens a way to realize Datta-Das spin-based transistor.


4:30PM P5.00009 Hole spin coherence in coupled GaAs/AlAs quantum wells1, CHRISTIAN GRADL, MICHAEL KEMPFL, JOHANNES HOLLER, DIETER SCHUH, DOMINIQUE BOUGEARD, CHRISTIAN SCHUeller, TOBIAS KORN, University of Regensburg — Due to its p-like character, the valence band in GaAs-based heterostructures offers rich and complex spin-dependent phenomena. Especially for some low-symmetry growth directions, a strong anisotropy of the hole g factor with respect to the in-plane magnetic field direction is theoretically predicted. Therefore, we perform time-resolved Kerr rotation measurements on an undoped [113]-grown double quantum well (QW) structure to resolve the spin dynamics of hole ensembles at low temperatures. Our gated system consists of two QWs with different well widths, which we use for the spatial separation of the optically excited electron-hole pairs. Thus, we are able to create hole ensembles with spin lifetimes of several hundreds of picoseconds in the broader QW without any doping. This allows the observation of a strong hole g factor anisotropy by varying the magnetic field direction in the QW plane. This opens up a possibility to construct a new type of spin transistor.

1Supported by DFG via SFB 689 and SPP 1285

4:42PM P5.00010 Investigation and direct mapping of the persistent spin helix in confined structures1, MARKUS SCHWEMMER, MATTHIAS WEINGARTNER, ROLAND VÖLKL, MARTIN OLTSCHER, DIETER SCHUH, DOMINIQUE BOUGEARD, TOBIAS KORN, CHRISTIAN SCHÜLLER, University Regensburg — The spin-orbit field in GaAs-based quantum well (QW) structures typically consists of two different contributions: Dresselhaus and Rashba field. The geometry of the Dresselhaus field, which arises due to the bulk inversion asymmetry, is mostly determined by the growth direction of the quantum well. The Rashba field instead is caused by a structure inversion asymmetry, which can be controlled, e.g. by the modulation doping. For the specific case of a [001]-grown GaAs quantum well with equal strength of Dresselhaus and Rashba fields, the effective spin-orbit field is oriented along the in-plane [110] direction for all k values and the spin splitting for this direction vanishes. For optically excited spins, which are initially oriented perpendicular to the QW plane, a persistent spin helix (PSH) state forms. We use a femtosecond pulsed TiSa-Laser system combined with a magneto-optical Kerr effect microscope for time- and space-resolved mapping of the PSH. With this technique, we investigate the PSH behavior in confined structures, e.g., thin channels along the helix direction. Hence we find that lateral confinement increases the effective PSH lifetime drastically. In more complex structures, we observe that PSH formation is even stable under a forced direction change.

1Financial support by the DFG via SFB 689 is gratefully acknowledged
4:54PM  P5.00011 Role of contact resistance in the effective spin relaxation rate in graphene spin valves.  
GORDON STECKLEIN, YOSKA ANUGRAH, JING LI, STEVEN J. KOESTER, PAUL CROWELL, University of Minnesota — Recent experiments (Maassen et al., PRB 86 235408 (2012), Ilduz et al., PRB 81 241407(R) (2015)) have identified the role of finite contact resistances in determining the spin lifetime in graphene based on Hanle measurements of lateral spin valves. We have investigated this effect in spin valves fabricated using Co/AIOx tunnel barriers and graphene grown by chemical vapor deposition. By carrying out non-local spin valve and Hanle measurements over a wide range of gate voltages, we observe a variation in the spin signal that can be explained by the role of the contacts. Using the measured interface resistance, we quantify the degree of contact-induced spin sinking as the ratio of the contact resistance to the channel spin resistance and show that the variation in spin signal is explained by variation in this spin sinking parameter. By properly accounting for the effect of the contact resistance, we measure a spin lifetime that varies between 150-500 picoseconds.

2This work was supported by NSF ECCS-1124831, the NRI NEB program, and C-SPIN, a SRC STARNET center sponsored by MARCO and DARPA.

5:06PM  P5.00012 Boundary conditions for transition-metal dichalcogenide monolayers in the continuum model.  
CSABA G. PÉTERFALVI, ANDOR KORMÁNYOS, GUIDO BURKARD, Department of Physics, University of Konstanz, Germany — We derive the boundary conditions for MoS2 and similar transition-metal dichalcogenide honeycomb (2H polytype) monolayers with the same type of k·p Hamiltonian within the continuum model around the K points. [1] In an effective 2-band description, the electron-hole symmetry breaking quadratic terms are also taken into account. We model the effect of the edges with a linear edge constraint method that has been applied previously to graphene. Focusing mainly on zigzag edges, we find that different reconstruction geometries with different edge-atoms can generally be described with one scalar parameter varying between 0 and 2π. We analyze the edge states and their dispersion relation in MoS2 in particular, and we find good agreement with the results of previous density functional theory calculations for various edge types.


Wednesday, March 16, 2016 2:30PM - 5:30PM
Session P6 GMAG DMP: Magnetic Complex Oxides I

2:30PM  P6.00001 High antiferromagnetic transition temperature for a layered hexagonal compound: SrRu2O4.  
JIAQIANG YAN, Oak Ridge National Laboratory and University of Tennessee — 4d or 5d transition metal oxides (TMOs) are not radioactive, which allows the study of the underlying physics by a large variety of techniques as well as the possible fine tuning of the magnetic ground state; and (2) SrRu2O4 crystallizes into a quasi-two-dimensional structure with layers of edge-sharing RuO6 octahedra separated by nonmagnetic Sr layers. Our density functional calculations and Monte Carlo simulations suggest an origin of the reduced moment size and the high Neel temperature.

1Work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division and by the CEM and NSF MRSEC under Grant No. DMR-1420451.

3:06PM  P6.00002 Molecular orbitals vs. relativistic orbitals in t2g honeycomb lattices: SrRu2O4 as compared to Na3IrO3, RuCl3, and Li2RuO3.  
IGOR MAZIN, Naval Research Laboratory; SERGEY STRELTsov, Institute of Metal Physics, Ekaterinburg, Russia; KATERYNA FOYEVTSEVA, University of British Columbia, Canada — t2g states on a honeycomb lattice tend to form non-dispersive localized states even if large intersite hopping is present. In the nonrelativistic case, these are molecular orbitals (MO) localized on metal hexagons, if the ligand-assisted nearest and next nearest hopping, t1 and t2, dominate, or dimers (DO), if the direct overlap, t1, dominates. In the ultrarelativistic limit t2g form effective relativistic orbitals (RO), j_eff = 3/2, which are atomically localized if t1 is the dominant hopping. On the first glance, the three regimes are defined by the conditions t1' ≫ t1, t2, or t2' ≫ t1, λ ≫ t1, t1' or t2. In reality, the latter condition is never fulfilled, especially in ruthenates, yet not only Na3IrO3, but also RuCl3 appear to be in a regime dominated by RO, even though the residual effect of MO critically influences magnetic interactions, while Li2RuO3, not far removed from RuCl3 in the parameter space, is in this talk, we will show that an additional, decisive factor is the doping level per site. The principal difference between Na3IrO3 or RuCl3, Li2RuO3, and SrRu2O4 is that the first two have one t2g hole per site, the second one two holes, and the last three electrons. In particular, the total dominance of MO in the latter compound fully explains its unique and unexpected magnetic properties.

2This work was supported by ONR (IIM) and CRDF (IIM and SYS)

3:18PM  P6.00003 Magnetization reversal and negative volume thermal expansion in Fe doped Ca3RuO4.  
T. F. QI, S. J. YUAN, Center for Advanced Materials, Department of Physics and Astronomy, University of Kentucky, Lexington, KY 40506, USA, F. YE, S. CHI, Quantum Condensed Matter Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA, J. TERZIC, H. ZHANG, Center for Advanced Materials, Department of Physics and Astronomy, University of Kentucky, Lexington, KY 40506, USA, Z. ZHAO, Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305, USA, X. LIU, Institute of Physics, Chinese Academy of Sciences, Beijing, 100190, China, S. PARKIN, Department of Chemistry, University of Kentucky, Lexington, KY 40506, USA, W. L. MAO, Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305, USA, G. CAO, Center for Advanced Materials, Department of Physics and Astronomy, University of Kentucky, Lexington, KY 40506, USA — We report structural, magnetic, transport and thermal properties of single-crystal Ca3Ru1-xFe2O4 (0 ≤ x ≤ 0.2) as functions of pressure, magnetic field and temperature. The central findings of this work are a pronounced magnetization reversal and a negative thermal expansion that are induced by Fe doping. Our results including neutron diffraction data suggest that the magnetization reversal is primarily a result of different temperature dependencies of two antiparallel, competing Ru and Fe sublattices and that the negative thermal expansion is achieved via magnetic and metal-insulator transitions. We will present and discuss our results with comparison drawn with relevant systems.

3This work was supported by the NSF via Grant No. DMR-1265162.
3:30PM P6.00004 NMR study of new ruthenates with high magnetic ordering, P.L. PAULOSE, TANMOY CHAKRABARTY, Tata Institute of Fundamental Research, Mumbai, India — The Ru based compounds, Ca$_3$LiRuO$_6$ and Ca$_3$NaRuO$_6$ show unusually high magnetic ordering temperature. Extended super exchange model is invoked to explain the magnetic behavior in the isostructural compound Ca$_3$LiOSO$_6$. We have carried out NMR investigation on these two Ru-based compounds. Ca$_3$LiRuO$_6$ is a weak ferromagnet with a magnetic ordering temperature (T$_C$) of 115 K which is explored by the temperature dependence of $^7$Li NMR line shift, line-width and spin-lattice relaxation rate (1/T$_1$). Above T$_C$, a broad maximum is observed in the evolution of line-width of the spectra. We speculate that this feature might be attributed to some low-dimensional magnetic behavior. Contrastingly, Ca$_3$NaRuO$_6$ with similar structure and local geometry of the Ru$^{3+}$ ions is a conventional antiferromagnet with a transition temperature of 90 K. The temperature dependence of $^{23}$Na NMR line shift and 1/T$_1$ is studied across magnetic transition in Ca$_3$NaRuO$_6$. The temperature variation of line-width is found to be different compared to Ca$_3$LiRuO$_6$. In both these systems, 1/T$_1$ decreases significantly below ordering temperature, characteristic of many antiferromagnetic systems.

3:42PM P6.00005 Spin-orbit dimers in double perovskites , GEORGE JACKELI. University of Stuttgart and Max Planck Institute for Solid State Research, Stuttgart, Germany — In Mott insulators, unquenched orbital degrees of freedom often frustrate the magnetic interactions and lead to a plethora of interesting phases with unusual spin patterns or non-magnetic states without long-range order. Here, we present a theoretical study of interplay of spin and orbital degrees in double-perovskite compounds with $d^1$ ions occupying the fcc sublattice. We show that the ground state of such a system is non-magnetic dimer pseudo-spin singlet with extensive orientational degeneracy of dimers. We discuss how the pseudo-spin state forming the singlet is altered upon increasing the strength of the relativistic spin-orbit coupling and show that the dimer ‘gas’ phase remains the ground state throughout. Our theoretical findings support and explain the experimentally observed non-magnetic amorphous valence bond state in Ba$_2$YMoO$_6$ and in related compounds.

4:18PM P6.00006 Doping an antiferromagnetic insulator : A route to an antiferromagnetic metallic phase , PRIYAA MAHADEVAN, SHISHIR PANDEY, S.N.Bose National Centre for Basic Sciences, D.D. SARMA, SSCU, Indian Institute of Science, Bangalore — Usually antiferromagnetism is accompanied by an insulating character of the ground state, while ferromagnetism is accompanied by metallicity. In the limit of half-filling, the Hubbard model yields an antiferromagnetic insulator as the ground state. From the Nagaoka theorem we expect ferromagnetism at any finite electron doping of this half filled state. Numerical studies on the other hand, have however shown, that at low doping concentrations one has a narrow region of an antiferromagnetic metallic phase. The question is whether this is realizable in real materials. Among the 3d transition metal oxides, this antiferromagnetic metallic phase has remained elusive as strong electron-phonon coupling results in a different phase diagram. The 5d transition metal oxides are therefore more suitable. In this work we solve a multiband Hubbard model relevant for a 5d transition metal oxide within a mean-field approach and show that the large bandwidth and the small intra-atomic Hund’s exchange associated with this limit gives us a robust AFM-M ground state for 25% electron doping. The conclusions are supported by ab-initio electronic structure calculations for NaOsO$_7$.

4:30PM P6.00007 Excitations and enhanced coupling at the magnetic metal-insulator transition in NaOsO$_3$ and Cd$_2$Os$_2$O$_7$, S. CALDER, J. H. LEE, M. B. STONE, ORNL, J. G. VALE, C. DONNERER, UCL, N. A. BOGDANOV, IFW Dresden, J. LANG, APS, M. FEYGENSON, ORNL, X. LIU, CAS, M. H. UPTON, D. CASA, APS, M. D. LUMSDEN, Z. ZHAO, J.-Q YAN, ORNL, Y.G. SHI, Y.S. SUN, Y. TSUJIMOTO, K YAMURA, NIMS, D. MANDRUS, University of Tennessee, S. NISHIMOTO, J. VD BRINK, IFW Dresden, J. P. HILL, BNL, D. F. MCMORROW, UCL, A. D. CHRISTIANSION, ORNL — 5d oxides provide new paradigms of cooperative interactions that drive novel emergent behavior. This is exemplified in the osmates NaOsO$_3$ and Cd$_2$Os$_2$O$_7$ that host MITs where magnetic order appears intimately entwined. However, unlike the inrates where spin-orbit coupling (SOC) behavior dominates, in the 5d$^2$ osmates an orbital singlet is expected and reduced effect of SOC. We measure the inelastic spectra with neutrons and RXS. Our results uncover the 5d-manifold splitting to reveal a suppressed role of SOC in the creation of the electronic ground state but dominant behavior in the creation of the magnetic state. Moreover at the MIT in NaOsO$_3$ we find a giant spin-phonon coupling and in Cd$_2$Os$_2$O$_7$ a magnetic excitation corresponding to a superposition of multiple spin-flips.

4:42PM P6.00008 Terahertz Spectroscopy of Osmate Double Perovskites$^1$, MATTHEW T. WARREN, Department of Physics, The Ohio State University. Columbus OH 43210, R. MORROW, Department of Chemistry, The Ohio State University. Columbus OH 43210, T. T. MAI, Department of Physics, The Ohio State University. Columbus OH 43210, J. XIONG, P. M. WOODWARD, Department of Chemistry, The Ohio State University. Columbus OH 43210, R. VALDES AGUILAR, Department of Physics, The Ohio State University. Columbus OH 43210 — Double perovskites containing 5d transition metal elements allow study of the interplay of spin-orbit coupling and electronic correlations due to the heavy nuclei and large electronic wavefunctions. Here we have studied polycrystalline Sr$_5$Mo$_6$O$_{17}$ (M = Mg, Fe, Co; with Os electronic configuration of d$^2$, d$^3$, d$^4$, respectively) with time-domain terahertz spectroscopy. Terahertz dynamics seem to be decoupled from observed magnetic and structural phase transitions in M=Mg, Co. A strong absorption is measured in M=Mg, Co around 1.5 THz, which softens with temperature, as expected for an optical phonon. The effectiveness of the variable-range hopping model and the origin of higher temperature conductivity are examined. Work at OSU supported by the NSF MRSEC Center for Emergent Materials under Grant DMR-1420451.

$^1$Work supported by the Center for Emergent Materials: an NSF MRSEC under award DMR-1420451.

4:54PM P6.00009 Numerical Implementation of a General Spinwave Model to Simulate Spin-wave Excitations Found in Inelastic Neutron Scattering Data, D. CASAVANT, I. BRODSKY, G. J. MACDOUGALL, Dept. of Physics, Univ. of Illinois at Urbana-Champaign — Many important details regarding magnetism in a material can be inferred from the magnetic excitation spectrum, and in this context, general calculations of the classical spinwave spectrum are often necessary. Beyond the simplest of lattices, however, it is difficult to numerically determine the full spinwave spectrum, due primarily to the non-linearity of the problem. In this talk, I will present MATLAB code, developed over the last few years at the University of Illinois, that calculates the dispersions of spinwave excitations out of an arbitrarily defined ordered spin system. The calculation assumes a standard Heisenberg exchange Hamiltonian with the incorporation of a single-ion anisotropy term which can be varied site-by-site and can also simulate the application of an applied field. An overview of the calculation method and the structure of the code will be given, with emphasis on its general applicability. Extensions to the code enable the simulation of both single-crystal and powder-averaged neutron scattering intensity patterns. As a specific example, I will present the calculated neutron scattering spectrum for powders of CoV2O4, where good agreement between the simulated and experimental data suggests a self-consistent picture of the low-temperature magnetism.
Unusual behaviour of thermal conductivity in vanadium dioxide across the metal-insulator transition

Effects of Paramagnetism and Electron Correlations on the Electronic Structure of MnO: \textit{Ab Initio} Study

Effects of Paramagnetism and Electron Correlations on the Electronic Structure of MnO using \textit{ab initio} density functional theory. Spin configurations of paramagnetism are postulated as the ensemble average of various spin disorders. Each initial disordered spin configuration is randomly generated with two constraints on magnetic local moments. We first investigate the influence of magnetic ordering on the electronic structure of MnO using noncollinear spin calculations and find that the magnetic disorders make valence band maximum more delocalized. Moreover, we examine the role of electron correlations in the electronic structure of paramagnetic MnO using DFT-LU calculations. Strong electron correlations modify not only the size of band gap but also the magnitude of local moments as in the antiferromagnetic MnO. Besides, the initialized spin disorder remains almost unchanged as electron correlation get stronger. Furthermore, our results obtained by considering both strong electron correlation and paramagnetism confirm experimentally-observed oxygen K edge X-ray emission spectra \cite{1} reflecting the feature of valence bands. \cite{1} E. Z. Kurmaev et al., Phys. Rev. B. 77, 165127 (2008).

Wednesday, March 16, 2016 2:30PM - 5:30PM – Session P18 GMAG DMP FIAP: Spin-Dynamics in Patterned Films and Devices 317 - Volker Sluka, New York University

Electrically driven magnetization dynamics in yttrium iron garnet

We also explored the possibility of driving magnetization dynamics with spin Hall effects (SHE) in bilayers of YIG/Pt microstructures. For this purpose we adopted a spin-transfer torque ferromagnetic resonance (ST-FMR) approach. Here a rf charge current is passed through the Pt layer, which generates a spin-transfer torque at the interface from an oscillating spin current via the SHE. This gives rise to a resonant excitation of the magnetization generates a spin-transfer torque at the interface from an oscillating spin current via the SHE. This gives rise to a resonant excitation of the magnetization.

This spin-wave 'bullet' is created due to nonlinear cross coupling of eigenmodes existing in the magnetic system, which is confirmed by micromagnetic simulations.

1 The work at Argonne was supported by the U.S. Department of Energy, Office of Science, Materials Science and Engineering Division.

2 This work was in collaboration with: W. Zhang, J. Sklenar, W. Jiang, J. Ding, H. Chang, F. Y. Fradin, S. M. Wu, J. E. Pearson, A. Bhattacharya, J. B. Ketterson, V. Novosad, M. Wu, and A. Hoffmann.


Spin Hall Control of Magnetization in a Perpendicularly-Magnetized Magnetic Insulator

Charge currents flowing in a HM can be used to both control and detect the magnetization direction in a FMI electrically. Our results show that charge currents flowing in a HM can be used to both control and detect the magnetization direction in a FMI electrically.

3:06PM P18.00022 Spin Hall Control of Magnetization in a Perpendicularly-Magnetized Magnetic Insulator

1 Unusual behaviour of thermal conductivity in vanadium dioxide across the metal-insulator transition

Electronic thermal conductivity amounts to only $<\frac{1}{2}$ in a strongly correlated metal, in which the electronic thermal conductivity and L nearly vanish at temperatures above room temperature, where the electronic thermal conductivity amounts to only $<5\%$ of the value expected from the WF law.
3:18PM P18.00003 Spin transfer torque switching in MTJ arrays with nanoengineered uniaxial anisotropy1. ILYAS A. H. FARHAT, Khalifa University, AMS Dept. and KSRC, Abu Dhabi, UAE; GALE, University of Bath, UK; M. ABI JAOUDE, A. F. ISAKOVIC, Khalifa University, AMS Dept. and KSRC, Abu Dhabi, UAE — Enhancing Magnetic Tunnel Junction (MTJ) energy efficiency is the key to embed it in low power applications. We report a detailed study on the behavior of the analytical expression of switching current density as a function of geometrical and magnetic parameters, for both I-MTJs and P-MTJs. Our study shows that the current model requires some modifications to improve the match between the model and the experiment. We also show under which criteria a scaledown of MTJ devices can help in reduction of current density. We then used the device model of MTJ to study the power performance of MTJ device, proposing a roadmap to lower switching power of the device. Comparisons between ours and data for similar devices in literature, combined with the above analysis, suggests the need for qualitatively different model, and for this purpose, we explored the variations of the effective energy density model [1], which may explain the device behavior better. [1] T. Taniguchi et al., Phys. Rev. B 87, 054406 (2013).

1Work supported by Mubadala-SRC 2012-VJ-2335. A part of the work done at Cornell CNF/CCMR, with special thanks to C. Alpha. A part of the work done at BNL-CFN, supported by DOE.

3:30PM P18.00004 Vortex Gyrotropic Motion in patterned Ferromagnetic Dots1. JUNJIA DING, PAVEL LAPA, TRUPTI CHAIR, CRYSTIAN POSADA, AXEL HOFFMANN, VALENTINE NOVOSAD, Argonne Natl Lab — A vortex state consists of a large region of in-plane curling magnetization and a small core region with out-of-plane magnetization. The gyrotropic oscillation frequency of the vortex core is known to be weakly dependent to the core position (which is adjustable by changing the applied field) and can only be efficiently tuned by changing the dimension of the dots. Here, we demonstrated that the vortex gyrotropic frequency can be stepwise tuned by introducing a vortex barrier to a regular ferromagnetic dot. Systematical investigations of the dynamic response of the engineered dots have been performed as a function of the outer dot diameter, barrier diameter and the barrier profile using both microwave absorption spectroscopy and micromagnetic simulation. We found that the vortex frequency is mostly dependent on the outer diameter of the dot when the core is outside the barrier, while it is more rely on the dimension of the barrier when the core is inside the barrier. This approach certainly gives several additional freedoms to adjust the vortex gyrotropic frequency and opens extra perspectives for spintronic applications.

1This work at Argonne was supported by the U.S. Department of Energy, Office of Science, Materials Science and Engineering Division.

3:42PM P18.00005 Dynamics of spin valves investigated using Magneto-Optical Kerr Effect Spectroscopy1. CHRISTOPHER STEVENS, JAGANNATH PAUL, PRASENJIT DEY, Univ of South Florida, CASEY MILLER, Rochester Institute of Technology, STEPHEN MCGILL, National High Magnetic Field Lab, FSU, DENIS KARAISKAJ, Univ of South Florida — Through an all-optical approach, we are investigating the spin dynamics in different spin torque based structures. Using pump-probe Time-Resolved Magneto-Optical Kerr Effect (TR-MOKE) spectroscopy, we are able to monitor the ultrafast magnon propagation on a sub-picosecond timescale as well as the longer lived oscillations and demagnetization. This represents a recent efforts to realize magnon induced spin torque using an all optical method.

1This research at USF is supported by the National Science Foundation, Division of Electrical, Communications and Cyber Systems under grant number: 1231929. The work was done in part at the NHMF, Tallahassee, FSU under grants: DMR-1229217, DMR-1157490.

3:54PM P18.00006 The shot noise like feature of the magnetic 1/f noise in CoFeB/MgO/CoFeB magnetic tunnel junctions. LIANG LIU, JIASEN NIU, HUIQIANG GUO, JIAN WEI, International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China and Collaborative Innovation Center of Quantum, D. L. LI, J. F. FENG, X. F. HAN, HAN, Beijing National Laboratory of Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China, X.-G. ZHANG, Center for Nanophase Materials Sciences, and Computer Science and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6493, J. M. D. COEY, CRANN and School of Physics, Trinity College, Dublin 2, Ireland — The magnetic field dependent 1/f noise in magnetic multilayers and magnetic tunnel junctions (MTJs) is conventionally considered as resistance fluctuations ($S_R$), for which an applied current (I) is merely used to convert $S_R$ to measurable voltage fluctuations ($S_V = I S_R$). From $S_R$ and magnetoresistance, magnetization fluctuations can be inferred obeying the fluctuation-dissipation relation (FDR), thus comes the name magnetoresistive noise. However, we find that 1/f noise in CoFeB/MgO/CoFeB MTJs is better described by $S_V/I$, instead of $S_V/I^2$, particularly near the magnetic reversal fields of the reference layer and the free layer, the latter of which has not been previously investigated in detail. More surprisingly, the bias dependence resembles that of shot noise. These findings call for further investigation on FDR for magnetic noise in MTJs, especially in the far from equilibrium state with high bias and possible contribution from collective magnon excitations.

4:06PM P18.00007 Coherent spin-transfer precession switching in orthogonal spin-torque devices. COLM RYAN, GRAHAM ROWLANDS, BBN Technology - Massachusetts, DANIELE PINNA, LI YE, LAURA REHM, VOLKER SLUKA, ANDY KENT, Department of Physics, New York University, New York, NY 10003, USA, THOMAS OHKI, BBN Technology - Massachusetts — We present experimental results in concert with macrospin simulations of the switching characteristics of orthogonal spin-transfer devices incorporating an out-of-plane magnetized polarizing layer and an in-plane magnetized spin valve device at cryogenic temperatures. Switching at 3.4K between parallel and anti-parallel spin-valve states is investigated for current pulses with varying durations from 0.1 to 1.4ns to observe the averaged response of the time dependent dynamics of the spin-transfer induced precession of the magnetization. We demonstrate high speed switching at short pulse lengths, down to 100ps, and also observe ensemble decoherence effects with longer pulses. The results show that even at cryogenic temperatures finite temperature noise is still important in the dynamics of precessional switching.

4:18PM P18.00008 Effects of spin relaxation on trap-assisted tunneling through ferromagnetic metal-oxide-semiconductor structures. VIKTOR SVERDLOV, SIEGFRIED SELBERHERR, Institute for Microelectronics, TU Wien — A signal measured within a three-terminal setup at room temperature [1,2] is attributed to the spin injection from a ferromagnetic electrode into n-silicon; however, its amplitude is orders of magnitude larger than predicted by theory [3]. The reasons for this discrepancy are heavily debated [3-6], with trap-assisted resonant tunneling [4] and spin-dependent magnetoresistance gaining recognition. However, effects of spin relaxation important at room temperature were not considered in [4]. To elucidate the role of spin relaxation and coherence, corresponding Lindblad terms are added to the equation for the density matrix evolution of spin on a trap coupled ferromagnets. KSRCC, Abu Dhabi, UAE — Enhancing Magnetic Tunnel Junction (MTJ) energy efficiency is the key to embed it in low power applications. We report a detailed study on the behavior of the analytical expression of switching current density as a function of geometrical and magnetic parameters, for both I-MTJs and P-MTJs. Our study shows that the current model requires some modifications to improve the match between the model and the experiment. We also show under which criteria a scaledown of MTJ devices can help in reduction of current density. We then used the device model of MTJ to study the power performance of MTJ device, proposing a roadmap to lower switching power of the device. Comparisons between ours and data for similar devices in literature, combined with the above analysis, suggests the need for qualitatively different model, and for this purpose, we explored the variations of the effective energy density model [1], which may explain the device behavior better. [1] T. Taniguchi et al., Phys. Rev. B 87, 054406 (2013).

1Work supported by Mubadala-SRC 2012-VJ-2335. A part of the work done at Cornell CNF/CCMR, with special thanks to C. Alpha. A part of the work done at BNL-CFN, supported by DOE.

1This research at USF is supported by the National Science Foundation, Division of Electrical, Communications and Cyber Systems under grant number: 1231929. The work was done in part at the NHMF, Tallahassee, FSU under grants: DMR-1229217, DMR-1157490.
4:30PM P18.00009 Thermally reliably cycled non-volatile spin wave logic device. SOURAV DUTTA, Georgia Inst of Tech, DMITRI NIKONOV, SASIKANTH MANIPATRUNI, IAN YOUNG, Components Research, Intel Corporation, Hillsboro, AZAD NAAEMI, Georgia Inst of Tech — The possibility of utilizing spin waves for information transmission and computation has been an area of active research due to the unique ability to manipulate the amplitude and phase of spin waves for building complex logic circuits. Here, we present a comprehensive scheme for building a thermally reliably cycled non-volatile spin wave logic device [1,2] (SWLD) by introducing a charge-to-spin converter that translates information from electronic to spin domain to spin domain, exploiting the magneto-electric effect for spin wave transmission, detection and non-volatile memory, utilizing the phase of the spin wave as information token, enabling phase-dependent deterministic switching of the magnetoelectric spin wave detector in the presence of thermal noise via compensation of demagnetization and a novel clocking scheme that ensures sequential transmission of information in a cascaded SWLD and non-reciprocity. [1] S. Dutta et. al., Non-volatile cycled spin wave interconnect for beyond-cmos nanomagnet pipelines, Scientific Reports 5 (2015). [2] S. Dutta et. al., Phase-dependent deterministic switching of magnetoelectric spin wave detector in the presence of thermal noise via compensation of demagnetization , Applied Physics Letters (accepted 2015).

4:42PM P18.00010 Magnetotransport properties of Co86Fe10/Cu/Ni80Fe20 pseudo-spin-valve with out-of-plane tilted magnetic field. LINQIANG LUO, NAM DAO, SALINPORN KITTIWATANAKUL, STUART WOLF, JIWEI LU, Univ of Virginia, UVA NANOSTAR TEAM — The giant magnetoresistance (GMR) effect of a pseudo spin valve made of Co86Fe10/Cu/Ni80Fe20 has been investigated, with a magnetic field applied perpendicularly tilted to the sample plane. Without using a pinning layer, the magnetic separation of the free and fixed layers is uniquely achieved by utilizing perpendicular fields due to different anisotropy energies between Ni80Fe20 and Co86Fe10. The magneto-transport measurements are carried out by Van der Pauw method in current-in-plane geometry at room temperature. By tilting the magnetic field at different angles from out-of-plane, the GMR plateau's width can be tuned. A plateau width of about 2000 Oe is observed at tilted angle 0°, which opens a significantly larger window for high-resistance states comparing with a plateau width of 10 Oe for in-plane fields. With the out-of-plane tilted fields, the orientation of the magnetic moments can be tuned continuously out of the sample plane, and the relative orientation between Ni80Fe20 and Co86Fe10 can also be tuned by the tilted angle, enabling us to precisely control the sample's states for current-induced spin dynamics study that is very difficult in the case of in-plane applied magnetic fields.

4:54PM P18.00011 Spin-torque ferromagnetic resonance in arbitrarily magnetized thin films. JOSEPH SKLENAR1, Physics and Astronomy, Northwestern University, Evanston, IL. Materials Science Division, Argonne National Laboratory, Argonne, IL — The spin Hall effect (SHE) in non-magnetic metals can be used to generate spin-transfer torque (STT), subsequently inducing ferromagnetic resonance (FMR) in magnetic thin films; this experimental method is termed spin-torque ferromagnetic resonance (ST-FMR). Most ST-FMR experiments that are reported have an applied magnetic field in the plane of the sample and the research focuses on material combinations that have large and efficient STT. The most common way ST-FMR signals are detected is through an anisotropic magnetoresistance (AMR) rectification process. In this work we will present ST-FMR results in thin films where the magnetization has both an in-plane and out-of-plane component. The arbitrary magnetization direction is achieved by tipping the applied magnetic field out of the sample plane. We find that when the material system is a permalloy/Pt bilayer, ST-FMR signals are not mirror-symmetric upon magnetic field reversal2. This is because the combination of both a STT from the bulk SHE and the Oersted field-like torque from the device do not drive the dynamics in the same manner when the field is reversed. We interpret our results in the Py/Pt experiment by extending an already established ST-FMR lineshape model to describe the general case of arbitrarily magnetized films. We compare and contrast our Py/Pt experiment with another system we measured, a Py/MoS2 bilayer. For the Py/MoS2 system, in-plane experiments suggest that a large STT is present and are comparable to what is observed for the more traditional Py/Pt system3. On the other hand, the out-of-plane experiment for the Py/MoS2 system is qualitatively very different from Py/Pt. Our results suggest that ST-FMR experiments in arbitrarily magnetized films are useful in characterizing STT generated from interface rather than bulk effects. Work at Northwestern was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Materials Science and Engineering Division under grant number DE-SC0014424. Work at Argonne was supported by the U.S. Department of Energy, OS, Materials Science and Engineering Division. Lithography was carried out at the Center for Nanoscale Materials, which is supported by DOE, OS-BES under Contract No. DE-AC02-06CH11357.

1This work is in collaboration with: W. Zhang, M. B. Jungfleisch, W. Jiang, H. Saglam, S. Grundchak, J. E. Pearson, J. B. Ketterson, and A. Hoffmann.
2J. Sklenar et al, Submitted
3W. Zhang, J. Sklenar et al, Submitted

Wednesday, March 16, 2016 2:30PM - 5:30PM – Session P19 GMAG DMP FIAP: Magnetic Materials 318 - Daniel Gopman, NIST

2:30PM P19.0001 Observation of Temperature Chaos in Mesoscopic Spin Glasses1, SAMARESH GUCHHAIT, Laboratory for Physical Sciences, College Park, MD 20740 and Department of Physics, University of Maryland, College Park, MD 20742 — Temperature Chaos (TC) results from a change in temperature for spin glasses (SG), polymers, and other glassy materials. When the temperature is changed, TC means that the new state has no memory of the preparation of the initial state. TC was predicted long ago [PRL 48, 767 (1982)]. However, “An experimental measurement of TC is still missing” [EPL 103, 67003 (2013)]. One reason for this is the question of length scale. In the thermodynamic limit, even an infinitesimal temperature change, ∆T, will create a chaotic condition. However, by working at the mesoscale, one can establish a length scale sufficiently small to exhibit reversible behavior before crossing over to chaotic behavior as the temperature change increases. Observation of TC is possible because, on reasonable laboratory time scales, the SG correlation length can grow to the size of the thickness of the film, L. The lower critical dimension for a SG is ~2.5, so that the thin film SG crosses over to a glass temperature Tg = 0. However, there remains quasi-equilibrium SG states with length scales < L. After crossover, a small ∆T will generate a TC coherence length which, if greater than L, will leave the system in a reversible state. However, when ∆T is sufficiently large, such that the TC coherence length is less than L, and chaos will ensue. We will discuss our recent results of temperature cycling on 15.5 nm SG films of amorphous Ge:Mn. By use of end of aging and temperature cycling, both the reversible region and the chaotic region are observed. Remarkably, the transition from a reversible to chaotic behavior is abrupt, and not smooth as a function of ∆T. This is in contrast to previous work using polycrystalline materials wherein the distribution of length scales smoothed out the transition to chaos. Using the calculated TC critical exponent, the range of ∆T for reversible behavior is calculated and is in very good agreement with the measured range.

1This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Science and Engineering under Award DE-SC0013599.

3:06PM P19.00002 An Investigation of the Spin Glass Properties of the Solid Solution CuAl12−x,Ga2xO4, THOMAS BULLARD, UES Inc, JACILYNN BRANT, National Research Council/TheAir Force Research Laboratory, CHARLES EBBING, The University of Dayton Research Institute, NEIL DILLEY, J. HAMILTON, Quantum Design, TIMOTHY HAUGAN, The Air Force Research Laboratory — The complete anti-ferromagnetic oxide spinel solid solution between end members CuAl2O4 and CuGa2O4 has been synthesized. The crystallographic and magnetic properties are examined as Ga is replaced with iso-valent Al. Crystallographic results show the solid solution obeys Vegards law, and the cation distribution among the tetrahedral and octahedral sites matches well with prior results. The evolution of the magnetic susceptibility is examined as a function of temperature and doping percentage. Evidence is presented that indicates that the majority of the solution displays paramagnetic behaviour at high temperatures and spin glass behaviour below 3K. Specifically, a freezing temperature in the AC susceptibility, irreversibility in the DC magnetization, and relaxation dynamics in the presence of a changing applied field are observed.
3:18PM P19.00003 Nonlinear scaling variable at the lower critical dimension: Scaling in the 2D random field Ising model\(^1\) — LORIEN HAYDEN, JAMES SETHNA, Cornell Univ — We systematically analyze the nonlinear invariant scaling variables at bifurcations in the renormalization-group flow, and apply our methods to the two-dimensional random-field Ising model (RFIM). At critical points, the universal scaling functions are usually written in terms of homogeneous invariant combinations of variables, like \(L\nu\) in the finite-size scaling form for the magnetization \(M(T/L) \sim t^{-\nu}M(L\nu)\), where \(t \sim T_c - T\). The renormalization-group flow for the RFIM has a pitchfork bifurcation in two dimensions, where the correlation length has been argued to diverge exponentially, \(\xi \propto \exp(2/\nu^2)\), leading to the invariant scaling combination \(L/\xi \sim L/\exp(2/\nu^2)\). Our analysis, inspired by normal-form theory, suggests that this exponential divergence can take a richer, more general scaling form at a generic pitchfork bifurcation. We explore possible consequences for simulations.

\(^1\)This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1144153.

3:30PM P19.00004 Response to a field of the \(D = 3\) Ising spin glass with Janus and JanusII dedicated computers\(^1\) — BEATRIZ SEOANE, LPT, Ecole Normale Superieure, JANUS COLLABORATION COLLABORATION\(^2\) — Using the Janus dedicated computer, and its new generation JanusII, we study the linear response to a field of the Edwards-Anderson model for times that cover twelve orders of magnitude. The fluctuation-dissipation relations are investigated for several values of \(\tau_w\). We observe that the violations of the fluctuation-dissipation theorem can be directly related to the \(F(q)\) measured in equilibrium at finite sizes, although a simple statics-dynamics dictionary \(L \leftrightarrow \xi(\tau_w)\) is not enough to account for the behavior at large times. We show that the equivalence can be easily restored by taking into account the growth of \(\xi(\tau + \tau_w)\). Interestingly, experimental measurements of the spin glass correlation length rely precisely on the response of a spin glass to a field, although a direct relation between the measured object and the real \(\xi\) has never been established. In this work, we mimic the experimental protocol with Janus data, which lets us relate the experimental \(\xi\) with the length extracted from the spatial correlation function. These results allow us for the first time to make a quantitative comparison between experiments and simulations, finding a surprising good agreement with measurements in supraspin glasses.

\(^1\)This project has received funding from the European Unions Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 654971, the ERC grant CRIIPHERASY (no. 247328) and from the MINECO(Spain) (no.FIS2012-35710-C02)

\(^2\)First results of the new machine JanusII

3:42PM P19.00005 Extremely large magnetoresistance and magnetic logic by coupling semiconductor nonlinear transport effect and anomalous Hall Effect. — XIAOZHONG ZHANG, ZHAOCHU LUO, Tsinghua University — Size limitation of silicon FET hinders the further scaling down of silicon based CPU. To solve this problem, spin based magnetic devices were proposed but almost all of them could not be realized experimentally except for NOT logic operation. A magnetic field controlled reconfigurable semiconductor logic using InSb was reported. However, InSb is very expensive and not compatible with the silicon technology. Based on our Si based magnetoresistance (MR) device [1], we developed a Si based reconfigurable magnetic logic device [2], which could do all four Boolean logic operations including AND, OR, NOR and NAND. By coupling nonlinear transport effect of semiconductor and anomalous Hall effect of magnetic material, we propose a PMA material based MR device with a remarkable non local MR of \(>20000\%\) at \(1\) mT. Based on this MR device, we further developed a PMA material based magnetic logic device which could do all four Boolean logic operations. This makes it possible that magnetic material does both memory and logic. This may result in a memory-logic integrated system leading to a non von Neumann computer. [1] CH Wan, et al, Nature 477, 304, (2011). [2] ZC Luo et al. Adv. Funct. Mater. 25, 158, (2015).

3:54PM P19.00006 Effects of transverse fields on spin-valve sensor magnetic field measurements — ALEX JEFFERS, University of Maryland, ANTONIO OROZCO, Neocera, Beltsville, MD, ALFRED CATHORNE, Terevoca Nazarene University, Nashville. TN, CHRISTOPHER ROWLETT, STEVE GARRAHAN, Neocera, Beltsville, MD, FREDERICK WELLSTOOD, University of Maryland, College Park, MD — Spin-valve sensors have become a popular magnetic sensor, used in many applications such as magnetic imaging or hard drive heads. Spin-valves are designed to measure only one component of the magnetic field, the manufacturing conditions, shape anisotropy, and other design decisions. We took magnetic images of L-shaped samples in order to determine if magnetic fields transverse to the direction of measurement affect spin-valve sensors. Specifically, we used a 2 m by 4 m Cu-Mn-Ir spin-valve sensor to take image of chips with “L-shaped” currents. We find that transverse fields can significantly affect the measurement direction of spin-valve sensors.

4:06PM P19.00007 Effect of tantalum on magnetocrystalline anisotropy and tunneling magnetoresistance in MgO/CoFeB junction from ab-initio calculations — ROMAN CHEPULSKY, DMYTRO APALKOV, New Memory Technology, Samsung Semiconductor RD Center, Samsung Electronics — Using ab-initio calculations, we demonstrate that boron is energetically attracted toward interface between MgO and CoFeB in MgO/CoFeB junction. We show that both magnetocrystalline anisotropy (MCA) and tunneling magnetoresistance (TMR) decrease when boron is present at the interface. However, when tantalum is used as seeding or capping layer (Ta/CoFeB/MgO), the segregation profile of boron changes. Namely, the most energetically preferable position of boron is inside and near tantalum rather than at MgO/CoFeB interface. Such change of boron segregation profile results in boron diffusion from MgO/CoFeB interface toward tantalum at annealing. The diffusion of boron toward tantalum may explain the experimentally observed effect of tantalum on increase of both MCA and TMR in MgO/CoFeB junction.

4:18PM P19.00008 Growth and properties of High-quality metal/ yttrium iron garnet/metal sandwich structures\(^1\) — MOHAMMED ALDOSARY, JUNXUE LI, CHI TANG, YADONG XU, JING SHI, University of California — Sandwiched structures of magnetic insulators (e.g. yttrium iron garnet or YIG) between two normal metals are potentially useful for spintronics. In this work, we report our approach of growing a single crystalline YIG thin film on a Pt or Cu thin layer using the combination of sputtering and PLD. First, either 5 nm of Pt or Cu is deposited on (110)-oriented gadolinium gallium garnet (GGG) substrate using sputtering and then YIG is grown by PLD at intermediate temperatures followed by rapid thermal annealing at higher temperatures. Surprisingly, YIG films show a well-defined single-crystal reflection high energy electron diffraction (RHEED) pattern, despite that they are grown on polycrystalline Pt or Cu. TEM images show flat, clean and sharp interfaces between YIG/metal and metals/GGG. The magnetic properties show in-plane magnetic anisotropy. However, when thicker metallic layers (20 nm) or amorphous metals/SiO2 substrate are used, only YIG polycrystalline phase is observed. We will show that by properly controlling the growth conditions the metal/YIG/ metal structures are not only of high structural quality, but also have desired properties for spin current transport.

\(^1\)This work was supported as part of the SHINES, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award SC0012670.
4:30PM P19.00009 Switching behavior of Nb/Exchange spring magnet/Nb Josephson Junctions fabricated by Nanosphere Lithography · JIYEONG GU, GILBERT ARIAS, SAMUEL HEDGES, Dept. of Physics and Astronomy, California State University, Long Beach — Superconductor(S)/ferromagnet(F)/superconductor Josephson junction was fabricated by nanosphere lithography method. Samarium-Cobalt (SmCo)/Permalloy(Py) exchange spring magnet system was used to generate an inhomogeneous magnetic structure in Niobium(Nb)-based Josephson junctions. We introduced nanosphere lithography in our device fabrication in order to decrease the lateral size of junctions and improve the quality of our devices. A bigger size junctions (tens of microns) were fabricated by optical photolithography using a mask. * Materials were deposited through DC magnetron sputtering. Base structure of devices was patterned through photolithography. Modulations of the critical current and IV-curve characteristics of the junction were used to search for direct evidence of the odd-triplet component. In addition, to investigate the switching behavior of S/F/S junction for memory application junction critical current was measured as a function of magnetic field and the angle between an easy axis of ferromagnetic layer and the external magnetic field by rotating the sample under magnetic field. Magnetic switching behavior of the ferromagnetic layers in our junction was also characterized based on this observation. * Junction fabrication in this research by an optical photolithography using a mask was conducted at the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory (CNMS User Project CNMS2014-257).

4:42PM P19.00010 How to move domain walls in an antiferromagnet† · KE WON KIM, Univ of California - Los Angeles — Domain walls (DWs) in an easy-axis antiferromagnet can be driven by several stimuli: a charge current (in conducting antiferromagnets), a magnon current, and a temperature gradient. In this talk, we discuss the dynamics of a DW induced by two latter external perturbations, which are applicable in both metallic and insulating antiferromagnets. First of all, we study the Brownian dynamics of a DW subjected to a temperature gradient [1]. To this end, we derive the Langevin equation for the DW’s center of mass with the aid of the fluctuation-dissipation theorem. A DW behaves as a classical massive particle immersed in a viscous medium. By considering a thermodinamic ensemble of DWs, we obtain the Fokker-Planck equation, from which we extract the average drift velocity of a DW. We briefly address other mechanisms of thermally driven DW motion. Secondly, we analyze the dynamics of a DW driven by circularly polarized magnons [2]. Magnons passing through a DW reverse their spin upon transmission, thereby transferring two quanta of angular momentum to the DW and causing it to precess. A precessing DW partially reflects magnons back to the source. The reflection of magnons creates a previously identified reactive force [3]. We point out a second mechanism of propulsion of the DW, which we term redshift: magnons passing through a precessing DW reduce their linear momentum and transfer the decrease to the DW. We solve the equations of motion for magnons in the background of a uniformly precessing DW with the aid of supersymmetric quantum mechanics and compute the net force and torque applied by magnons to the DW. The theory agrees well with micromagnetic simulations.


†This work has been supported in part by the ARO, the U.S. DOE-BES, and the U.S. NSF grants.

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**Wednesday, March 16, 2016 5:45PM - 6:45PM**  
**Session Q4 GMAG: GMAG Jobs Mixer**  
Hilton Baltimore Pickersgill -

**5:45PM Q4.00001 GMAG Jobs Mixer** — This event is open to the members of the magnetism community, especially postdocs and students, who are interested in jobs in industry, national labs, and academia, or have a job opportunity to offer. Refreshments will be served.

**Thursday, March 17, 2016 8:00AM - 10:24AM**  
**Session R2 DCMP GMAG: Advances in Collective Effects in Organic Semiconductors**  
Ballroom II - Michael Flatte, University of Iowa
Electrical detection of proton-spin motion in a polymer device at room temperature. CHRISTOPH BOEHME, Department of Physics and Astronomy, University of Utah — With the emergence of spintronics concepts based on organic semiconductors there has been renewed interest in the role of both, electron as well as nuclear spin states for the magneto-electronic properties of these materials. In spite of decades of research on these molecular systems, there is still much need for an understanding of some of the fundamental properties of spin-controlled charge transport and recombination processes [1]. This presentation focuses on mechanisms that allow proton spin states to influence electronic transition rates in organic semiconductors. Remarkably, even at low-magnetic field conditions and room temperature, nuclear spin states with energy splittings orders of magnitude below thermal energies are able to influence observables like magnetoresistance and fluorescence [2]. While proton spin coupling to charge carrier spins via hyperfine interaction, there has been considerable debate about the nature of the electronic processes that are highly susceptible to these weak hyperfine fields. Here, experiments are presented which show how the magnetic resonant manipulation of electron and nuclear spin states in a π-conjugated polymer device causes changes of the device current [3]. The experiments confirm the extraordinary sensitivity of electronic transitions to very weak magnetic field changes and underscore the potential significance of spin-selection rules for highly sensitive absolute magnetic fields sensor concepts [4]. However, the relevance of these magnetic-field sensitive spin-dependent electronic transitions is not just limited to semiconductor materials but also radical pair chemistry [5] and even avian magnetoreceptors [6].

Active control of magnetoresistance of organic spin valves using ferroelectricity. JIAN SHEN, Fudan Univ — Organic spintronic devices have been appealing because of the long spin lifetime of the charge carriers in the organic materials and their low cost, flexibility and chemical diversity. In previous studies, the control of resistance of organic spin valves is generally achieved by the alignment of the magnetization directions of the two ferromagnetic electrodes, generating magnetoresistance. Here we employ a new knob to tune the resistance of organic spin valves by adding a thin ferroelectric interfacial layer between the ferromagnetic electrode and the organic spacer: the magnetoresistance of the spin valve depends strongly on the history of the bias voltage, which is correlated with the polarization of the ferroelectric layer; the magnetoresistance even changes sign when the electric polarization of the ferroelectric layer is reversed. These findings enable active control of resistance using both electric and magnetic fields, opening up possibility for multi-state organic spin valves.

Organic magnetoelectroluminescence for room temperature transduction between magnetic and optical information. MARKUS WOHLGENANNT, University of Iowa — No abstract available.

New Directions for Organic Spintronics: Novel Materials and Emergent Phenomena. EZEKIEL JOHNSTON-HALPERIN, Department of Physics, The Ohio State University — Organic and organic-based materials are attractive candidates for applications in magnetoelectronics and spintronics due to their low cost, ease of fabrication, and low spin-orbit coupling (and consequently long spin lifetimes). However, in comparison to the case for inorganic systems, robust intrinsic magnetic ordering in this class of materials is exceedingly rare and as a result the potential of these materials has yet to be fully realized. Here we present a series of recent breakthroughs in the synthesis, encapsulation, and measurement of organic-based magnets that lay the foundation for all organic magnetoelectronic and spintronic devices. We will discuss advances in encapsulation strategies that allow lifetimes of up to 1 month in air for functional magnetoelectronic devices, the use of ligand substitution to generate a library of related magnetic materials, the growth of all-organic and hybrid organic/inorganic magnetic heterostructures, and measurements of the magnetization dynamics that reveal ferromagnetic resonance (FMR) linewidths of ~1 GHz, comparable to or narrower than corresponding measurements in yttrium iron garnet (YIG). These results establish the validity of organic-based magnets for applications in next-generation magnetoelectronics and provide unique leverage on long-standing challenges in the field of organic spintronics. For example, organic magnetic heterostructures promise to provide an exciting opportunity to explore exchange, dynamic spin injection, and spin transport in all-organic spintronic devices.

Electrical detection of proton-spin motion in a polymer device at room temperature. This work was supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0000969. The Utah NSF - MRSEC program #DMR 1121252 is acknowledged for instrumentation support.

Active control of magnetoresistance of organic spin valves using ferroelectricity. This work was supported in part by NSF DMR-1507775 and the Center for Emergent Materials (an NSFMRSEC; Award Number DMR-1420451) at The Ohio State University.

Thursday, March 17, 2016 8:00AM - 11:00AM — Session R6 GMAG DMP: Frustrated Magnetism: Triangular Lattice Magnets 302 - Collin Broholm, Johns Hopkins University

Frustrated quantum magnetism in the 6H-perovskites. JEFFREY QUILLIAM, Université de Sherbrooke — I will review the recent state of research on the 6H-perovskites, Ba$_3$M$_2$O$_9$, a large class of materials that can accommodate many different magnetic ions on ostensibly triangular lattices. This class of materials has given rise to several important discoveries in recent years, including quantum spin liquids, biquadratic quantum spin liquids, a new kind of magnetic liquid and the first liquid-like quantum spin liquid. I will also review the history of our understanding of the existence of spin jam states in SrCr$_2$Ga$_{12-2x}$O$_{19}$ (SCGO($p$)) in which the Cr$^{3+}$ ions form two-dimensional (2D) triangular lattice of bi-pyramids. Here we report a new structural new system BaCr$_2$Ga$_{12}$O$_{19}$ (BCGO($p$)) with $0.4 < p < 0.9$. Neutron diffraction results show that BCGO($p$) is inosstructural as SCGO($p$) but with a larger clattice indicating that BCGO($p$) is more 2D. BCGO($p$) exhibits similar glassy behaviors as SCGO($p$) but with higher freezing temperature. Very high Curie-Weiss temperature and frustration index were also observed in BCGO($p$) suggesting that BCGO($p$) is one of the most frustrating system. Inelastic neutron scattering results show that BCGO($p$) has dispersionless magnetic excitations at an energy of 16.5(1) meV arising from $4f_{x^2}$-$4f_{y^2}$ spin dimers. These spin dimers are adjacent spins in neighboring triangular lattice planes which separate the 2D interacting triangular lattice of bi-pyramids. These results indicate that BCGO($p$) is a new good candidate for studying spin jam states.
8:48AM R6.00003 Muon spin rotation study of spin dimers on a triangular lattice in Ba₃MRu₂O₉. DJAMEL ZIAT, AIM VERRIER, Graduate student. JEFFREY QUILLIAM, Professor. ADAM ACZEL, RYAN SINCLAIR, QIANG CHEN, HAI DONG ZHOU, PhD — The family of hexagonal perovskites, Ba₃MA₂O₉ has recently been proven to be fertile ground for the discovery of new, exotic magnetic phases, including several quantum spin liquid candidates. The 6H-perovskites can also accommodate spin dimers on a triangular lattice, as well as in the ruthenate materials Ba₃MRu₂O₉. We will present measurements on materials containing M= Y, La, Lu, In, which give rise to mixed valence Ru4.5+ ions wherein the orbital and charge degrees of freedom must also be considered. In particular, muon spin rotation (SR) experiments, have allowed us to probe the nature of the magnetically ordered ground state of these materials at low temperatures.

9:00AM R6.00004 Magnetic Correlations in the Triangular Antiferromagnet TbInO₃. GABRIELE SALA, McMaster University. LUCY CLARK, University of St Andrews. DALINI MAHARAJ, McMaster University. MATTHEW B. STONE, Oak Ridge National Laboratory. KEVIN S. KNIGHT, ISIS Neutron Facility. SANG-WOOK CHEONG, Rutgers University. BRUCE D. GAULIN, McMaster University — TbInO₃ crystallizes with a hexagonal P6₃cm structure in which layers of edge-sharing triangles of magnetic Tb³⁺ ions are separated by non-magnetic [InO₃]⁻⁻ units. TbInO₃, therefore, realizes an excellent opportunity to explore the behavior of a two-dimensional magnetic triangular lattice, a canonical model of geometric frustration. Here we present our study of a polycrystalline sample of TbInO₃. Our high resolution powder neutron diffraction data (HRPD, ISIS) of TbInO₃ confirm that the triangular layers of Tb³⁺ remain undistorted to at least 0.4K. Magnetic susceptibility data follow Curie-Weiss behavior over a wide range of T with θ = −17.19(3) K indicating the dominance of antiferromagnetic correlations. The susceptibility data also show an absence of conventional long-range spin order down to at least 0.5 K, reflecting the frustrated nature of TbInO₃. Elastic magnetic diffuse neutron scattering (SEQUOIA, SNS) is observed below ~15 K, due to the presence of static two-dimensional spin correlations. The spectrum of crystal field excitations in TbInO₃ appears to have an exotic form due to the existence of two crystallographically distinct Tb³⁺ sites and leads to a strong Ising anisotropy of the spin symmetry.

9:12AM R6.00005 ABSTRACT WITHDRAWN —

9:24AM R6.00006 A spin-orbit coupled triangular lattice quantum spin liquid in YbMgGaO₄: a semiclassical study. YAO-DONG LI, Department of Computer Sciences, Fudan University. GANG CHEN — The family of hexagonal perovskites, Ba₃MA₂O₉ has recently been proven to be fertile ground for the discovery of new, exotic magnetic phases, including several quantum spin liquid candidates. The 6H-perovskites can also accommodate spin dimers on a triangular lattice, as well as in the ruthenate materials Ba₃MRu₂O₉. We will present measurements on materials containing M= Y, La, Lu, In, which give rise to mixed valence Ru4.5+ ions wherein the orbital and charge degrees of freedom must also be considered. In particular, muon spin rotation (SR) experiments, have allowed us to probe the nature of the magnetically ordered ground state of these materials at low temperatures.

9:36AM R6.00007 Magnetic Ground State of the Ideal Triangular-Lattice Antiferromagnets Tuned by the Inter-layer Interactions. JIE MA, University of Tennessee, M MATSUDA, Oak Ridge National Laboratory. Y. KAMIYA, RIKEN, Z. L. DUN, University of Tennessee, C. DELA CRUZ, Oak Ridge National Laboratory. C. D. BATISTA, Los Alamos National Laboratory. Y. QIU, N BUTCH, J. R. D. COOLEY, J. FATT, H. ZHOU, University of Tennessee — Neutron scattering and diffraction techniques have been applied to investigate both structures and spin wave excitations of the tri-perovskite Ba₃MM’₂O₉, which is antiferromagnetic with the equilateral-triangular lattice M layers. Although the magnetic structure of the system is non-collinear 120° in ab-plane, the c-axis canting appears by increasing the spin momentum from ½Σ(Mn²⁺) = 1/2 to S(Mn²⁺) = ½, due to the presence of static two-dimensional spin correlations. The spectrum of crystal field excitations in TbInO₃ appears to have an exotic form due to the existence of two crystallographically distinct Tb³⁺ sites and leads to a strong Ising anisotropy of the spin symmetry.

1 Collaborative Innovative Center of Advanced Microstructures, Fudan University

9:48AM R6.00008 An indirect RIXS study of roton excitation in triangular lattice antiferromagnet. TRINANJAN DATTA, Georgia Regents University. CHENG LUO, DAO-XIN YAO, Sun Yat-Sen University — The antiferromagnetic triangular lattice is characterized by the presence of roton excitations. We propose that the K-edge indirect resonant inelastic x-ray scattering (RIXS) spectrum of a triangular lattice antiferromagnet can serve as a novel spectroscopic tool to detect the presence of roton excitations. By considering self-energy corrections to the spin-wave spectrum and magnon decay rates in its ordered coplanar three-sublattice 120° degree magnetic state, we find that a single-peak RIXS spectrum forms at the roton momentum, Luo et. al. Phys. Rev. B 92. 035109 (2015). The single peak feature is in sharp contrast to the other high symmetry points where the RIXS spectrum splits into a multipake structure. It is this contrast which can be utilized as an experimental signature to detect the presence of rotons. We also investigate the effect of XXZ spin anisotropy, orthorhombic spatial anisotropy, and DM interaction in the triangular lattice and find that the roton peak is affected.

10:00AM R6.00009 2D Heisenberg Triangular Antiferromagnet in Ba₃CoSb₂O₉. ALUN BIFFIN, Laboratory for Neutron Scattering, Paul Scherrer Institute. CH-5232 Villigen PSI, Switzerland. FRANZ DEMMEL, HELEN WALKER, ISIS Facility. DIDOT, OXFORDSHIRE. DOUGLAS HAYWARD, Professor. DON HAYWARD, Department of Chemistry, Inorganic Chemistry Laboratory, University of Oxford. SOUTH PARKS ROAD, OXFORD OX1 3QR, United Kingdom. RADU COLDEA, Clarendon Laboratory, University of Oxford. PARKS ROAD, OXFORD OX1 3PU, U.K. — We present inelastic neutron scattering (INS) experiments on the triangular antiferromagnet (TAF) Ba₃CoSb₂O₉. High energy INS measurements allowed the crystal field levels of Co³⁺ ions to be resolved, and subsequently the terms relevant to its single ion Hamiltonian to be derived with the conclusion that the ions have a A_f = 1/2 doublet as their groundstate with relatively weak local trigonal distortion of CoO₆ octahedra. The result is a system which is a rare realisation of the canonical spin 1/2 Heisenberg TAF. Following this, low energy, high-resolution INS experiments have been performed which reveal the spin wave excitations emanating from the 120° ordered phase below TN = 3.8K. However, as will be seen, linear spin wave calculations are not sufficient to describe all the features of the data, and these anomalies hint at quantum dynamics beyond linear spin wave theory within this realisation of the canonical S=1/2 TAF system.
10:12AM R6.00010 Quantum phase transitions in triangular lattice Heisenberg antiferromagnet in a magnetic field. MENGXING YE, ANDREY CHUBUKOV, Univ of Minnesota - Twin Cities — We present the zero temperature phase diagram of a large S Heisenberg anti-ferromagnet on a frustrated triangular lattice with the nearest neighbor (J1) and the next nearest neighbor (J2) interactions, in a magnetic field. We show that the classical model has an accidental degeneracy for all J2/J1, and all fields below the saturation field, which gives rise to the extended manifold of the ground state spin configurations. Quantum fluctuations, however, lift this degeneracy. For small J2/J1, they select one of three different co-planar states, depending on the field value. We argue that above some critical ratio of J2/J1, which weakly depends on a magnetic field, these fluctuations select the stripe phase. We analyze in detail the mechanism of the selection of the stripe phase and explore the nature of the quantum phase transition in a magnetic field between the ordered phases as J2/J1 passes through a critical value.

10:24AM R6.00011 Neutron diffraction study of low dimensional magnetic system: single crystal α-NaMnO2, REBECCA DALLY, Boston College, STEPHEN WILSON, University of California, Santa Barbara, JEFFREY LYNN, ROBIN CHISNELL, LELAND HARRIGER, NIST Center for Neutron Research, MICHAEL GRAF, Boston College — α-NaMnO2 contains complex, low dimensional interactions and is magnetically frustrated due to the triangular arrangement of Mn3+ (S=2, t2g3 eg1) atoms in the crystal. Nearest neighbor Mn atoms lie along the b-axis in a chain; these chains span the ab-plane, where a mean-field approach to the interchain exchange predicts the cancellation of interactions, giving rise to quasi-1D behavior. Here we will present the results of our recent single crystal neutron diffraction measurements of correlated spin behavior in this Na3MnO2. A complex evolution of the ordering wave vector, spin anisotropy, and dimensionality is observed as the system approaches the antiferromagnetic phase transition. The implications for the inherent dimensionality of this system and its coupling to the lattice will be discussed.

10:36AM R6.00012 Giant magnon-phonon coupling in LiCrO2, KATHARINA ROLF, Paul Scherrer Institut, Laboratory for Neutron Scattering and Imaging, University of Geneva, Department of Quantum Matter Physics, TURAN BIROL, Rutgers University Department of Physics and Astronomy, UWE STUHR, Paul Scherrer Institut, Laboratory for Neutron Scattering and Imaging, BJFR FK, Institut Laue Langevin, KENTA KIMURA, Osaka University, Department of Materials Engineering Science, HIROSHI TAKATSU, Tokyo Metropolitan University, Department of Physics, CHRISTIAN REGG, Paul Scherrer Institut, Laboratory for Neutron Scattering and Imaging — The study of low dimensional and frustrated quantum magnets has been a central problem in condensed matter physics over the past decades. The main feature of frustrated magnets is the macroscopic degeneracy of the ground state that can be lifted by weak additional effects such as quantum fluctuations. This can lead to exotic ground states without long-range order and novel excitations. Here we present an example, LiCrO2, where frustration (and electronic properties) leads to strong coupling between magnons and phonons in a triangular lattice antiferromagnet. This coupling leads to a novel magnon dispersion with a roton minima at the zone boundary. We show direct evidence using inelastic neutron and X-ray scattering that the roton is the direct result of the magnon-phonon coupling. Furthermore, the discovered effect could shed light on the underlying physics of other Cr3+ compounds with strange properties, such as the observed flat magnetic modes in the pyrochlore lattice antiferromagnet Mg2Cr2O7. [1] S. Toth et al., PRL 109, 127203 (2012).

10:48AM R6.00014 Nanosized helical magnetic domains in strongly frustrated Fe3PO4O13, MITCHELL BORDELON, KATE ROSS, GREG TERHO, JAMES NEILSON, Colorado State University — Non-centrosymmetric Fe3PO4O13 (space group R3m) contains triaxial motifs of Fe3+ ions coupled by strong antiferromagnetic interactions ((9CTW) > 900 K). Neutron powder diffraction below TN = 163 K reveals the formation of an ordered heliconsequemorous magnetic structure, with magnetic axis in the ab plane and modulation length of ~100 nm. The magnetic structure forms needle-like correlation volumes perpendicular to the ab plane that extend at least to 900 along the c-axis, but are confined to ~70 in the ab plane. The refined magnetic moment, supported by magnetization measurements of a magnetically diluted series (Fe3−xGaxPO4O13), indicates a reduced Fe3+ moment, suggesting metal-ligand charge transfer. High-resolution synchrotron X-ray diffraction reveals no lattice symmetry change below TN. Absence of long-range in-plane order below TN signifies the formation of a high density of defects in the magnetic structure. The defect-rich helical magnetic phase in Fe3PO4O13 offers insight into the stabilization of topological spin textures in antiferromagnets.

3Partial support from NSERC of Canada.

Thursday, March 17, 2016 8:00AM - 11:00AM
Session R11 MAG DMP FIAP: Spin-Hall IV

8:00AM R11.00001 Magnonic charge-pumping and spin-orbit torques in conducting ferromagnets, ARNE BRATAAS, Norwegian University of Science and Technology — In conducting ferromagnets, the spin-transfer torque and spin-motive force are known to exhibit a reciprocal relationship. Recent works on ferromagnets with strong spin-orbit coupling have revealed a rich complexity of the interaction between itinerant charge carriers and magnetization. As a result, currents can also induce magnetization excitations via spin-orbit torques, sometimes in more efficient ways than via spin-transfer torques. The reciprocal phenomenon of spin-orbit torques is magnonic charge-pumping. We will discuss how the material symmetry governs spin-orbit torques and magnonic charge-pumping. We will also relate magnonic charge pumping and spin-orbit torques via the Onsager reciprocal relations. Finally, we will give examples for important classes of systems including isotropic ferromagnets with nonuniform magnetization.

8:36AM R11.00002 The Spin Hall Effect in Rare Earth Thin Films, NEAL REYNOLDS, JONATHAN GIBBONS, JOHN HERON, Physics Department Cornell University, DARRELL SCHLOM, Materials Science and Engineering Cornell University, DANIEL RALPH, Physics Department Cornell University — The spin Hall effect results in a spin current which flows transverse to an applied electric field in non-magnetic materials. We report measurements of the strength of the spin Hall effect in a series of lanthanide rare earth materials in order to determine whether the large spin and orbital moments in f-electron materials might enhance the spin Hall effect. To ensure trustworthy results, we compare the results of several complementary measurement techniques: off-resonant electrical and optical second harmonic detection of current-induced magnetic tilting, spin-torque ferromagnetic resonance, and spin Hall voltage. We compare the results to ab-initio calculations of the intrinsic Berry curvature contribution to spin Hall effect.

8:48AM R11.00003 Towards brain-inspired computing with spin-torque nano-oscillators, JACOB TORREJON, JACOB BINETTE, PIERRE-ANDRE HAMMOND, Thales Research & Technology, IGNACIO JUAREZ, Universidad de Buenos Aires, MAGNUS KULON, Thales Research & Technology — The spin Hall effect results in a spin current which flows transverse to an applied electric field in non-magnetic materials. We report measurements of the strength of the spin Hall effect in a series of lanthanide rare earth materials in order to determine whether the large spin and orbital moments in f-electron materials might enhance the spin Hall effect. To ensure trustworthy results, we compare the results of several complementary measurement techniques: off-resonant electrical and optical second harmonic detection of current-induced magnetic tilting, spin-torque ferromagnetic resonance, and spin Hall voltage. We compare the results to ab-initio calculations of the intrinsic Berry curvature contribution to spin Hall effect.
9:00AM R11.00004 Oscillatory spin transport in spin Hall multilayers, IGOR BARSUKOV, University of California, Irvine, A. M. GONALVES, P. SOLEDADE, C. A. C. PASSOS, M. COSTA, CBPF, Rio de Janeiro, Brazil, N. M. SOUZA-NETO, LNLs, Campinas, Brazil, F. GARCIA, CBPF, Rio de Janeiro, Brazil, H. K. LEE, A. SMITH, University of California, Irvine, O. TRETIAKOV, Tohoku University, Sendai, Japan, I. N. KRIVOROTOV, University of California, Irvine, L. C. SAMPAIO, CBPF, Rio de Janeiro, Brazil — We study multilayers of sputtered Pt/(d)Cu/Pt as a function of the Cu thickness d using ferromagnetic resonance (FMR). The FMR linewidth reveals a linear dependence on the frequency with negligible inhomogeneous contribution. The Gilbert damping falls smoothly with increasing d, but presents a strong superimposed oscillation with a period of ~1.5nm. We attribute this behavior to RKKY-like spin transport in the confinement of the Cu layer. The induced perpendicular anisotropy due to the proximity effect shows a similar behavior. We evaluate the induced magnetic moment on Pt using x-ray magnetic circular dichroism and find that it decreases with increasing Cu thickness smoothly. Again, we see oscillations of the magnetic moment and show that the oscillatory spin transport affects proximity induced magnetism in Pt. We extend our study to multilayer systems with increased oxidation levels and with out-of-plane crystal texture, in order to investigate the effects of disorder and electron’s k-vectors that are responsible for the oscillatory spin transport.

9:12AM R11.00005 Magnon emission and radiation induced by spin–polarized current,1, ANDREI ZHOLUD, RYAN FREEMAN, RONGXING CAO, SERGEI URAZHGIN, Emory University — The spin-torque effect due to spin injection into ferromagnets can affect their effective dynamical damping, and modify the magnet populations. The latter leads to the onset of nonlinear damping that can prevent spontaneous current-induced magnetization oscillations. It has been argued that these nonlinear processes can be eliminated by the radiation of magnons excited by local spin injection in extended magnetic films. To test these effects, studied of the effects of spin injection on the magnet populations in nanoscale spin valves and magnetic point contacts. Measurements of the giant magnetoresistance show a significant resistive component that is spin asymmetric in nature, and linearly dependent on temperature T. This component is significantly larger for the nanopatterned ferromagnets than for point contacts. We interpret our observations in terms of stimulated generation of magnons by the spin current, and their radiation in point contacts. 1. V.E. Demidov, S. Urazhdin, H. Ulrichs, V. Tiberkevich, A. Slavin, D. Baither, G. Schmitz, and S. O. Demokritov, Nature Mater., 11, 1028-1031 (2012)

9:24AM R11.00006 Electric probe for spin transition and fluctuation, ZHIYONG QIU, Tohoku University, JIA LI, University of California at Berkeley, DAZHI HOU, Tohoku University, ELKE ARENHOLZ, ALPHA T. NDIAYE, ALI TAN, Lawrence Berkeley National Laboratory, KEN-ICHI UCHIDA, KOJI SATO, Tohoku University, YAROSŁOW TSERKOVNYAK, University of California, Z. Q. QIU, University of California at Berkeley, ELJI SAITOH, Tohoku University — Spin fluctuation and transition have always been one of central topics of magnetism and condensed matter science. To probe them, neutron scatterings have been used as powerful tools. A part of neutrons injected into a sample is scattered by spin fluctuation inside the sample. This process transcribes the spin fluctuation onto scattering intensity, which is commonly represented by dynamical magnetic susceptibility of the sample. This component is significantly larger for the nanopatterned ferromagnets than for point contacts. We interpret our observations in terms of stimulated generation of magnons by the spin current, and their radiation in point contacts. 1. V.E. Demidov, S. Urazhdin, H. Ulrichs, V. Tiberkevich, A. Slavin, D. Baither, G. Schmitz, and S. O. Demokritov, Nature Mater., 11, 1028-1031 (2012)

9:36AM R11.00007 Electrical manipulation of a ferromagnet by an antiferromagnet, V TSHITOYAN, C CICCARELLI, Cavendish Laboratory, University of Cambridge, UK, A P MIHAI, M ALI, School of Physics and Astronomy, University of Leeds, UK, A C IRVINE, Cavendish Laboratory, University of Cambridge, UK, T A MOORE, School of Physics and Astronomy, University of Leeds, UK, T JUNGRWIRTH, Institute of Physics ASCR, Prague, CZ and School of Physics and Astronomy, University of Nottingham, UK, A J FERGUSON, Cavendish Laboratory, University of Cambridge, UK — Several recent studies of antiferromagnetic (AFM) spintronics have focused on transmission and detection of spin-currents in AFMs. Efficient spin transmission through AFMs was inferred from experiments in FM/AFM/NM (normal metal) structures. Measurements in FM/AFM bilayers have demonstrated that a metallic AFM can also act as an efficient ISHE detector of the spin-current, with spin-Hall angles comparable to heavy NMs. Here we demonstrate that an antiferromagnet can be employed for a highly efficient electrical manipulation of a ferromagnet. We use an all-electrical excitation and detection technique based on spin Hall enabled Fe/Py interfacial layer. We observe antidamping-like spin torque acting on the NiFe generated by the in-plane current driven through the IrMn antiferromagnet. A large enhancement of the torque, characterized by an effective spin-Hall angle exceeding most heavy transition metals, correlates with the presence of the exchange-bias field at the NiFe/IrMn interface. It highlights that, in addition to strong spin-orbit coupling, the AFM order in IrMn governs the observed phenomenon.

9:48AM R11.00008 Spin pumping and inverse spin Hall effects in heavy metal/antiferromagnet/Permalloy trilayers1, HILAL SAGLAM, WEI ZHANG, M. BENJAMIN JUNGFLIECH, WANJUN JIANG, JOHN E. PEARSON, AXEL HOFFMANN, Argonne National Laboratory — Recent work shows efficient spin transfer via spin waves in insulating antiferromagnets (AFMs) [1], suggesting that AFMs can play a more active role in the manipulation of ferromagnets. We use spin pumping and inverse spin Hall effect experiments on heavy metal (Pt and W)/AFMs/Py (Ni80Fe20) trilayer structures, to examine the possible spin transfer phenomenon in metallic AFMs, i.e., FeMn and PdMn. Previous work has studied electronic effects of the spin transport in these materials, yielding short spin diffusion length on the order of 1 nm [2]. However, the work did not examine whether besides diffusive spin transport by the conduction electrons, there are additional spin transport contributions from spin wave excitations [1]. We clearly observe spin transport from the Py spin reservoir to the heavy metal layer through the sandwiched AFMs with thicknesses well above the previously measured spin diffusion lengths, indicating that spin transport by spin waves may lead to non-negligible contributions. [1] H. Wang, et al., Phys. Rev. Lett. 113, 097202 (2014). [2] W. Zhang et al., Phys. Rev. Lett. 113, 196602 (2014).

1This work was supported by US DOE, OS, Materials Sciences and Engineering Division. Lithographic patterning was carried out at the CNM, which is supported by DOE, OS under contract no. DE-AC02-06CH11357.

10:00AM R11.00009 Phase-sensitive inductive detection of ac currents due to spin-pumping/inverse spin Hall effect in unpatterned Permalloy/Pt bilayers, THOMAS SILVA, NIST, HANS NEMBACH, University of Colorado, JUSTIN SHAW, NIST, ALEXY KARENOWSKA, Oxford University, MATTHIAS WIELER, WMI — We present a new method to measure the ac inverse spin Hall effect at GHz frequencies. Unlike previous methods [1-3], our does not rely on any patterning or electrical contacts. We utilize phase-sensitive, broad-band, perpendicular-field ferromagnetic resonance to detect the ac current by the inverse spin Hall effect (ISHE) in Pt/Pt bilayers. The ISHE component of the signal is non-linear in the excitation frequency; while the inductive FMR response scales linearly with frequency, the ISHE signal scales quadratically because the ISHE current itself is proportional to dm/dt. This differential gain affords us detection of previously unreported higher order contributions to the ISHE signal. We compare FMR measurements with a control samples that do not include the high spin-orbit layer, e.g. Pt. Data sets are analyzed with a simple model that considers how the ac currents generated by the ISHE couple inductively back into the excitations waveguide. The linear iSHE signal agrees with previous reported values. The nonlinear iSHE signal is 3-4 orders of magnitude weaker, but is easily detected over the frequency range of 5-45 GHz. [1] M. Weiler, et al., PRL 113, 157204 (2014). [2] C. Hahn, et al., PRL 111, 217204 (2013) [3] D. Wei, et al., Nat. Comm. 5, (2014)
properties, such as the spin transfer torque. From our calculations is a non-collinear k-dependent spin texture at the interface which may have important consequences for the spin-dependent transport.

Bi$_2$Se$_3$ hybridization between FM and Bi$_2$Se$_3$. In this study, the structural, magnetic, and electron-transport properties of a SGS material CoFeCrAl in the thin film geometry have been investigated. CoFeCrAl films were grown on atomically flat SiO$_2$ substrates using magnetron sputtering. The Curie temperature was measured to be 550 K very close to the value reported for bulk CoFeCrAl. Electron-transport measurements on the oriented films revealed a negative temperature coefficient of resistivity, small anomalous Hall conductivity and linear field dependence of magnetoresistance, which are transport signatures of SGS. The effect of elemental compositions and structural ordering on the SGS properties of the CoFeCrAl films will be discussed.

Using time reversal properties, we show that this asymmetry cannot be attributed to an effective field but originates from a purely dissipative mechanism. The study of the asymmetry induced by an in-plane magnetic field on field induced domain wall motion in perpendicularly magnetized asymmetric Pt/Co/Pt trilayers. The observation of chiral damping, not only enriches the spectrum of physical phenomena engendered by the SIA, but since it can coexist with DMI it is essential for conceiving DW and skyrmion devices. [1] A. Thiaville, et al., EPL 100, 57002 (2012)

Thursday, March 17, 2016 8:00AM - 10:12AM – Session R18 GMAG DMP FIAP: Spintransport Phenomena II 317 - See-Hun Yang, IBM Almaden

8:00AM R18.00001 Magnetic and electron-transport properties of spin-gapless semiconducting CoFeCrAl films.1, DAVID SELLMYER, YUNLONG JIN, University of Nebraska Lincoln, PARASHU KHAREL, South Dakota State University, SHAH VALLOPPILLY, TOM GEORGE, BALAMURUGAN BALASUBRAMANIAN, RALPH SKOMSKI, University of Nebraska Lincoln — Recently, spin-gapless semiconductors (SGS) with a semiconducting or insulating gap in one spin channel and zero gap in the other at the Fermi level have attracted much attention due to their new functional properties such as voltage-tunable spin polarization, the ability to switch between spin-polarized n-type and p-type conduction, high spin-polarization and carrier mobility. For the development of spintronic devices utilizing SGS, it is necessary to have a better understanding of the magnetic and transport properties of SGS materials. In this work, the structural, magnetic, and electron-transport properties of CoFeCrAl thin films were studied. CoFeCrAl films were grown on TiO$_2$ substrates using magnetron sputtering. The Curie temperature was measured to be 550 K very close to the value reported for bulk CoFeCrAl. Electron-transport measurements on the oriented films revealed a negative temperature coefficient of resistivity, small anomalous Hall conductivity and linear field dependence of magnetoresistance, which are transport signatures of SGS. The effect of elemental compositions and structural ordering on the SGS properties of the CoFeCrAl films will be discussed.

1Research supported by NSF (Y. J.), DoE (B. B., D. J. S), ARO (T. A. G, S. R. V), SDSU (P. K. ), and NRI (Facilities)

8:12AM R18.00002 Theory of spin relaxation at metallic interfaces1, K. D. BELASHCHENKO, ALEXEY K. KOVALEV, University of Nebraska-Lincoln, MARK VAN SCHILFGAARDE, King’s College London — Spin-flip scattering at metallic interfaces affects transport phenomena in nanostructures, such as magnetoresistance, spin injection, spin pumping, and spin torques. It has been characterized for many material combinations by an empirical parameter $\delta$, which is obtained by matching magnetoresistance data for multilayers to the Valet-Fert model [J. Bass and W. P. Pratt, J. Phys.: Condens. Matter 19, 183201 (2007)]. However, the relation of the parameter $\delta$ to the scattering properties of the interface remains unclear. Here we establish this relation using the scattering theory approach and confirm it using a generalization of the magnetoelastic circuit theory, which includes interfacial spin relaxation. The results of first-principles calculations of spin-flip scattering at the Cu/Pd and Cu/Pt interfaces are found to be in reasonable agreement with experimental data.

1Supported by NSF Grant DMR-1308751.

8:24AM R18.00003 Spin relaxation through Kondo scattering in Cu/Pt lateral spin valves. J. T. BATLEY, M. C. ROSAOND, M. ALI, E. H. LINFIELD, G. BURNELL, B. J. HICKEY, University of Leeds — Within non-magnetic metals it is reasonable to expect the Elliot-Yafet mechanism to govern spin-relaxation and thus the temperature dependence of the spin diffusion length might be inversely proportional to resistivity. However, in lateral spin valves, measurements have found that at low temperatures the spin diffusion length unexpectedly decreases. We have fabricated lateral spin valves from Cu with different concentrations of magnetic impurities. Through temperature dependent charge and spin transport measurements we present clear evidence linking the presence of the Kondo effect within Cu to the suppression of the spin diffusion length below 30 K. We have calculated the spin-relaxation rate and isolated the contribution from magnetic impurities. At very low temperatures electron-electron interactions play a more prominent role in the Kondo effect. We observed the Kondo temperature a strong-coupling regime exists, where the moments become screened and the magnetic depinning occurs. We also investigate the effect of this low temperature regime (T > 1 K) on a pure spin current. This work shows the dominant role of Kondo scattering, even in low concentrations of order 1 ppm, within pure spin transport.

8:36AM R18.00004 Electronic structure and magnetocrystalline anisotropy of the Bi$_2$Se$_3$topological insulator/ferromagnet interface. JIA ZHANG, Physics and Astronomy, University of Nebraska, Lincoln, Nebraska 68588, USA, JULIAN P. VELEV, Department of Physics, Puerto Rico, San Juan, Puerto Rico 00931, USA, EVGENY Y. TSYMBAL, Physics and Astronomy, University of Nebraska, Lincoln — Interesting spin-dependent phenomena are expected to emerge when a topological insulator is interfaced with a magnetic material. In this work the magnetic properties of the interface between a topological insulator Bi$_2$Se$_3$ and ferromagnetic metals (FM) fcc (111) Ni and Co are investigated by first-principles calculations. Different interface terminations are considered, and the most stable interface termination is identified to be an interface Ni (Co) atom located atop the hollow site of the interfacial Se monolayer. We find that the proximity effect induces a small magnetic moment on the interface Se atom (0.028 $\mu_B$ for Ni and 0.023 $\mu_B$ for Co). The surface state in Bi$_2$Se$_3$ disappears due to the strong interface hybridization between FM and Bi$_2$Se$_3$ and metal induced gap states appear in the bandgap region of Bi$_2$Se$_3$. We find that both the Bi$_2$Se$_3$/Ni(111) and Bi$_2$Se$_3$/Co(111) interfaces exhibit an in-plane easy axis with the magnetic anisotropy energy of around 2 erg/cm$^2$ per interface. An interesting feature resulting from our calculations is a non-collinear k-dependent spin texture at the interface which may have important consequences for the spin-dependent transport properties, such as the spin transfer torque.
are various spin relaxation mechanisms, including spin absorption, interfacial spin scattering, and fringe field effects, which may account for the observed short
University — Contact induced spin relaxation in graphene lateral spin valves is one of major limiting factors for obtaining long spin lifetimes in graphene. There
tunnel barriers
of Material Science and Engineering, University of Ioannina, SEUNG JOO LEE, Quantum-functional Semiconductor Research Center, Dongguk University —
local magnetostatic fields due to contact roughness are likely to be more important.

damping in metallic ferromagnets is mainly governed by the exchange coupling between the electrons and the magnetic degree of freedom, where the time-dependent evolution of the magnetization leads to the excitation of electrons and loss of energy as a result of flow of spin and charge currents. However, it turns out that when the magnetization evolves slowly in time, in the presence of spin-orbit interaction (SOI), the resonant electronic excitations has a major contribution to the damping which leads to infinite result in ballistic regime. In this work we consider the inelastic spin-flip scattering of electrons from the magnetic moments and show that in the presence of SOI it leads to the relaxation of the excited electrons. We show that in the case of clean crystal systems such scattering leads to a linear dependence of the Gilbert on the SOI strength and in the limit of diffuse systems we get the Gilbert damping expression obtained from Kambersky’s Fermi breathing approach. This research was supported by NSF-PREM Grant No. DMR-1205734

9:12AM R18.00007 Carbon Tetrags as Definitive Spin Switches in Narrow Zigzag Graphene Nanoribbons1. ZHENYU ZHANG, PING CUI, QIANG ZHANG, HONGBIN ZHU, XIAOLONG FAN, DESHENG XUE, The Key Lab for Magnetism and Magnetic Materials of Ministry of Education, Lanzhou University, DIMITRI HOUSSEMMEDDINE, Everspin Technologies — The temperature gradient driven spin-transfer torque, called the thermal spin-transfer torque (TSST) attracts people’s attention since it has potential in magnetization switching by utilizing wasted heat as well as in the study of spin transportation. We observed the effects of TSST on magnetic tunnel junction (MTJ) via analysis of the ferromagnetic resonance (FMR) spectra. We used an external laser beam to heat the MTJ in order to establish a temperature gradient effectively. A TSST was driven by the temperature gradient and applied to the magnetization of the free FM layer of the MTJ. By measuring and analyzing the FMR spectra, after excluding the effects caused by the temperature rise, we conclude that the FMR line-shape change is a result of the TSST generated by a temperature gradient via laser heating. The most interesting result is that the angular dependence of the TSST and DC-bias spin-transfer torque are very different. A modified or new theory may be needed to explain this in the future.

9:24AM R18.00008 Spin Transport and Giant Electroresistance in Ferromagnetic Graphene Vertical Heterostructures2. HEE CHUL PARK, Center for Theoretical Physics of Complex Systems, IBS, NOJOON MYUNG, Department of Material Science and Engineering, University of Ioannina, SEUNG JOO LEE, Quantum-functional Semiconductor Research Center, Dongguk University — We investigate spin transport through ferromagnetic graphene vertical heterostructures where a sandwiched tunneling layer is either a normal or ferroelectric insulator. We show that the spin-polarization of the tunneling current is electrically controlled via gate voltages. We also demonstrate that the tunneling current of Dirac fermions can be prohibited when the spin configuration of ferromagnetic graphene sheets is opposite. Giant electroresistance can thus be developed by using the proposed vertical spintronology in this study. The effects of temperature on spin transport and the giant electroresistance ratio are also investigated. Our findings discover the prospect of manipulating the spin transport properties in vertical heterostructures through electric fields via gate and bias electrodes.

9:36AM R18.00009 Spin relaxation mechanism in graphene spin valves with AlO3 and MgO tunnel barriers1. WALID AMAMOU, ZHISHENG LIN, JEREMIAH VAN BAREN, JING SHI, UC Riverside, ROLAND KAWAKAMI, Ohio State University — Contact induced spin relaxation in graphene lateral spin valves is one of major limiting factors for obtaining long spin lifetimes in graphene. There are various spin relaxation mechanisms, including spin absorption, interfacial spin scattering, and fringe field effects, which may account for the observed short spin lifetimes. One possible solution is to introduce a tunnel barrier between graphene and the ferromagnetic electrode, which should reduce contact induced spin relaxation and allow for longer spin lifetimes. We study the spin relaxation mechanisms in our graphene spin valves with two different types of tunnel barriers, aluminum oxide and MgO/TiO2 using the standard non-local measurement geometry. To extract the spin lifetime from Hanle spin precession data, we perform fits based on Bloch equation models that include the effects of spin absorption into the magnetic contacts. We observe a strong dependence of the extracted spin lifetime on the resistance-area (RA) product of the contacts. To understand the role of spin absorption, we compare these results to fits obtained using Hanle models that do not take spin absorption into account. Analysis shows that spin absorption might not be the dominant source of contact induced spin relaxation for graphene spin valves with sputtered Al2O3 and MgO/TiO2 barriers. Interfacial spin-flip scattering or spin dephasing resulting from local magnetostatic fields due to contact roughness are likely to be more important.

C-SPIN, ONR

9:48AM R18.00010 Spin fluctuations in 3d paramagnetic metals. ALEKSLANDER WYSOCKI, ANDREY KUTEPOV, VLADIMIR ANTOPROV, Ames Laboratory, U.S. Department of Energy, Ames, Iowa 50011, USA — Spin fluctuations (SFs) in 3d paramagnetic metals were investigated using the linear response formalism within the time dependent density functional theory. An efficient scheme of frequency integration using the Matsubara technique has been implemented and tested. The SFs spectrum in 3d paramagnets is analyzed in real and reciprocal spaces as a function of frequency and temperature. For all materials the SFs are characterized by the coexistence of low and high energy branches which originate from different regions of the Brillouin zone. The low-energy ones can be measured by neutron scattering experiments while the high-energy SFs appear to be more localized. Further, we studied the nature of square of fluctuating magnetic moment in these materials. This work was supported, in part, by the Critical Materials Institute, an Energy Innovation Hub funded by the U.S. Department of Energy, Division of Materials Science and Engineering. The research was performed at Ames Laboratory, which is operated for the U.S. DOE by Iowa State University under contract # DE-AC02-07CH11358.
8:00AM R19.00001 Field induced spin density and spiral phases in a layered antiferromagnet¹
MATT THOM STONE, MARK LUMSDEN, VALSIE GARLEA, Quantum Condensed Matter Division, Oak Ridge National Laboratory, BEATRICE GRENÉRIER, ERIC RESSOUCHA, INAC-SPSMS, CEA & Univeristie Grenoble Alpes, ERIC SAMULON, IAN FISHER, Department of Applied Physics and Geballe Laboratory for Advanced Materials Stanford University, LISA DEEBER-SCHM IDT, Chemical & Engineering Materials Division, Oak Ridge National Laboratory, ALEXANDER HRISTOV, Department of Applied Physics and Geballe Laboratory for Advanced Materials Stanford University, JORGE GAVILANO, Paul Scherrer Institute, Villigen, Switzerland — We will present neutron scattering measurements examining the low-field ordered magnetic phases of the S = 1 dimerized antiferromagnet Ba₃MnO₆. We find that for magnetic both spin density wave order with incommensurate wave vectors and a higher field spiral phase with incommensurate wave vectors only along the [hh0] direction. For both field induced ordered phases, the magnetic moments are lying in the plane perpendicular to the field direction. The nature of these two transitions is fundamentally different: the low-field transition is a second order transition to a spin-density wave ground state, while the one at higher field, toward the spiral phase, is of first order. More recent SANS measurements of the magnetic phases with H | c will be presented if available at the time of the meeting.

¹A portion of this research at ORNL was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U.S. DOE. Work at Stanford supported by the NSF

8:12AM R19.00002 Incommensurate Spin Density Wave state in metamagnetic Fe₃Ga₆. VAN WU, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803, HUIBO CAO, ANTONIO DOS SANTOS, Quantum Condensed Matter Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, GREG MCCANDLESS, JULIA CHAN, Department of Chemistry, University of Texas at Dallas, Richardson, TX 75080, AMAR KARKI, RONGYING JIN, JOHN DITUSA, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803 — Fe₃Ga₆ displays a rich competition between magnetic states without structural transitions: a ferromagnetic(FM) ground state transitions to an antiferromagnetic(AFM) intermediate state above 68 K followed by a reemergence of the FM state above room temperature(T). The reentrance of the FM state hints of a coupling of the magnetic degrees of freedom to other modes. To explore the nature of the magnetic states, we have performed extensive single crystal neutron diffraction measurements over a wide range of T and pressure. These measurements revealed two very different magnetic states with the low T FM state having magnetic moments along the c-axis while we discovered that the AFM state is in an incommensurate spin density wave(SDW) order with moments mostly along the a-axis. However, there is still considerable non-collinear and non-coplanar contributions along the b- and c-axis directions. This non-coplanar moment is likely to be the origin of the very large anomalous Hall effect(HE) including a substantial topological HE that we discovered in Fe₃Ga₆. Study of the effect of hydrostatic pressure indicates a reduction of the Tc and a destabilization of the SDW phase.

8:24AM R19.00003 Increased operational temperature of Cr₂O₃-based spintronic devices¹
MICHAEL STREET, WILL ECHTENKAMP, TAKASHI KOMESU, SHI CAO, University of Nebraska-Lincoln, JIAN WANG, University of Saskatchewan, PETER DOWBEN, CHRISTIAN BINEK, University of Nebraska-Lincoln — Spintronic devices have been considered a promising path to revolutionizing the current data storage and memory technologies. This work is an effort to utilize voltage-controlled boundary magnetization of the magnetoelectric chromia (Cr₂O₃) to be implemented into a spintronic device. The electric switchable boundary magnetization of chromia can be used to voltage-control the magnetic states of an adjacent ferromagnetic layer. For this technique to be utilized in a spintronic device, the antiferromagnetic ordering temperature of chromia must be enhanced above the bulk value of Tc ~ 307K. Previously, based on first principle calculations, boron doped chromia thin films were fabricated via pulsed laser deposition showing boundary magnetization at elevated temperatures. Measurements of the boundary magnetization were also corroborated by spin polarized inverse photoemission spectroscopy. Exchange bias of B-doped chromia was also investigated using magneto-optical Kerr effect, showing an increased blocking temperature from 307K. Further boundary magnetization measurements and spin polarized inverse photoemission measurements indicate the surface magnetization to an in-plane orientation from the standard perpendicular orientation.

¹This project was supported by the SRC through CNFD, an SRC-NRI Center under Task ID (2398.001) and by C-SPIN, part of STARnet, sponsored by MARCO and DARPA (No. SRC 2381.001)

8:36AM R19.00004 ”Switching” of Magnetic Anisotropy in Magnets with Strong Spin-Orbit Coupling HIROAKI IISHIZUKA, LEON BALENTS, Univ of California – Santa Barbara — Motivated by recent studies on heavy-element magnetic oxides, we theoretically study a spin model on a fcc lattice with bond-dependent anisotropic interactions. Strong spin-orbit coupling in heavy elements often gives rise to bond-dependent anisotropic interactions in magnetic compounds. Such anisotropic interactions are known to induce peculiar magnetic behavior such as quantum spin-liquid and order-by-disorder. In this study, we investigate magnetic anisotropy of a fcc lattice antiferromagnet with bond-dependent interactions. We show that, in this model, the magnetic anisotropy is induced by fluctuations in both high-temperature paramagnetic and low-temperature magnetically-ordered phases. Furthermore, they show strong temperature dependence and switching of the magnetic anisotropy as the temperature decreases, [111] direction is favored in high-temperature above magnetic transition, while [100] or [110] is favored in the ordered phase, depending on the parameter. This is in contrast to the magnetic anisotropy induced by crystal field, which is independent of temperature. Observation of this temperature dependent anisotropy may provide a way to experimentally determine the anisotropic interaction in heavy-element magnets.

8:48AM R19.00005 Lattice Dynamics and Magnetoelastic Coupling in a microstructures of Yb₂Pt₃Pb , TONI HELM, PHILIP J.W. MOLL, NoneMax-Planck-Institute for Chemical Physics of Solids, Dresden, Germany — The Yb₃⁺ moments in Yb₂Pt₃Pb (YPP) form a strongly frustrated Shastry-Sutherland lattice (SSL) [1]. Below 2K, a dimerized antiferromagnetic order consisting of two AF sublattices has been recently identified by neutron diffraction [2]. Unlike other quantum magnets, YPP is a highly conductive metal and the large Sommerfeld coefficient α ~ 300 mJ/molK² suggests hybridization of the Yb-4f states with the conduction band [3]. This opens the possibility to search for signatures of the metamagnetism associated with the plateaus at fractions of the saturation magnetization, a characteristic of SSL systems. To study the influence of YPPs rich magnetic structure on the anisotropic charge transport, we fabricated micron-sized transport devices from single crystalline YPP byFocused Ion Beam etching. This technique enables thickness and length dependent magnetotransport measurements along the most relevant lattice directions. [1] M. S. Kim et al. PRB 77,144425 (2008) [2] W. Müller et al. arXiv:1408.0209v1 (2014) [3] M. S. Kim, M. C. Aronson, PRL 110, 017201 (2013)
9:12AM R19.00007 Magnetic anisotropy of rare-earth magnets calculated by SIC and OEP
HISAZUMI AKAI, ISPP, Univ of Tokyo, MASAKO O GURA, PGJ, Juelich Research Center — We have pointed out in our previous study that the chemical bonding between N and Sm plays an important role in the magnetic anisotropy change of Sm$_2$Fe$_{17}$ from in-plane to uniaxial ones caused by the introducing of N. This effect of N insertion was discussed in terms of change in the electronic structure calculated in the framework of LDA+SOC. The main issue here is whether the 4f states are dealt with properly in LDA+SOC. In the present study, we examine the applicability of SIC for the evaluation of the magnetic anisotropy of rare-earth magnets. Comparing the results with various methods, in particular, the optimized-effective potential (OEP) method. In this study, OEP is applied only on the RE sites. Admittedly, this is a drawback from the viewpoint of the consistent treatment of uncertainty inherent in the so-called KLI (Kriegler-Li-iafrate) constants. Putting this aside for the moment, we have calculated the electronic structure of RE magnets R$_2$Fe$_{17}$N$_6$ and RCo$_5$(R=light RE), by OEP with exact-exchange (EXX) combined with Colle-Salvetti correlation. Our preliminary results have shown considerable differences between the SIC and OEP calculations. We will discuss the meaning of this discrepancy.

1This work was supported by the Elements Strategy Initiative Center for Magnetic Materials under the outsourcing project of MEXT and by a Grant-in-Aid for Scientific Research (No. 26400330) from MEXT.

9:24AM R19.00008 Domain wall order and motion in Mn$_3$O$_7$
ALEXANDER THALER, Oak Ridge National Lab, Oak Ridge, TN, ALEXANDER ZAKJEVSKII, BRIAN NGUYEN, YEWON GIM, Physics Illinois & Setz MRL, University of Illinois, Urbana, IL, ADAM ACZEL, LISA DEBEER-SCHMIDT, ALEXER ZAKJEVSKII, BRIAN NGUYEN, YEWON GIM, Physics Illinois & Setz MRL, University of Illinois, Urbana, IL — Mn$_3$O$_7$ is an orbitally ordered, magnetically frustrated spin with strong spin-lattice coupling, which exhibits a series of low temperature magnetic and structural transitions. Transverse field $\mu$SR has shown that ordered and disordered volumes coexist within this material, while MFM measurements have further shown that the magnetic domain walls themselves order in specific crystallographic directions, with a typical length scale of 100's of nm. In order to directly study these phenomena, we have performed small angle neutron scattering (SANS) measurements at both zero and applied magnetic field. We will present the results of these measurements and discuss what they show as far as the formation of domains, as well as the motion of the domain walls. We will also discuss the effects of internal disorder on the behavior of the material. This work was sponsored by the National Science Foundation, under grant number DMR-1455264.

9:36AM R19.00009 Nanoscale Magnetic Structure of Non-Joulian Magnets
RAVINI CHANDRASENA, WEIBING YANG, Department of Physics, Temple University, ANDREAS SCHOLL, Advanced Light Source, LBNL, JAN MINAR, Department of Chemistry, Ludwig Maximilian University, PADRAIC SHAFER, ELKE ARENHOFL, Advanced Light Source, LBNL, HUBERT EBERT, Department of Chemistry, Ludwig Maximilian University, ALEXANDER GRAY, Department of Physics, Temple University, HARSH DEEP CHOPRA, Mechanical Engineering Department, Temple University — Strain dependence of magnetic anisotropy energy produces Joule magnetostriiction that is a volume conserving process, whereas sensitivity of isotropic exchange energy to interatomic distance is the cause of volume magnetostriiction. In a typical magnet, Joule magnetostriiction dominates as the volume fraction occupied by regions of uniform spin alignment (domains) is 2-4 orders of magnitude higher than which that is occupied with magnetoelastic gradients (domain walls). Recently, ‘giant’ non-volume conserving or non-Joulian magnetostriiction has been discovered in iron-gallium alloys. Here we show using high-resolution polarization-dependent photoelectron microscopy that non-Joulian magnetism arises from an unusual partition of the crystal into nm-scale lamellar domains and domain walls within highly periodic magnetic microcells. High-resolution x-ray circular dichroism measurements at the Fe and Ga L$\alpha$ edges further provide evidence of weak iron-induced magnetism on gallium atoms via negative exchange. The results are in excellent agreement with the state-of-the-art theoretical electronic-structure calculations.

9:48AM R19.00010 Control over magnetic properties in bulk hybrid materials
CHRISTIAN URBAN, University of California San Diego, ARIADNE QUESADA, Instituto de Ceramica y Vidrio, CSIC, 28049, Madrid, Spain, THOMAS SAERBECK, Instituto Laue-Langevin, 71 Av. Des Martyrs, 38000 Grenoble, France, MIGUEL ANGEL DE LA RUBIA, MIGUEL ANGEL GARCIA, JOSE FRANCISCO FERNANDEZ, Instituto de Ceramica y Vidrio, CSIC, 28049, Madrid, Spain, IVAN K. SCHULLER, University of California San Diego, UCSD COLLABORATION, INSTITUTO DE CERAMICA, MADRID COLLABORATION, INSTITUT LAUE-LANGEVIN, GRENoble COLLABORATION — We present control of coercivity and remanent magnetization of a bulk ferromagnetic material embedded in vanadium sesquioxide (V2O3) by using a standard bulk synthesis procedure. The method generalizes the use of structural phase transitions of one material to control structural and magnetic properties of another. A structural phase transition (SPT) in the V2O3 host material causes additional magnetic properties of Ni to change as function of temperature. The remanent magnetization and the coercivity are reversibly controlled by the SPT without additional external magnetic fields. This work was sponsored by the National Science Foundation, under grant number DMR-1455264.

This Work is supported by the Office of Basic Energy Science, U.S. Department of Energy, BES-DMS funded by the Department of Energy's Office of Basic Energy Science, DMR under grant DE FG02 87ER-45332.

10:00AM R19.00011 A Study of Phase Stability and Properties of TiO2 Polymorphs with Diffusion Monte Carlo
YE LUO, ANOUAR BENALI, Argonne National Laboratory, LUKE SHULENBURGER, Sandia National Laboratories, JARON KROGEL, Oak Ridge National Laboratory, OLLE HEINONEN, Argonne National Laboratory, PAUL KENT, Oak Ridge National Laboratory — In the past decades, many studies have focused on the fundamental properties of TiO2 due to its important role in effectively converting solar energy such as in photovoltaic batteries and photocatalytic water splitting. TiO2 presents many stable and metastable phases of which, Rutile Anatase and Brookite are the most studied. Using density functional theory (DFT), the energy ordering of these phases depends strongly on the scheme describing the electronic correlation, for instance GGA+U and Hybrid functionals, often tied to an empirical parameter for reproducibility with no guarantee of predictability. We present the first analysis of the polymorphic energy ordering and properties of three naturally existing phases Rutile, Anatase and Brookite, by performing the highly accurate ab initio calculation with fixed node diffusion Monte Carlo (DMC) implemented in QMCPACK[1]. [1] QMCPACK, http://www.qmcpack.org

10:12AM R19.00012 On the Electronic and Magnetic Properties of the ionic superatomic solid Ni$_9$Te$_6$(PET$_3$)$_8$C$_{60}$$^\text{1}$
VIKAS CHAHUAN, SANJUBALA SAHOO, SHIV KHANNA, Virginia Commonwealth University, PHYSICS DEPARTMENT VCU COLLABORATION — We have carried out first principles electronic structure studies to examine the atomic structure, stability, and electronic and magnetic properties of the recently synthesized Ni$_9$Te$_6$(PET$_3$)$_8$C$_{60}$ ionic material consisting of Ni$_9$Te$_6$ (PET$_3$)$_8$ superatoms and C$_{60}$. It is shown that the PET$_3$ ligands result in an internal coulomb well that lifts the quantum states of the Ni$_9$Te$_6$ cluster lowering its ionization potential to 3.39 eV thus creating a superatomic alkali motif. The metallic core has a spin magnetic moment of 5.3 $\mu$B in agreement with experiment. The clusters are marked by low magnetic anisotropy energy (MAE) of 2.72 meV and a larger intra-exchange coupling exceeding 0.2 eV indicating that the observed paramagnetic behavior around 10K is due to superparamagnetic relaxations. The magnetic motifs separated by C$_6$H$_4$ experience a weak superexchange that stabilizes a ferromagnetic ground state as observed around 2K. The calculated MAE is sensitive to the charged state that could account for the observed change in magnetic transition temperature with size of the ligands or anion.

1We gratefully acknowledge funding support from the Department of Energy under Award Number DE-SC0006420.
10:24AM R19.00013 Submicron sized R2Fe14B particles fabricated by mechanochemical process1. OZLEM KOYLU-ALKAN, Department of Physics and Astronomy, University of Delaware, Newark, DE, USA, JOSE MANUEL BARANDI-ARAN, BCMaterials, Technology Park of Biscay E-48160 Derio, Spain & Dept. Electricity & Electronics, Univ. Basque Country (UPV/EHU) E-48080 Bilbao, Spain, DANIEL SALAZAR, BCMaterials, Technology Park of Biscay E-48160 Derio, Spain, GEORGE C. HADJIPANAYIS, Department of Physics and Astronomy, University of Delaware, Newark, DE, USA, UNIV. OF DELAWARE TEAM, UNIV. BASQUE COUNTRY TEAM — In this work, we have synthesized submicron R$_2$Fe$_{14}$B particles by the mechanochemical process. Mechanical activation of oxides of rare earth, iron and boron was done by high energy ball milling in a CaO with water and glycerol solution to remove the dispersant and other non-magnetic phases. Magnetic measurements showed that the as-synthesized unwashed powders had coercivity values of 10.3 kOe, 12.8 kOe, and 24.6 kOe for R=Nd, Pr, and Dy, respectively. During washing, H$_2$ is released and absorbed by the 2:14:1 structure. After removing the H$_2$, the submicron particles have coercivities of 3.3 kOe (Nd), 4.4 kOe (Pr) and 21.0 kOe (Dy) with average sizes 160 nm, 242 nm, and 107 nm, respectively. Fitting of high field M(H) measurements to the law of approach to saturation showed that the anisotropy constant of the Nd$_2$Fe$_{14}$B particles are 3.73x10^5 erg/cm^3 which is comparable to bulk. Work supported by DOE DE-FG02-04ER46126 and Bizkaia Talent AYD-000-195.

1DOE DE-FG02-04ER46126

10:36AM R19.00014 First-principles study of intrinsic magnetic properties of hexagonal and orthorhombic (Fe$_{1-x}$Co$_x$)$_2$P alloys1. IVAN ZHURAVLEV, University of Nebraska-Lincoln, V. P. ANTOPROV, Ames Laboratory, K. D. BELASHCHENKO, University of Nebraska-Lincoln — (Fe$_{1-x}$Co$_x$)$_2$P is a candidate rare-earth-free alloy for permanent-magnet applications, which is hexagonal (h) up to $x \approx 0.12$ and orthorhombic (o) at larger $x$. The Curie temperature $T_C$, which is only 270 K in Fe$_2$P, raises sharply with $x$, peaking above 450 K in the $o$-phase [1]. The measurement [2] of magnetocrystalline anisotropy (MCA) in the $o$-phase is inconsistent with Mössbauer data suggesting a spin reorientation transition (SRT) at $x \approx 0.3$ [1]. Here we report the results of ab initio calculations of the magnetization, mean-field $T_C$, and MCA in h- and o-phases as a function of $x$, addressing the role of unequal site occupation, which is confirmed by total-energy calculations. The trends in the magnetization are reproduced, as well as MCA in the $h$-phase, and so is the SRT near $x \approx 0.3$ (at odds with the results of Ref. 2). The trends in the mean-field $T_C$, obtained using the disordered-local-moment method, agree with experimental data. [1] R. Fruchart et al., J. Appl. Phys. 40, 1250 (1969). [2] T. Hokabe et al., J. Phys. Soc. Japan 36, 1704 (1974).

1Work at UNL is supported by NSF Grant DMR-1308751.

10:48AM R19.00015 Magnetic effects of H in Metals, the case of Iron1. PATRICIO VARGAS, ANDREA LEN, JUAN MANUEL FLOREZ, Physics Department, USM, Valparaiso, Chile — A growing consensus on the possible role of hydrogen in future energy technology has incited worldwide efforts for the development of new hydrogen-storage materials and their application to rechargeable batteries and fuel cells. Meanwhile, research in the basic properties of metal-hydrogen systems has also been advanced. High-pressure experiments have unraveled new features of elemental hydrogen (phases of solid H2 and metallization of liquid H2 and superconductivity) as well as of many metal–hydrogen systems (superabundant vacancy formation, phase diagrams over wide p–x–T ranges). In this work we address the magnetic changes induced by interstitial hydrogen in Fe. From the point of view of the Slater Pauli Curve, Fe alloys (Fe(1-x)Mx) show an increase of the magnetization (but always less than pure Fe) due substitutional non magnetic impurities like M=Cr, Ti. For the magnetic impurity Cobalt, the Slater Pauli Curve reaches its maximum of about 2.5 Bohr magnetons per atom when $x=0.4$. For an interstitial impurity H, which adds one electron to the system, we observe an increasing of the magnetization too but less than the effect induced by the volume expansion. Therefore like the case of NiHx, one of the effects of interstitial hydrogen on a ferromagnetic material is to fill the minority spin states.

1Authors acknowledge financial support from FONDECYT under contract 1130950 and DGIP contract11.15.73.

Thursday, March 17, 2016 11:15AM - 2:15PM —
Session S6 GMAG DMP: Magneto-Optic/Electric and Strain/Shape Induced Magnetism 302 -
Anirudh Sharma, Flanders University

11:15AM S6.00001 magnetoelectric switching and spin wave generation. BART SOREE, DAVIDE TIERNO, CHRISTOPH ADELMANN, ODYSSEAS ZOGRAFOS, ADRIEN VAYSSET, FLORIN CIUBOTARU, imec, SPIN WAVE IMEC TEAM — We have investigated the dynamics of the magnetization in magnetoelectric elements for switching and generation of spin waves. The behavior of the magnetization in the magnetostrictive material coupled to the piezoelectric not only depends on the strain induced by the piezo, but also depends on the relative contribution of the different magnetic anisotropies (shape, magnetocrystalline, magnetoelastic) present in the magnetoelectric element which is coupled to a spin wave bus. Performing micromagnetic simulations allow us to draw several conclusions w.r.t. the switching behavior of magnetoelectric elements as well as conditions to generate spin waves in an effective manner.

11:27AM S6.00002 Electric field controlled strain induced reversible switching of magnetization in Galfenol nanomagnets delineated on PMN-PT substrate1. HANSAH AHMAD, Department of Electrical and Computer Engineering, Virginia Commonwealth University, JAYASIMHA ATULASIMHA, Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, SUPRIYO BANDYOPADHYAY, Department of Electrical and Computer Engineering, Virginia Commonwealth University — We report a non-volatile converse magneto-electric effect in elliptical Galfenol (FeGa) nanomagnets of ~300 nm lateral dimensions and ~10nm thickness delineated on a PMN-PT substrate. This effect can be harnessed for energy-efficient non-volatile memory. The nanomagnets are fabricated with e-beam lithography and sputtering. Their major axes are aligned parallel to the direction in which the substrate is poled and they are magnetized in this direction with a magnetic field. An electric field in the opposite direction generates compressive strain in the piezoelectric substrate which is partially transferred to the nanomagnets and rotates their magnetization away from the major axes to metastable orientations. There they remain after the field is removed, resulting in non- volatility. Reversing the electric field generates tensile strain which returns the magnetization to the original state. The two states can encode two binary bits which can be written using the correct voltage polarity, resulting in non-toggle behavior. Scaled memory fashioned on this effect can exhibit write energy dissipation of only ~2 aJ.

1Work is supported by NSF under ECCS 1124714 and CCF- 1216614. Sputtering was carried out at NIST Gaithersburg.
11:39AM S6.00003 Giant magnetoelastic effect in thin magnetic films utilizing inter-ferroelectric transitions. PETER FINKEL, MARGO STARUCH, US Naval Research Laboratory — There has recently been much interest to multiferroic magnetoelastic composites based on relaxor ferroelectric single crystals as potential candidates for devices such as magnetic field sensors, energy harvesters, or transducers. Large magnetoelastic coupling coefficient is prerequisite for superior device performance in a broad range of frequencies and functioning conditions. In magnetoelastic heterostructures based on ternary relaxors Pb(In$_{1/2}$Nb$_{1/2}$)$_2$O$_3$-Pb(Mg$_{1/3}$Nb$_{2/3}$)$_2$O$_5$-PtTiO$_3$ (PIN-PMN-PT) crystal better operational range and temperature stability as compared to binary relaxors can be achieved. Giant linear converse magnetoelastic coupling up to $2 \times 10^{-6}$ m$^{-1}$ were observed in heterostructural composites with multilayered FeCo/Ag deposited on (011) PIN-PMN-PT crystals. Further enhancement of magnetoelastic coupling is demonstrated by utilizing inter-ferroelastic rhombohedral – orthorhombic phase transitions in PIN-PMN-PT. Mechanical clamping was a precondition to utilize this inter-ferroelastic transition mode to bring the crystal to a point just below its transformation threshold when very small perturbations at the input will cause large swings at the output generating a sharp uniaxial increase in strain (0.5 %) and polarization change, giving rise to nonlinear effects. Details of these results and their implications will be presented.

1 Giant magnetoelastic effect in thin magnetic films utilizing inter-ferroelectric transitions

11:51AM S6.00004 Exploring Strain Induced Magnetization Effects in Metamagnetic Artificial Multiferroics using Polarized Neutron Reflectometry STEVEN BENNETT, ANDREAS HERKLOTZ, ANTHONY WONG, THOMAS WARD, VALERIA LAUTER, Oak Ridge National Laboratory — There is currently a strong drive to realize a controllable magnetic ordering transition for use in next generation spintronic based memory and computation devices. One proposed method to gain such control is the use of a changing strain in a thin film metamagnetic artificial multiferroic system. While basic concepts using electric field actuated piezoelectric strain have been recently demonstrated, there is very little understanding of the details of strains effect on such magnetic phase transitions. Using the depth sensitive method of polarized neutron reflectometry we have been able to probe the fine details of strains contribution to the metamagnetic transition in thin films of metamagnetic FeRh. Here we explore the effects of changing lattice strain as a function of depth using both a barium titanate substrate’s structural phase transitions and He ion implantation. These studies have discovered a remarkably large coupling between the systems strain state and the switching behavior across the magnetostructural metamagnetic transition. Cherifi, R. O. et al. Nat. Mater. 31, 345–351 (2014), Bennett, S. P. et al. Sci. Rep. 5, 9142 (2015), Bennett, S. P. et al. submitted (2015).

12:03PM S6.00005 Writing magnetic phase and domain structure in FeRh by controlling lattice symmetry with strain doping T. ZAC WARD, ANDREAS HERKLOTZ, Oak Ridge National Lab, ANTHONY WONG, UNIV. OF TENNESSEE, STEVEN BENNETT, VALERIA LAUTER, Oak Ridge National Lab — Low energy helium ion implantation is an effective approach to strain doping materials which allows one to expand the out-of-plane lattice parameter in epitaxial films without vacancy generation or electron/hole doping the system [1]. The ability to control crystal anisotropy and overcome Poisson’s drive to conserve volume can thus offer huge dividends in controlling magnetic properties due to magnetostrictive phenomena. We present recent studies on epitaxial FeRh films which demonstrate how controlling crystal symmetry in this important intermetallic material can be used to finely control magnetic properties. We find that the first order magneto-structural phase transition from antiferromagnetic to ferromagnetic can be directly controlled through single axis lattice expansion; this effectively allows us to dictate the transition temperature anywhere between 400K and 150K. Polarized Neutron Reflectometry (PNR) data and scanning Magneto-optic Kerr effect (MOKE) measurements will be presented which demonstrate that this phase control can be confined to a specific region of the film both in depth and/or lateral position. While this holds great promise for magnetocaloric applications, many possibilities remain for devising new functionalities and gaining a deeper understanding of material properties using this technique. [1] H.W. Guo, S. Dong, P.D. Rack, J.D. Budai, A.T. Wong, A. Herklotz, P.C. Snijders, E. Dagotto, and T.Z. Ward, Phys. Rev. Lett. 114, 256801 (2015). Funded by DOE-BES-MSED.

12:15PM S6.00006 Current Control of Magnetic Anisotropy via Strain in a CoFeB Waveguide KYONGMO AN, XIN MA, DEPARTMENT OF PHYSICS, University of Texas, Austin, Texas 78712, USA, CHI-FENG PAI, CORNHILL UNIVERSITY, Ithaca, New York 14853, USA, JUSANG YANG, KEVIN OLSSON, JAMES ERSKINE, ALLAN MACDONALD, DEPARTMENT OF PHYSICS, University of Texas, Austin, Texas 78712, USA, DANIEL RALPH, ROBERT BUHRMAN, CORNHILL UNIVERSITY, Ithaca, New York 14853, USA, XIAOQIN LI, DEPARTMENT OF PHYSICS, University of Texas, Austin, Texas 78712, USA — We demonstrate that in-plane charge current can effectively control the spin precession resonance in an Al$_2$O$_3$/CoFeB/Ta heterostructure. Brillouin Light Scattering (BLS) was used to detect the ferromagnetic resonance field under microwave excitation of the spin waves at fixed frequencies. Such control originates from the modified in-plane uniaxial magnetic anisotropy field $H_A$, which changes symmetrically with respect to the current direction. Numerical simulation suggests that the anisotropic stressintroduced by Joule heating plays an important role in controlling $H_A$. The results provide new insights into current manipulation of magnetic properties and have broad implications on spintronic devices.

1 This work is supported by SHINES, an Energy Frontier Research Center funded by the U.S. Department of Energy (DoE), Office of Science, Basic Energy Science (BES) under award DE-SC0012670.

12:27PM S6.00007 Incoherent stress-mediated magnetization reversal in shape anisotropic multiferroic nanomagnets DHIRITAM BHATTACHARYA, MD MAMUN AL-RASHID, VIMAL SAMPATH, NOEL D’SOUZA, SUPRIYO BANDYOPADHYAY, JAYASIMHA ATULASIMHA, VIRGINIA COMMONWEALTH UNIV — Strain mediated switching of multiferroic nanomagnets promises to be extremely energy efficient with dissipation per switching event of $1 \times 10^{-15}$ J. Most theoretical approaches to studying the switching dynamics use the macrospin approximation in which all the spins in the nanomagnet are assumed to rotate coherently. However, recent experiments show that while initial and final states are well approximated by this single domain assumption, intermediate states visited during the magnetization rotation process cannot be described by it. In such cases, an interplay between the exchange, magnetostatic and stress anisotropy energies can introduce incoherent magnetization dynamics. Hence, intermediate micromagnetic configurations such as vortex states can be stabilized, particularly in nanomagnets of larger dimensions. In this work, we present rigorous micromagnetic simulations to study the peculiarities of the incoherent switching process in the context of shape anisotropic nanomagnets subjected to stress. 1. Appl. Phys. Lett., 97, 173105, 2010. 2. Appl. Phys. Lett., 99, 063108, 2011. 3. Nanotechnology, 23, 105201, 2012.

1 This work is supported by NSF under grant CAREER grant CCF-1253370.
12:39PM S6.00008 Experimental manipulation of magnetic states of magnetostrictive nanomagnets using surface acoustic waves\textsuperscript{1}. VIMAL SAMPATH, DHRIITIMAN BHATTACHARYA, NOEL D’SOUZA, SUPRIO BANDYOPADHYAY, JAYASIMHA ATULASIMHA, Virginia Commonwealth University — The use of Surface Acoustic Waves (SAW) to assist magnetization switching in magnetostrictive nanomagnets has been theoretically studied \cite{1} and SAW-induced magnetization switching in micron size magnets has been experimentally demonstrated \cite{2}. We report recent experiments on manipulation of magnetic states of Co nanoscale magnets shaped like elliptical disks (~300 nm major axis, 240 nm minor axis and 10 nm thickness) delineated on bulk 128 Y-cut lithium niobate using SAW. Specifically, isolated nanomagnets that are initially in single domain states with magnetization pointing along the major axis of the ellipse are driven into a vortex state by SAW waves. However, SAW waves can trigger complete magnetization reversal in nanomagnets of moderate shape anisotropy that are dipole coupled to a highly shape anisotropic neighboring nanomagnet. \cite{1} A.K. Biswas, S. Bandyopadhyay & J. Atulasimha, Appl. Phys. Lett., 105, 072408 (2014). \cite{2} S. Davis, A. Baruth & S. Adenwalla, App. Phys. Lett., 97, 232507 (2010). The authors acknowledge the use of high voltage and high frequency pulse generator from Prof. Umit Ozgür’s lab and the help of Prof. Gary Atkinson in fabrication of the IDTs for generating the SAW.

\textsuperscript{1}We acknowledge SHF-Small CCF-1216614 and CAREER CCF-1253370 grants; and use of CNST Nanofab facility at NIST, Gaithersburg.

12:51PM S6.00009 Magnetic domain response to strain generated by focused surface acoustic waves \textsuperscript{1, 2}. UDAY SINGH, SHIREEN ADENWALLA, University of Nebraska - Lincoln — The effects of strain on magnetostrictive ferromagnets include changes in the magnetization, anisotropy and domain wall velocities. A ferromagnet (FM) on the surface of a surface acoustic wave (SAW) is subjected to periodic compressive and tensile strain that has resulted in coherent rotation of the magnetization, as well as inducing ferromagnetic resonance in FM films. We describe the response of magnetic domains in Co/Pt multilayers when subjected to the high strains generated by a focused SAW. Annular interdigital transducers (AIDT)patterned on LiNb\textsubscript{O} \textsubscript{3} form a SAW standing wave pattern with large strain amplitude at the focal center. Domains in (Co(3A/Pt(8A))\textsubscript{x5} with perpendicular magnetic anisotropy were observed using a MOKE microscope within this focal region. Controlled magnetic pulses steered a magnetic domain boundary to the large strain region after nucleation. Excitation of the AIDT resulted in a reversible change in the domain wall boundary in the high strain region. We attribute this to magnetic anisotropy changes in the presence of RF strain, which results in changes in the domain configuration to minimize the free energy. We will present results showing both slow and fast magnetization changes in Co/Pt occurring in the presence of high frequency strain. This work is supported by NSF (DMR 1406622) and Nebraska MRSEC (DMR-1420645).

\textsuperscript{1}This work is supported by NSF (DMR 1406622) and Nebraska MRSEC (DMR-1420645).

1:03PM S6.00010 Orientation dependences of surface morphologies and energies of iron-gallium alloys \textsuperscript{1}. MARCIO COSTA, HUI WANG, JUN HU, RUQIAN WU, Department of Physics and Astronomy, University of California, Irvine, SUOK-MIN NA, HYUNSUK CHUN, ALISON B FLATAU, Department of Aerospace Engineering, University of Maryland, College Park, MD. UNIVERSITY OF CALIFORNIA, IRVINE COLLABORATION, UNIVERSITY OF MARYLAND COLLABORATION — MagnetostRICTive Fe-Ga alloys (Galfenol) are very promising rare-earth free materials for applications in sensors, actuators, energy harvesters and spintronic devices. Investigation on surface energies of Galfenol based on density functional calculations (DFT) and contact angle measurements may provide fundamental understandings and guidance to further optimize the performance of Galfenol. DFT calculations predict that Ga-covered (110) surface of Galfenol is more stable in Ga-rich condition, while Ga-covered (001) surface of Galfenol surface become more favorable in Ga-poor condition. Moreover, a full Ga overlayer tends to form on top of Galfenol surfaces regardless their orientation, both in agreement with the experimental observation. Further studies on Ga segregation in the Fe bcc matrix demonstrate that the Fe-Ga separation is unlikely to occur since Ga diffusion toward the surface is effectively self-stopped once the Ga overlayers form on the facets.

\textsuperscript{1}This work was supported by the National Science Foundation through the SUSCHEM-Collaborative Research program (grant numbers: DMR- 1310494 at UCI and DMR-1310447 at UMD). Work at UCI was also supported by the ONR (grant number: N00014-13-1-O445).

1:15PM S6.00011 Fingerprinting Morphology of Magnetic Shape Memory Alloys Using First Order Reversal Curves (FORC) and Neutron Scattering \textsuperscript{1, 2}. IGOR V. ROSCHCHIN, Texas A&M Univ., PAVEL N. LAPA, Texas A&M Univ., Argonne Nat. Lab., KATHRYN L. KRYCKA, BRIAN B. MARANVILLE, CNR, NIST, JAMES A. MONROE, BRIAN E. FRANCO, IBRAHIM KARAMAN, Texas A&M Univ. — In Ni-Mn-In- and Ni-Mn-Sn-based alloys, two magnetic phases with ferromagnetic and antiferromagnetic exchange couplings between two nearest Mn atoms can coexist. Interaction between these phases results in exchange bias (EB). The EB field depends on the cluster sizes. Using the first order reversal curve (FORC) analysis of magnetization for Ni-Co-Mn-Sn and Ni-Co-Mn-In samples with different heat treatment, we can obtain information about cluster sizes of the structural phases in these alloys. This is especially important for polycrystalline alloy samples where dark-field images showing different phases are hard to obtain. Such a Ni-Co-Mn-Sn polycrystalline sample was characterized with small angle neutron scattering (SANS). Analyses of the scattering as a function of wavevector transfer in 50 Oe and 15 kOe applied field yield the average magnetic domain size of 21.2±0.02 at 300 K, in good agreement with our prediction. The temperature evolution of the domain size will be discussed. Using an off-specular reflectometer in transmission geometry, the same sample was measured at a field of 270 Oe and 5.15 kOe. The fit of the 270 Oe data yields grain sizes of approximately 0.11−0.12 \textmu m with polydispersions between 0.98 and 1.27.

\textsuperscript{1}Supported by Texas A&M University, US-DOE, and US NSF-DMR.

\textsuperscript{2}Supported by Texas A&M University, US-DOE, and US NSF-DMR.

1:27PM S6.00012 Detecting an in-plane rotation of magnetization in GdFeCo films \textsuperscript{1}. FARZANEH HOVEYDA, SERBAN SMADICI, University of Louisville — It is often important to distinguish between magnetization reversal by coherent rotation in different planes and domain wall motion. Magnetization curves were measured at different temperatures with magneto-optical Kerr Effect in longitudinal (L-MOKE) and polar (P-MOKE) geometries on sputter-deposited Gd\textsubscript{0.7}Fe\textsubscript{0.3}Co\textsubscript{1−x−y} (GFC) films of variable thickness. Depending on the probed region, the L-MOKE signal measured with decreasing external field \textit{H}_{\text{ext}} was found to be lower than the signal observed with increasing \textit{H}_{\text{ext}} (negative remanence magnetization). We show that this is due to a contribution to the signal of \textit{M}_{\perp}, the magnetization component perpendicular to the scattering plane. This identifies the type of reversal in these GFC films as in-plane coherent rotation of magnetization. \textit{M}_{\perp} is also proportional to the torque. Azimuthal measurements on Co\textsubscript{2}FeAl samples showed a regular variation of the MOKE signal, in one possible application of these observations to torque measurements.

\textsuperscript{1}Work supported by the University of Louisville Research Foundation.
we will discuss different roles of DMI exerted on the two Mn thin films. Experimental results revealed that the spin spiral structure of DL Mn is homochiral but right-handed, which is opposite to that of ML Mn. In the presentation, however, the chirality and its driving interaction have not been revealed yet. Here in this study, we have investigated the chirality of DL Mn by SP-STM. Our recent study revealed that double layer (DL) Mn thin films on W(110) show a conical spin spiral structure whose propagation direction is along [001]. Spin-polarized scanning tunneling microscopy (SP-STM) and theoretical analysis based on density functional calculation revealed left-handed chirality of the structure and concluded that it is driven by DMI.

The first surface spin spiral structures, show a cycloidal spin spiral structure propagating along the [1-10] axis. Because of DMI, magnetic thin films formed on a heavy-elemental substrate such as W often exhibit peculiar spin spiral structures whose chirality is fixed and determined by the polarity of DMI. Investigating the chirality of spin structures is thus important to reveal the formation mechanism of spin structures and, more specifically, to determine whether DMI plays a decisive role on it. Monolayer (ML) Mn thin films formed on W(110), the first surface spin spiral structures, show a cycloidal spin spiral structure propagating along the [1-10] axis. Spin-polarized scanning tunneling microscopy (SP-STM) and theoretical analysis based on density functional calculation revealed left-handed chirality of the structure and concluded that it is driven by DMI.
11:39AM S11.00003 Determination of interfacial Dzyaloshinskii-Moriya exchange interaction from static domain size imaging , PARNIKA AGRAWAL, IVAN LEMESH, MIT, SARAH SCHLOTTER, Harvard University, GEOFFREY BEACH, MIT — Dzyaloshinskii-Moriya interaction (DMI) has been identified [1-2] as a necessary ingredient for the formation of chiral spin structures such as skyrmions and Néel domain walls in perpendicularly magnetized thin films. Various simulation and experimental studies have tried to quantify DMI from domain wall [2] and skyrmion [3-4] motion with applied currents and magnetic fields. Here, a means to quantify DMI in multilayer films using only static magnetic characterizations is proposed. Static domain structure is observed using magnetic force microscopy (MFM) in multilayer stacks of [Pt(2.5-7.5nm)/CoFeB(0.8nm)/MgO(1.5nm)]$_{15}$ where the thickness $t_{Pt}$ of the Pt layer is systematically varied from 2.5 nm to 7.5 nm. A variation of domain size from 300 nm to 70 nm is seen in the labyrinthine demagnetized state as $t_{Pt}$ is decreased. It is shown that the domain size as a function of $t_{Pt}$ can be well-fitted analytically by a model in which the domain wall energy is the sole free parameter. Additional measurements of magnetic anisotropy of the film reveal the significant contribution of interfacial DMI ("1.4 mJ/m$^2") to the domain wall energy. Ref: 1. Fert et al., Nat. Nanotech., 8, 152-156 (2013); 2. S. Emori et al., Nature Materials 12,611–616 (2013); 3. S. Woo et al., arXiv:1502.07376; 4.W. Jiang et al., arXiv:1502.08028v1

11:51AM S11.00004 Interface-induced skyrmions in magnetic films and multilayers, ALBERT FERT, CNRS/THALES and Université Paris Saclay, Palaiseau, France — The talk is on individual skyrmions induced by interface Dzyaloshinskii-Moriya Interactions (DMI) in thin magnetic films or multilayers. I will present:

1. Ab-initio calculations of the characteristic features of interface DMI [1]: extension of the DMI away from the interface in the magnetic film, thickness dependence, influence of the existence of proximity-induced magnetism in neighbor layers, influence of interface roughness, perspective with new materials.

2. Experimental results on small skyrmions at room temperature in (Ir/Co/Pt)$_{10}$ multilayers [2].

3. Towards applied devices: micromagnetic simulations of the nucleation and current-induced motion of skyrmions [3].


1Work supported by the Department of Energy, Office of Science, Basic Energy Science, Materials Sciences and Engineering Division.

12:39PM S11.00006 Skyrmions in thin-film multilayers with interfacially-induced Dzyaloshinskii-Moriya interaction observed by MFM , MIRKO BACANI, MIGUEL A. MARIONI, JOHANNES SCHWENK, SARA ROMER, XUE ZHAO, ALEXANDRE GUILLER, Empa, Duebendorf, Switzerland, HANS J. HUG, Empa, Duebendorf, Switzerland and Department of Physics, University of Basel, Basel, Switzerland — By proper selection of interfaces in thin-film multilayers one can separately engineer the anisotropy, magnetization and Dzyaloshinskii-Moriya (DMI), which is useful in the design of skyrmion materials. We use high-sensitivity, high-resolution magnetic force microscopy (MFM) in various applied magnetic fields to image the micromagnetic structures in multilayers based on symmetric-interface stacks of Pt/Co/Pt and asymmetric ones of Pt/Co/Ir. The former have domain sizes of several microns, whereas the latter show considerably smaller domain sizes. These are (246±40) nm independently of the demagnetization process used. We attribute the lower domain size to a net DMI. The calculated DMI in the asymmetric case is too small to support a skyrmion phase, but isolated skyrmions can exist. MFM experiments reveal skyrmions with a diameter below 50 nm, when the field is reduced from positive saturation. In negative fields these skyrmions are either incorporated into expanding domains or burst into a larger domain. Local DMI constants estimated from the bursting fields agree well with the average DMI constant. Our work demonstrates that MFM can detect skyrmions in thin films, and can help accelerate research in this field.

12:51PM S11.00007 Engineering of the anisotropy and Dzyaloshinskii-Moriya interaction energies in Pt-Co and Pt-Co-Cu heterostructures, SARAH SCHLOTTER, Harvard University SEAS, GEOFFREY BEACH, Massachusetts Inst of Tech-MIT — It has previously been shown that perpendicular magnetic anisotropy is increased in Pt-Co-Pt structures by placing a Cu spacer between the top, diffuse Co-Pt interface. However, including a spacer layer increases interfacial asymmetry in the system: a prerequisite for a strong Dzyaloshinskii-Moriya interaction (DMI) which governs helical spin structures such as skyrmions and chiral domain walls. We show that the increased asymmetry significantly enhances DMI strength in Pt-Co-Cu/Pt heterostructures as compared to corresponding Pt-Co-Pt systems. We further show that one can control the characteristic length scales governing domain width by engineering the magnetostatic, anisotropy, and DMI energies in heavy-metal/ferromagnet heterostructures. These structures may provide insight into engineering the size of skyrmions in spintronic devices.


1:03PM S11.00008 Skyrmion bubble stability in thin films with strong Dzyaloshinskii-Moriya interaction , LUCAS CARETTA, UWE BAUER, ALEXANDRA CHURIKOVA, MAXWELL MANN, GEOFFREY BEACH, Massachusetts Inst of Tech-MIT — The Dzyaloshinskii-Moriya interaction (DMI) at heavy-metal/FM interfaces stabilizes chiral spin textures, such as magnetic skyrmions [1]. Magnetic skyrmions are applicable to energy efficient spintronics [2,3]. However, room temperature stability of skyrmion bubbles (SBs) has not been quantified experimentally. We show when the ratio of the DMI effective field to the perpendicular anisotropy field is large, expanding bubble domains leave behind fine-scale dendritic structure, consisting of coupled 360 degree domain walls (DW). Dendritic structures are manipulated to form stable SBs. We imaged SBs in Pt(3nm)/Co(0.9nm)/Gd(1nm)/GdOx(30nm) films using Kerr microscopy to characterize the stability of SBs. We show that the field stability of SBs is a strong function of the applied in-plane field. Increasing in-plane field reduces the annihilation threshold of the skyrmions. The SB annihilation field becomes deterministc at in-plane fields near the DMI effective field. Simulations show Bloch points are formed in the SB DW at high in-plane fields, leading to the deterministic collapse of the bubbles [1]. A. Fert et al., Nat. Nano., 8, 152-156 (2013) [2] S. Woo et al., arXiv:1502.07376 (2015) [3] A. Fert et al., arXiv.1502.08028v1
In a 5π microscopy, we quantify the amplitude and phase of local magnetic precession, which allows us to image the total driving field vector orientation. The skyrmion texture couples to the spin of the surface state electron with strength $\Delta_S$. In the hedgehog case, it is shown that the in-plane components cannot be disregarded and thus a realistic description for the skyrmion is required. Working in the micromagnetic framework, we derive a macrospin description for the skyrmion using the variational principle and then numerically solve for the bound states. It is shown that the existence and properties of these states as a function of skyrmion size, strongly depend on the skyrmion type. Both vortex and hedgehog skyrmions or anti-skyrmions can induce bound states with energies $|E| < \Delta_S$. For the hedgehog skyrmion case however, bound state appearance depends on the chirality. Finally, the probability densities in these states are computed and it is demonstrated that the electrons are localized throughout the skyrmion region.

1 Also affiliated with imec, Belgium
2 Also affiliated with imec, Belgium

Skyrmion-induced bound states in a superconductor

Skyrmion-induced bound states in magnets

Stability of skyrmion lattices and symmetries of Dzyaloshinskii-Moriya magnets

Increasing skyrmion lattice stability: theory and experiment

Enhanced stability of skyrmions in magnets with broken mirror symmetry

Thursday, March 17, 2016 11:15AM - 2:03PM
Session S18 GMAG DMP FIAP: Magnetic Thin Films

11:15AM S18.00001 Imaging of precessional phase variations in spin Hall devices using pico-second heat pulses
FENG GUO, JASON BARTELL, GREGORY FUCHS, Cornell University — We introduce a new approach of studying the spin Hall effect in patterned magnetic multilayers by imaging ferromagnetic resonance (FMR) precession phase. Using time-resolved anomalous Nernst effect (TRANE) microscopy, we quantify the amplitude and phase of local magnetic precession, which allows us to image the total driving field vector orientation. In a 5 μm wide channel, we observe a substantial variation of the driving field vector as a function of lateral position that we attribute to variations in the total Oersted field angle and the demagnetization field. Next, using the same device, we compare TRANE phase imaging measurements to all-electrical spin-transfer torque ferromagnetic resonance (STFMR) measurements that sense the spatially averaged precession phase. We find that spatial phase variations introduce a systematic error in the spin Hall efficiency measured using conventional STFMR analysis in our devices. These results underscore the importance of phase-sensitive dynamic imaging to augment all-electrical FMR techniques in quantifying the spin Hall efficiencies of devices.

1 S.S.P. and A.V.B are supported by US DOE BES E304. S.N. is supported by the Grant-in-Aid for Research Activity Start-up (No. 15H06858).

2 We acknowledge support by the National Science Foundation by the NSF Graduate Research Fellowship Program Grant No. DGE-1343012 (JR), by an NSF grant DMR-1410364 (MR), and by the CEM, an NSF MRSEC, under grant DMR-1420451.
In this talk, I will describe the dynamical role of disorder in a large and flat thin film of Cu$_2$OSeO$_3$, exhibiting a skyrmion phase in an insulating material. Through calculation of the Fourier transform of space-displaced time-displaced correlation functions, vibrational and magnetic excitations have been studied. The application of an external magnetic field up to 10-T has now been included and has been shown to increase the characteristic frequencies of the single-spin-wave excitations. Two-spin-wave interactions have also been investigated.

This work was supported by NSFC grant No.11274240 and 51471119

Parity-Time Symmetry Breaking in Non-Equilibrium Magnetic Systems

ALEXEY GALDA, VALERII VINOKUR, Argonne National Laboratory — We introduce generalized non-Hermitian Hamiltonian approach for description of out-of-equilibrium phase transitions in the exemplary context of dissipative non-equilibrium dynamics of an open quantum spin system. The imaginary part of the proposed Hamiltonian describes effects of damping and the applied Slonczewski spin-transfer torque (STT). In the classical limit, our approach reproduces Landau-Lifshitz-Slonczewski dynamics of a large macrospin. We reveal the STT-driven parity-time (PT) symmetry-breaking transition corresponding to a phase transition from precessional magnetization dynamics to controlled switching. Micromagnetic simulations for nanoscale ferromagnetic disks demonstrate the predicted effect. Our findings break ground for a general quantitative description of out-of-equilibrium phase transitions.

Unveiling magnetic Hysteresis

PAULA MELLADO, ANDRES CONCHA, DAVID AGUAYO, Adolfo Ibanez University — Hysteresis manifests as the lack of retraceability of the magnetization curve in magnetic systems. It has been associated with rotation of magnetization and changes of magnetic domains. However, up to date there has been no realization that allows to separate these coupled mechanisms. We introduce a minimal magnetic system where hysteresis is realized in a simple and minimal fashion. The basic units are a few U(1) ferromagnetic altitudinal rotors placed along a one dimensional chain. They exhibit a dissipative dynamics, interacting via magnetic coupling among them and via Zeeman interaction with the external magnetic field. The system displays a hysteretic behavior starting with N=2 rotors which remains qualitatively invariant as more magnets are added to the chain. We explain this irreversibility by using a model that includes Coulombic interactions between magnetic charges located at the ends of the magnets, zeeman coupling and viscous dissipation. We show that interactions between the unit components is the key element responsible for hysteresis and find that the ability to perceive hysteresis, depends on how the time frequencies of damping and interactions inherent to the system compare with the time frequency set by the external field ramping rate.

Combined Molecular Dynamics-Spin Dynamics Simulation of α-Iron in an External Magnetic Field

MARK MUDRICK, DILINA PERERA, DAVID P. LANDAU, Univ of Georgia — Using an atomistic model that treats both translational and spin degrees of freedom, combined molecular and spin dynamics simulations have been performed to study dynamic properties of α-iron. Atomic interactions are described by an empirical many-body potential while spin-spin interactions are handled with a Heisenberg-like Hamiltonian with a coordinate dependent exchange interaction. Each of these interactions are parameterized by first-principles calculations. These simulations numerically solve equations of motion using an algorithm based on the second-order Suzuki-Trotter decomposition for the time evolution operator. Through calculation of the Fourier transform of space-displaced time-displaced correlation functions, vibrational and magnetic excitations have been studied. The application of an external magnetic field up to 10-T has now been included and has been shown to increase the characteristic frequencies of the single-spin-wave excitations. Two-spin-wave interactions have also been investigated.

Magnetic dynamics studied by high-resolution electron spectroscopy and time-resolved electron microscopy

RAJESWARI JAYARAMAN, EPFL - Lausanne — Future information technology requires an increased magnetically encoded data density and novel electromagnetic modes of data transfer. While to date magnetic properties are observed and characterized mostly statically, the need emerges to monitor and capture their fast dynamics. In this talk, I will focus on the spin dynamics i.e. spin wave excitations and the dynamics of a new topological distribution of spins termed “skyrmions”. Wave packets of spin waves offer the unique capability to transport a quantum bit, the spin, without the transport of charge or mass. Here, large wave-vector spin waves are of particular interest as they admit spin localization within a few nanometers. By using our recently developed electron energy loss spectrometer, we could study such spin waves in ultrathin films with an unprecedented energy resolution of 4 meV. By virtue of the finite penetration depth of low energy electrons, spin waves localized at interfaces between a substrate and a thin capping layer can be been studied yielding information about the exchange coupling between atoms at the interface. The quantization of spin waves with wave vectors perpendicular to the film gives rise to standing modes to which EELS has likewise access. Such studies when carried out as function of the film thickness again yield information on the layer dependence of the exchange coupling. Magnetic skyrmions are promising candidates as information carriers in logic or storage devices. Currently, little is known about the influence of disorder, defects, or external stimuli on the spatial distribution and temporal evolution of the skyrmion lattice. In this talk, I will describe the dynamical role of disorder in a large and flat thin film of Cu$_2$OSeO$_3$, exhibiting a skyrmion phase in an insulating material. We image up to 70,000 skyrmions by means of cryo-Lorentz Transmission Electron Microscopy as a function of the applied magnetic field. In the skyrmion phase, dislocations are shown to cause the emergence and switching between domains with different lattice orientations, and the temporal fluctuation of these domains is filmed. These observations pave the way to the control of a large 2D array of skyrmions.
Longitudinal line oscillations are excited using a pulsed laser. The laser pulse duration is typically 0.5 to 1 ns, and the repetition rate can range from 1 to 100 Hz. The laser pulse energy is in the range of 1-10 mJ, with a wavelength of 1064 nm. The laser beam is incident on the sample at an angle, typically 45° to 75°, with respect to the magnetic field direction. The laser light is absorbed in the sample, leading to the generation of heat in the form of a train of ultrafast thermal pulses. These thermal pulses create local temperature gradients in the sample, which in turn induce stress waves. The stress waves propagate through the material, exciting the magnetic domains and leading to the generation of longitudinal magnetic oscillations.

**References**


Thursday, March 17, 2016 11:15AM - 2:15PM –
Session S19 GMAG DMP FIAP: Cooperative Phenomena: Spin-Orbit Coupling and Antiferromagnetism 318 - Ian Gilbert, NIST

11:15AM S19.00001 Electron correlation, spin-orbit coupling, intersite effects and the metal-insulator transition in pyrochlore iridates1, RUNZHI WANG, ARA GO, ANDREW MILLIS, Columbia University — We perform density functional theory (DFT) plus single-site and cluster dynamical mean-field theory (DMFT/CDMFT) calculations to study the metal-insulator transition in the pyrochlore iridides Lu$_2$Ir$_2$O$_7$, Y$_2$Ir$_2$O$_7$ and Eu$_2$Ir$_2$O$_7$. The calculations include spin-orbit coupling. Single-site DMFT calculations indicate that the Lu compound is much more insulating than the Y or Eu materials but predict that the critical interaction strength is almost exactly the same for the Eu and Y compounds, although experimentally the metal-insulator transition temperatures are quite different. We further carry out the cluster DMFT (CDMFT) and observe much larger differences, consistent with experiments, demonstrating the crucial role played by spatial correlations.

1This work is supported by NSF DM 1308236

11:27AM S19.00002 Magnetization and transport properties of single RPd$_2$P$_2$ (R=Y, La-Nd, Sm-Ho, Yb)1, GIL DRACHUCK, ANNA BOEHMER, SERGEY L. BUD’KO, PAUL CANFIELD, Iowa State University/Ames Lab — Single crystals of RPd$_2$P$_2$ (R=Y, La-Nd, Sm-Ho, Yb) were grown using a self-flux method and were characterized by room-temperature powder X-ray diffraction, anisotropic temperature and field dependent magnetization and temperature dependent in-plane resistivity. Anisotropic magnetic properties, arising mostly from crystal electric field (CEF) effects, were observed for most magnetic rare earths. The experimentally estimated CEF parameters B$_{2g}^2$ were calculated from the anisotropic paramagnetic $\theta_{ab}$ and $\theta_{c}$ values. Ordering temperatures, as well as the polycrystalline averaged paramagnetic Curie-Weiss temperature, $\theta_{ave}$, were extracted from magnetization and resistivity measurements.

1Work done at Ames Laboratory was supported by US Department of Energy, Basic Energy Sciences, Division of Materials Sciences and Engineering under Contract NO. DE-AC02-07CH11358.

11:39AM S19.00003 Dynamic scaling invariance at low temperatures, VLADIMIR UDODOV, Katanov Khakas State University, KATANOV KHAKAS STATE UNIVERSITY TEAM — Using thermodynamic arguments we prove that the conventional consequences of the dynamic scale hypothesis change their character in the limit as the critical temperature $T_c$ approaches zero. In particularly, for liquid helium-4, the critical exponent $\alpha$ associated with the heat capacity ($\alpha < 0$) and other exponents related by the following new relation

$$\nu(z - 1) = (1 + S_I - \alpha)/6, \quad T_C = T_\lambda \geq 0,$$

$$S_I = \left(\frac{T_C}{T}\right)^n, \quad T \geq T_C,$$

where $n$ is a positive constant [1] and $z$ is the dynamic critical exponent, $\nu$ -- the critical exponent of the correlation length. It is important that now the exponent $z$ depends on $T$ and $T_\lambda$. If $T_\lambda = 0$ and $T > 0$, then the $S_I$-function [1] is zero and Eq. (1) becomes

$$\nu(z - 1) = (1 - \alpha)/6, \quad T_C = 0, \quad (T > 0, \quad \alpha < 0).$$


11:51AM S19.00004 Application of Novel Molecular Field Theory to Helical Antiferromagnetic Ordering in EuCo$_2$P$_2$*, D. C. JOHNSTON, N. S. SANGEETHA, Iowa State Univ — A formulation of Weiss molecular field theory (MFT) was recently advanced for antiferromagnetic (AFM) systems of identical crystallographically-equivalent local moments interacting by Heisenberg exchange that does not utilize the concept of magnetic sublattices.1 This formulation has the attractive feature that the magnetic and thermal properties in magnetic fields $H \to 0$ depend only on the interactions of a representative spin with its neighbors, and thus allows the properties of collinear and coplanar noncollinear AFM structures to be understood and modeled on the same footing. Neutron diffraction measurements showed that EuCo$_2$P$_2$ with the bct ThCr$_2$Si$_2$-type structure undergoes an AFM transition to a coplanar noncollinear c-axis helical AFM structure below the ordering temperature $T_N = 66.5$ K.2 Here we report the properties and apply our MFT to model the anisotropic magnetic susceptibility of single-crystal EuCo$_2$P$_2$ below $T_N$.


*This work was supported in part by the National Science Foundation.

12:03PM S19.00005 Investigation of Quantum Phase Transitions of Spin-3/2 AKLT Systems On the Hexagonal Lattice via the Tensor-Network Method1, TZU-CHIEH WEI, CHING-YU HUANG, C.N. Yang Institute for Theoretical Physics, Stony Brook University — The spin-3/2 Affleck-Kennedy-Lieb-Tasaki (AKLT) state on the hexagonal lattice is an example of valence-bond solid state (VBSS), which is recently shown to provide resource for quantum computation and is also a nontrivial symmetry protected topologically ordered state if the translation invariance is imposed in addition to the rotation symmetry. Niggemann et al. previously studied a deformation of the AKLT model and derived a one-parameter family of ground states (parametrized by $a$) that are deformed from the AKLT point ($a = \sqrt{3}$). By mapping to a free-fermion eight-vertex model, they identified a VBS to Néel transition at $a_{c1} \approx 2.5425$. We employ the tensor network method to directly compute the Néel order parameter and obtain results that agree with theirs. We also study the regime where the deformation parameter $a$ decreases close to zero. We find that there is a transition at $a_{c1} \approx 0.58$ to an XY phase, which is characterized by algebraically decaying correlations, rotation invariance of spins in the x-y plane and the induced magnetization being aligned with the direction of the extend field.

1This work was supported in part by the National Science Foundation.
12:15PM S19.00006 Inelastic neutron scattering study and magnetic excitations on the low-dimensional antiferromagnet \( \alpha - \text{Cu}_2\text{V}_2\text{O}_6 \). GANATEE GITGEATPONG, Mahidol University; YANG ZHAO, University of Maryland, YIMING QIU, NIST Center for Neutron Research, KITTTIWIT MATAN, Mahidol University — Magnetic excitations of the low-dimensional antiferromagnet \( \alpha - \text{Cu}_2\text{V}_2\text{O}_6 \) have been investigated using inelastic neutron scattering. The study reveals unusual commensurate splitting of magnetic excitation branches centered at a wave vector \((0, \pm \delta, 0)\) with \(\delta = 0.25\) away from a magnetic zone center, where a magnetic Bragg peak is observed. The energy gap of 0.75 meV at \((0, 0, 0)\) was found to decrease as a function of temperature and the magnetic excitations become diffusive and disappear above 35 K coincident with \(T_N = 33.4\) K. A recent experiment at the Multi Axis Crystal Spectrometer, MACS, to map the excitations over a large momentum space clearly shows the splitting of the dispersion at most of the allowed magnetic reflections. This commensurate splitting of the spin-wave-type excitations without the magnetic Bragg reflections at the same commensurate wave vectors has not yet been previously observed and remains unexplained. In the presentation, the experimental data will be shown and the possible explanation will also be discussed.

12:27PM S19.00007 Tunable Collective Modes in the Dilute Ising Magnet LiHo\(_{0.045}\)Y\(_{0.955}\)F\(_4\). D.M. SILEVITCH, California Institute of Technology, G. AEPPLI, Paul Scherrer Institute, T.F. ROSENBAUM, California Institute of Technology — Collections of quantum mechanical spins with dipolar interactions exhibit a complex set of states and excitations due to the long range and alternating sign of the dipolar potential. We use nonlinear ac magnetic susceptibility on the dilute dipole Ising magnet LiHo\(_{0.045}\)Y\(_{0.955}\)F\(_4\) to study the behavior of coupled clusters of spins. Pump-probe spectroscopy excites Fano resonance behavior between coherent, isolated spin clusters and a background spin bath. The evolution of these clusters exhibits universal behavior as a function of several different tuning parameters such as static transverse field, ac pump field, and thermal connectivity to a heat reservoir. We discuss our results within the framework of many-body localization.

12:39PM S19.00008 Physical properties of \(R\text{Mg}_2\text{Cu}_9\) \((R = \text{Y, Ce-Nd, Gd-Dy})\). TAI KONG, SERGEY BUD’KO, PAUL CANFIELD, Ames Laboratory/Iowa State University — \(R\text{Mg}_2\text{Cu}_9\) is a family of hexagonal compounds with a single rare earth site that has a \(6\text{m}2\) local symmetry. In this talk, magnetic, electric transport and specific heat data measured on single crystals of \(R\text{Mg}_2\text{Cu}_9\) synthesized using Ta crucible will be presented and discussed. Due to a strong CEF effect, all local moment bearing members (except for isotropic GdMg\(_2\text{Cu}_9\)) in the present study show a higher magnetic susceptibility when external field is applied along the ab-plane than along the c-axis. For \(R = \text{Ce, Nd, Gd-Dy}\), the compounds order antiferromagnetically above 2 K. The ordering temperature deviates from de Gennes scaling with GdMg\(_2\text{Cu}_9\) ordering at a lower temperature than TbMg\(_2\text{Cu}_9\). PrMg\(_2\text{Cu}_9\) does not order magnetically down to 2 K and might have a singlet ground state. This series of compounds offer an opportunity to study in-plane anisotropy of rare earth in a hexagonal CEF configuration, following our previous work on in-plane 4-state clock model in a tetragonal system, for example: HoNi\(_2\)B\(_2\)C (P.C. Canfield et al. PRB 55, 970) and DyAgSb\(_2\) (K.D. Myers et al. PRB 59, 1121).

1This work is supported by the US DOE, Basic Energy Sciences under Contract No. DE-AC02-07CH11358

12:51PM S19.00009 Multiplicative logarithmic corrections to quantum criticality in three-dimensional dimerized antiferromagnets. YANQI QIN, Institute of Physics, Chinese Academy of Sci (CAS), BRUCE NORMAND, Department of Physics, Renmin University of China, Beijing 100872, China, ANDERS SANDVIK, Department of Physics, Boston University, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA, ZI YANG MENG, Institute of Physics, Chinese Academy of Sci (CAS) — We investigate the quantum phase transition in an \(S=1/2\) dimerized Heisenberg antiferromagnet in three spatial dimensions. By means of quantum Monte Carlo simulations and finite-size scaling analyses, we generalize and improve existing results for the exact quantum critical point. The magnetically ordered dimer-singlet phase and the Neel phase. This transition breaks O(3) symmetry with N=3 in D=3+1 dimensions. This is the upper critical dimension, where multiplicative logarithmic corrections to the leading mean-field critical point are expected; we extract these corrections, establishing their precise forms for both the zero-temperature Neel phase and the quantum critical point.

This work is supported by the Gordon and Betty Moore Foundation GBMF4416 and U.S. DOE, Office of Science, BES, Materials Science and Engineering Division

1:03PM S19.00010 Magnon-induced nonanalyticities in thermodynamic and transport properties of quantum ferromagnets. SRIPOROONA BHARADWAJ, DIETRICH BELITZ, Department of Physics and Institute of Theoretical Science, University of Oregon, Eugene, OR 97403. THEODORE R. KIRKPATRICK, Institute for Physical Science and Technology, and Department of Physics, University of Maryland, College Park, MD 20742 — Soft modes and their effects on thermodynamic and transport properties are of great interest. An example of a nonanalyticity induced by Goldstone modes is the divergence of the longitudinal susceptibility, \(\chi_L(k) \sim 1/k^{1.4} \cdot \text{meV} \), in a classical isotropic Heisenberg ferromagnet in \(2 < d < 4\) dimensions everywhere in the ordered phase. Here we investigate the fate of this nonanalyticity in a quantum ferromagnet. Power counting at \(T = 0\) suggests a weaker singularity, \(\chi_L(k) \sim k^{-1} \cdot \text{meV} \), due to the additional frequency integration. We find that this term has a zero prefactor due to spin conservation. Consistent with this, a corresponding term in an antiferromagnet has a nonzero prefactor. A small but nonzero temperature restores the nonanalyticity in a ferromagnet, and the prefactor vanishes linearly with \(T\). Similarly, magnetic impurities violate the spin conservation and lead to a nonanalytic term even at \(T = 0\). We explore all of these effects by means of nonlinear sigma models for both ferromagnets and antiferromagnets, and by an effective field theory for itinerant ferromagnets, and discuss the crossover from the classical result to the \(T = 0\) limit in detail.

1Supported by the National Science Foundation under Grants No. DMR-140410 and DMR-140449

1:15PM S19.00011 Magnetic phase transitions and magnetization reversal in MnRuP. P. LAMPEN-KELLEY, D. MANDRUS, University of Tennessee and Oak Ridge National Lab — The ternary phosphide MnRuP is an incommensurate antiferromagnetic metal crystallizing in the non-centrosymmetric \(\text{Fe}_2\text{P}\)-type crystal structure. Below the Neel transition at 250 K, MnRuP exhibits hysteretic anomalies in resistivity and magnetic susceptibility curves as the propagation vectors of the spiral spin structure change discontinuously across \(T_1 = 180\) K and \(T_2 = 100\) K. Temperature-dependent X-ray diffraction data indicate that the first-order spin reorientation occurs in the absence of a structural transition. A strong magnetization reversal (MR) effect is observed upon cooling the system through \(T_N\). Including logarithmic corrections, which agrees with our data and indicates exact linearity with \(T_N\), implying a complete decoupling of quantum and thermal fluctuations effects close to the quantum critical point. These logarithmic scaling forms have not previously identified or verified by unbiased numerical methods and we discuss their relevance to experimental studies of dimerized quantum antiferromagnets such as TlCuCl\(_9\). Ref.: arXiv:1506.06073

1This work is supported by the US DOE, Basic Energy Sciences under Contract No. DE-AC02-07CH11358

1:53PM S19.00012 From antiferromagnetism to spin glasses by tuning the magnetic moment in a rare earth doped Fe\(_3\)O\(_4\). YUAN QING, Institute of Physics, Chinese Academy of Sci, Beijing 100190, China, TAI KONG, SERGEY BUD’KO, PAUL CANFIELD, Ames Laboratory/Iowa State University — Fe\(_3\)O\(_4\) is an antiferromagnet, but the magnetic moment of the Fe ions is strongly reduced by the doping of Ce, Pr, Nd, Gd-Dy, the compounds order antiferromagnetically above 2 K. The ordering temperature deviates from de Gennes scaling with GdMg\(_2\text{Cu}_9\) ordering at a lower temperature than TbMg\(_2\text{Cu}_9\). PrMg\(_2\text{Cu}_9\) does not order magnetically down to 2 K and might have a singlet ground state. This series of compounds offer an opportunity to study in-plane anisotropy of rare earth in a hexagonal CEF configuration, following our previous work on in-plane 4-state clock model in a tetragonal system, for example: HoNi\(_2\)B\(_2\)C (P.C. Canfield et al. PRB 55, 970) and DyAgSb\(_2\) (K.D. Myers et al. PRB 59, 1121).

This work is supported by the US DOE, Basic Energy Sciences under Contract No. DE-AC02-07CH11358

1:39PM S19.00013 Lifshitz-type metal-to-insulator transition via strong relativistic renormalization in NaOsO$_3$, BONGJAE KIM, PEITAO LIU, ZEYNEP ERGÔNEÇ, University of Vienna, Faculty of Physics, Computational Materials Physics, ALESSANDRO TOSCHI, Institut für Festkörperphysik, Technische Universität Wien, SERGII KHMELEVSKYI, University of Vienna, Faculty of Physics, Computational Materials Physics and Department of Physics, Budapest University of Technology and Economics, CESARE FRANCHINI, University of Vienna, Faculty of Physics, Computational Materials Physics — Using ab initio band structure methods in the framework of density functional theory (DFT), we study the mechanism responsible for the metal-to-insulator transition (MIT) in the 5d oxide NaOsO$_3$ and reinterpret its previously proposed Slater nature. We show that spin-orbit coupling (SOC) causes a strong relativistic renormalization of the electronic correlation that moves the system to a weakly interacting itinerant limit, where the physics of itinerant magnetism prevails. This is the opposite effect as compared to the widely studied iridates, where SOC drives the formation of a relativistic Mott state. By mapping the magnetically constrained non-collinear DFT calculation using spin-fluctuation theory, we explain the MIT of the system in connection with the anomalies observed in the experimental resistivity curve. We show that the continuous MIT is associated to the progressive disappearance of electron and hole pockets in the Fermi surface, typical of a Lifshitz-type MIT, and is mediated by spin-fluctuations. We discuss the inconsistencies of a pure Slater interpretation and propose that NaOsO$_3$ should be classify as a magnetically-driven relativistic Lifshitz insulator.

1:51PM S19.00014 Spin-texture induced by oxygen vacancies in Strontium perovskites (001) surfaces: A theoretical comparison between SrTiO$_3$ and SrHfO$_3$, MAIA VERGNIOI, Donostia International Physics Center, ANDRS-CAMILO GARCA-CASTRO, ERIC BOUSQUET, Physique Thorique des Matriaux, Universite de Liege, B-4000 Sart-Tilman, Belgium, ALDO HUMBERTO ROMERO, Physics Department, West Virginia University, WV-26506-6315, Morgantown, USA — The electronic structure of SrTiO$_3$ and SrHfO$_3$ (001) surfaces with oxygen vacancies is studied by means of first-principles calculations. We reveal how oxygen vacancies within the first atomic layer of the SrTiO$_3$ surface (i) induce a large antiferromagnetic spin ordering, (ii) drive localized magnetic moments on the Ti-3$d$ orbitals close to the vacancies and (iii) form a two-dimensional electron gas localized within the first layers. The analysis of the spin-texture of this system exhibits a splitting of the energy bands according to the Zeeman interaction, lowering of the Ti-3$d_{yz}$ level in comparison with $d_{xz}$ and $d_{xy}$ and an in-plane precession moment in conventional systems, the impurity here develops a fractional local moment of 2/3. The concomitant Kondo effect has a high Kondo temperature $(T_K)$. Our theory explains these novel features including the origins of the fractional local moment and provides a recipe to use spin-orbit coupling($\lambda$) to enhance Kondo temperature $(T_K \sim \lambda^{2/3})$. These results will be useful in shedding light on a range of experiments, including those of magnetic impurities at oxide interfaces. Our predictions can also be directly tested in cold-atom systems where the spin-orbit coupling can be engendered via a uniform synthetic non-Abelian gauge field. In addition, this work opens up new directions of research in spin-orbit coupled Kondo lattice systems. Reference: arXiv:1509.07328

Thursday, March 17, 2016 2:30PM - 5:30PM —
Session V5 GMAG DMP: Frustrated Magnetism: Low Dimensional Magnets II 301 - Alexander Chernyshev, University of California, Irvine

2:03PM S19.00015 Quantum Impurities develop Fractional Local Moments in Spin-Orbit Coupled Systems, ADHIP AGARWALA, VIJAY B. SHENOY, Indian Institute of Science Bangalore — Systems with spin-orbit coupling have the potential to realize exotic quantum states which are interesting both from fundamental and technological perspectives. We investigate the new physics that arises when a correlated spin-1/2 quantum impurity hybridizes with a spin-orbit coupled Fermi system. The intriguing aspect uncovered is that, in contrast to unit local moment in conventional systems, the impurity here develops a fractional local moment of 2/3. The concomitant Kondo effect has a high Kondo temperature $(T_K)$. Our theory explains these novel features including the origins of the fractional local moment and provides a recipe to use spin-orbit coupling($\lambda$) to enhance Kondo temperature $(T_K \sim \lambda^{2/3})$. These results will be useful in shedding light on a range of experiments, including those of magnetic impurities at oxide interfaces. Our predictions can also be directly tested in cold-atom systems where the spin-orbit coupling can be engendered via a uniform synthetic non-Abelian gauge field. In addition, this work opens up new directions of research in spin-orbit coupled Kondo lattice systems. Reference: arXiv:1509.07328

2:30PM V5.00001 Chiral spin liquids in arrays of spin chains, RODRIGO PEREIRA, University of Sao Paulo — The chiral spin liquid proposed by Kalmeyer and Laughlin is a spin analogue of the fractional quantum Hall effect: it has gapped bulk quasiparticles, charge-neutral chiral edge modes and topological order in the ground state. Recently there has been unambiguous numerical evidence that the chiral spin liquid can be stabilized as the ground state of extended Heisenberg models on the kagome lattice. I will talk about an analytical approach to investigate the emergence and the properties of the chiral spin liquid phase in spatially anisotropic 2D lattices. The approach is inspired by coupled-wire constructions of quantum Hall states: starting from a quasi-1D system, we build towards the 2D limit by coupling Heisenberg chains with three-spin interactions that drive the chiral spin order. Using a renormalization group analysis, we show that the chiral spin liquid is more easily stabilized in the kagome lattice than in the triangular lattice. Moreover, using the conformal field theory that describes single chains, we explicitly construct the operators that create bulk quasiparticles and those that account for the topological degeneracy on the torus. I will also discuss possible extensions of this approach to construct more exotic quantum spin liquids.

3:06PM V5.00002 Entanglement Entropy and Topological Order in Resonating Valence-Bond Quantum Spin Liquids, JULIA WILDEBOER, National High Magnetic Field Laboratory, ALEXANDER SEIDEL, Washington University in St. Louis, ROGER MELKO, University of Waterloo, PI — On the triangular and kagome lattices, short-ranged resonating valence bond (RVB) wave functions can be sampled without the sign problem using a recently-developed Pfaffian Monte Carlo scheme [1]. In this talk [2], we present a study of the Renyi entanglement entropy in these wave functions using a replica-trick method [3]. Using various spatial bipartitions, including the Levin-Wen construction, our finite-size scaled Renyi entropy gives a topological contribution consistent with $\gamma \approx \ln(2)$, as expected for a gapped $Z_2$ quantum spin liquid. We prove that the mutual statistics are consistent with the spin code anyon model. Furthermore, we show that the mutual entropy is a topological invariant and can distinguish any ordered state from any other spin liquid. The results are independent of the RVB wave function and also apply to strongly correlated systems, such as the spin 1/2 chain. We demonstrate this by calculating the mutual entropy on various spatial bipartitions.

A numerical study of the energy gap of the quantum dimer-pentamer model, OWEN MYERS, University of Vermont, CHRIS HERDMAN, University of Waterloo — We present a study of the energy gap in the quantum dimer-pentamer model (QDPM) on the square lattice. This model is a generalization of the square lattice quantum dimer model (QDM), with a configuration space comprising fully-packed hard-core dimer coverings of the lattice, as well as configurations containing pentamers, where four dimers touch a vertex. Thus in the QDPM, the fully-packed, hard-core constraint of the QDM is relaxed such that the local dimer number at each vertex is fixed modulo 3; correspondingly, the local \( U(1) \) gauge symmetry of the QDM Hilbert space is reduced to a local \( Z_3 \) gauge symmetry in the QDPM. Previous work has demonstrated the disordered quantum liquid nature of the ground state of the QDPM at the Rothsarr-Kivelson point. Here we present a study of the energy gap above the ground state at the RK point, as computed via Monte Carlo from imaginary time correlations. To investigate the possibility of \( Z_3 \) topological order in this system, we study both the dimer density correlations as well as a \( Z_3 \) generalization of \( Z_2 \) vision correlations. Such vision correlations have previously been shown to display the nature of the low lying excitations in \( Z_2 \) topologically ordered QDMs.


Magnetic Frustration from Nonuniform \( g \)-factors, WEIGUO YIN, Brookhaven National Laboratory — Frustrated magnets are commonly known as materials in which localized magnetic moments, or spins, interact through competing exchange interactions that cannot be simultaneously satisfied. Here we show that even when the exchange interactions are fully cooperative, magnetic frustration can be induced by nonuniform Landé \( g \) factors, leading to a mutual interplay of typical ferromagnetic (FM) and antiferromagnetic (AF) features. This novel physics—exactly demonstrated in the one-dimensional Ising model with alternating \( g \) factors [1]—provides new insights into the puzzling phenomenon that the magnetic susceptibility of many AF or FM materials is FM-like at low temperature but AF-like at high temperature. Furthermore, we found a unique magnetic-field-driven quantum critical point at which one half of the spins are frozen into a complete order and the other half are fully disordered. The present theory joins the recent intensive search for frustrated magnets beyond the “standard model” of condensed matter physics. It could broaden our understanding and design of exotic magnetic behaviors such as spin ice, spin glass, and spin liquid that are essential to quantum computing, spintronics, and high-temperature superconductivity. [1] W.-G. Yin and C. R. Roth, arXiv:1510.00030.

Complex field-induced states in Linarite PbCuSO\(_4\)(OH)\(_2\) with a variety of high-order exotic SDW\(_p\) states, STEFAN SÜLLOW, TU Braunschweig, Braunschweig, Germany — Low-temperature neutron diffraction and NMR studies of field-induced phases in linarite are presented for magnetic fields \( H \parallel p \) axis. This way, we establish the magnetic phase diagram up to saturation. A two-step spin-flop transition is observed as well as a transition transforming a helical magnetic ground state into an unusual magnetic phase with sine-wave modulated moments \( ||H| > |J_1| \). The latter is governed by skew interchain couplings and shifted to the vicinity of the ferromagnetic critical point. It explains qualitatively the observation of a rich variety of exotic (for strongly correlated cuprate spin-1/2 Heisenberg systems) longitudinal collinear spin-density wave SDW\(_p\) states \(( \geq 2 \geq 9 \rangle \).

Large-scale simulations of spin-density-wave order in frustrated lattices, KIPTON BARROS, CRISTIAN BATISTA, Los Alamos National Laboratory, GIA-WEI CHERN, University of Virginia — We investigate spin-density-wave (SDW) phases within a generalized mean-field approximation. This approach incorporates the thermal fluctuations of SDW order and the development of short-range order above magnetic ordering temperatures \( T_c \). Using a new Langevin dynamics method, we study mesoscale structures associated with triple-Q SDW states that are induced by Fermi surface nesting in triangular and Kagome lattice Hubbard models. The core of our linear-scaling Langevin dynamics simulations is an efficient stochastic kernel polynomial method for computing the electron density matrix. We also investigate exotic phases above \( T_c \) arising from preformed magnetic moments.
4:54PM V5.00009 Electronic route to stabilize nanoscale spin textures in itinerant frustrated magnets, SANJEEV KUMAR, ISHEE Mohali, SAHINUR REJA, JEROEN VAN DEN BRINK, IFW Dresden, Germany — We unveil novel spin textures in an itinerant fermion model on a frustrated triangular lattice in the limit of low electronic density. Using hybrid Monte Carlo simulations on finite clusters we identify two type of nanoscale spin textures in the background of 120° order: (i) a planar ferromagnetic cluster, and (ii) a non-coplanar cluster with spins oriented perpendicular to the 120° plane. Both these textures lead to localization of the electronic wavefunctions and are in-turn stabilized by the concomitant charge modulations. The non-coplanar spin texture is accompanied by an unusual scalar chirality pattern. A well defined electric charge and magnetic moment associated with these textures allow for their easy manipulation by external electric and magnetic fields – a desirable feature for data storage. We identify a localization-delocalization behavior for electronic wavefunctions which is unique to frustrated magnets, and propose a general framework for stabilizing similar spin textures in spin-charged coupled systems.

5:06PM V5.00010 Stability and magnetization curve of spin-nematic phase slightly below saturation field, HIROAKI UEDA, Toyama Prefectural University, KEISUKE TOTSUKA, Yukawa Institute for Theoretical Physics — We discuss the magnetization process slightly below the saturation field in frustrated magnets. A condensation of bound magnons on the spin-polarized state induces either a spin nematic phase or a state with phase separation. The (effective) interaction between the bound magnon pairs not only is crucial to the stability of the nematic phase, but also determines the slope of the magnetization curve near saturation. We generally derive the expression of this interaction by using the perturbative scattering theory. By applying the method to coupled zigzag chains LiCuVO4, we find the positive pair-pair interaction implying the stability of the spin nematic phase. We also point out that the magnetization curve of LiCuVO4 is almost vertical (i.e. very large dM/dH) near the saturation exhibiting one-dimensional feature despite non-negligible interchain couplings.

5:18PM V5.00011 Density-matrix renormalization group study of triangular and square Hubbard models, SHIGETOSHI SOTA, RIKEN AICS, TAKAMI TOHYAMA, Tokyo University of Science, TOMONORI SHIRAKAWA, SEIJI YUNOKI, RIKEN — We perform large-scale density-matrix renormalization group calculations for two-dimensional Hubbard models with a triangular lattice and a square lattice [T. Tohyama, K. Tsutsui, M. Mori, S. Sota, and S. Yunoki, Phys. Rev. B 92, 014515 (2015)]. In the triangular Hubbard model, we determined a boundary between metal and insulator and a boundary between spin liquid and antiferromagnetic phases. The presence of spin-liquid phase is confirmed by spin-spin correlation function. In the square Hubbard model, we introduce a second-neighbor hopping interaction and calculate the dynamical spin correlation function to clarify the doping dependence of magnon excitations. We find a shift of a peak position toward higher energy in the electron-doped side, being consistent with recent resonant-inelastic x-ray scattering.

Thursday, March 17, 2016 2:30PM - 5:30PM – Session V6 GMAG DMP: Bulk Multiferroics 302 - Srinivasa Singamaneni, North Carolina State University

2:30PM V6.00001 Electric field control of magnetization dynamics in multiferroics, VETLE RINGGARD, IRYNA KULAGINA, JACOB LINDER, Department of Physics, Norwegian University of Science and Technology — Multiferroics with a strong magnetoelectric coupling hold great promise in spintronics because they enable magnetic control of the electric polarization as well as electric control of the magnetization. We take an analytical approach, using the Landau-Lifshitz-Gilbert equation to describe the dynamic state of the magnetization. In particular, we show that in insulating multiferroics which exhibit the inhomogeneous magnetoelectric effect there exists an electrically controlled magnon-induced torque that acts even on a homogeneous magnetization. Unlike the magnon-induced torques that arise from Dzyaloshinskii-Moriya interactions or in the proximity of a topological insulator, the strength and direction of this torque is tunable by the externally applied electric field.

2:42PM V6.00002 Understanding the spin-driven polarizations in BiMO3 (M =3d transition metals) multiferroics,1,2 SANTOSH KC, JUN HEE LEE, VALENTINO R. COOPER, Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA — Bismuth ferrite (BiFeO3), a promising multiferroic, stabilizes in a perovskite type rhombohedral crystal structure (space group R3c) at room temperature. Recently, it has been reported that in its ground state it possess a huge spin-driven polarization [1]. To probe the underlying mechanism of this large spin-phonon response, we examine these couplings within other Bi based 3d transition metal oxides BiM2O5 (M = Ti, V, Cr, Mn, Fe, Co, Ni) using density functional theory. Our results demonstrate that this large spin-driven polarization is a consequence of symmetry breaking due to competition between ferroelectric distortions and anti-ferrodistortive octahedral rotations. Furthermore, we find a strong dependence of these enhanced spin-driven polarizations on the crystal structure; with the rhombohedral phase having the largest spin-induced atomic distortions along [111]. These results give us significant insights into the magneto-electric coupling in these materials which is essential to the magnetic and electric field control of electric polarization and magnetization in multiferroic based devices. [1] J. H. Lee, and R. S. Fishman, http://arxiv.org/abs/1504.07106

1Research is supported by the US Department of Energy, Office of Science, Basic Energy Sciences, Materials Science and Engineering Division and the Office of Science Early Career Research Program (V.R.C) and used computational resources at NERSC.

2:54PM V6.00003 Spin Excitations and Phonon Anomaly in Quasi-1D Spiral Magnets CuBr2, YUAN LI, CHONG WANG, DAIWEI YU, LICHEN WANG, FA WANG, Peking University, China, KAZUKI IDA, KAZUYA KAMAZAWA, CROSS, Japan, SHUICHI WAKIMOTO, Japan Atomic Energy Agency — CuBr2 can be considered as a model quasi-one-dimensional (quasi-1D) spin-1/2 magnet, in which the frustrating ferromagnetic nearest-neighbor and antiferromagnetic next-nearest-neighbor exchange interactions give rise to a cycloidal magnetic order below TN = 73 K. The removal of inversion symmetry by the magnetic order also makes the material a type-II multiferroic system with a remarkably simple crystal structure. Using time-of-flight inelastic neutron scattering spectroscopy, we have determined the spin-wave as well as phonon spectra throughout the entire Brillouin zone. The spin-wave spectrum exhibits pronounced anisotropy and magnon damping, consistent with the materials quasi-1D nature and the non-collinear spin structure. The phonon spectrum exhibits dramatic discontinuities in the dispersion across the quasi-1D magnetic wave vector, indicative of strong magnetoelastic coupling and possibly of a spin-orbital texture that comes along with the spin correlations.
3:06PM V6.00004 Magnetic and Magnetoelectroelastic excitations in the Multiferroic CuBr2 determined by Raman, Infrared and Neutron Spectroscopy, CHONG WANG, DAIWEI YU, RONGYAN CHEN, XINYU DU, LIUCHEN WANG, XIAOQIANG LIU, ICQM, Peking University, KAZUKI IIDA, KAZUYA KAMAZAWA, Comprehensive Research Organization for Science and Society, Japan, SHUICHI WAKIMOTO, Japan Atomic Energy Agency, JI FENG, NAN LIN WANG, YUAN LI, ICQM, Peking University, YUAN LI GROUP AT ICQM PEKING UNIVERSITY TEAM, NANLIN WANG GROUP AT ICQM PEKING UNIVERSITY TEAM, JI FENG GROUP AT ICQM PEKING UNIVERSITY TEAM, COMPREHENSIVE RESEARCH ORGANIZATION FOR SCIENCE AND SOCIETY (CROSS) TEAM, SHUICHI WAKIMOTO COLLABORATION — Multiferroicity was recently discovered in anhydrous copper (II) bromide CuBr2 with a rather high transition temperature (TN = 73.5 K). By the combination of the Raman, Infrared (IR) and inelastic neutron scattering (INS) experiments, evidences for strong magneto-elastic coupling and magneto-elastic excitations are found in CuBr2. In the Raman spectra, a range of broad peaks were observed with the indications of magnetic and phonon origin at the same time. The inelastic neutron scattering experiment reveals that those nontrivial broad peaks originate from the sites of the phonons at incommensurate Q vectors that correspond to the spiral magnetic order. These results strongly suggest the existence of hybrid excitations that involve both the spin and lattice degrees of freedom, and render CuBr2 a promising platform for studying dynamic magneto-elastic coupling.

3:18PM V6.00005 Pressure effect on ferroelectric properties of multiferroics RMn2O5, (R = Gd, Tm), NARAYAN POUDEL, MELISSA GOOCH, BERND LORENZ, TC SUH and Department of Physics, University of Houston, CHING-WU CHU, TC SUH and Department of Physics, University of Houston and Lawrence Berkeley National Laboratory, JAEWOOK KIM, SANG-WOOK CHEONG, Rutgers Center for Emergent Materials and Department of Physics and Astronomy, Rutgers University — The pressure effect on the ferroelectric properties of the multiferroics GdMn2O5 and TmMn2O5 is studied up to 18.2 kbar. Unlike in RMn2O5 (R = Tb, Ho, Y), no significant change in polarization is observed in TmMn2O5 up to 16.6 kbar. However, a new ferroelectric phase is observed in GdMn2O5 above a critical pressure, Pc = 10 kbar at higher temperature. Our result indicates that pressure decouples the Gd moment from the Mn spin system and splits the ferroelectric phase. Thermal expansion data shows a large increase of the c axis at the ambient-pressure ferroelectric transition. The pressure-induced contraction of the c-axis parameter is found to be the cause for splitting of ferroelectric phase by decoupling of two spin systems above Pc. The pressure-temperature phase diagram is derived based on dielectric and ferroelectric properties.

3:30PM V6.00006 Doping-Tunable Ferrimagnetic Effect in a Polar Magnet Fe2Mo3O8, TAKASHI KURUMAJI, RIKEN, CEMS, SHINTARO ISHIWATA, Univ. Tokyo, YOSHINORI TAKURA, RIKEN, CEMS, SHINTARO ISHIWATA, Univesity of Tokyo. — The magnetoelectric (ME) effect, i.e., cross control of magnetization and electric polarization by an external magnetic field, may introduce a new design principle for novel spin devices. To enhance the ME signal, control of a phase competition has recently been revealed as a promising approach. Here, we report the successful chemical-doping control of the distinct ME phases in a polar magnet Fe2Mo3O8, in which an antiferromagnetic state is competing with a ferrimagnetic state. We demonstrate that Zn doping stabilizes the metamagnetic state to realize the spontaneous ferrimagnetic state and varies the ME coefficients from large negative to large positive values; for instance, the diagonal component of the ME coefficients under the magnetic field perpendicular to the polar axis varies from −142??ps/m to 107??ps/m by doping Zn from 12.5% to 50%. This remarkable doping control of the ME property originates from coexisting distinct ME mechanisms, which are selectively tunable by substituting one of the two distinct magnetic sites in the unit cell with nonmagnetic Zn.

3:42PM V6.00007 Field evolution of magnetism in multiferroic (ND4)2[FeCl5(D2O)]1, WEI TIAN, HUIBO CAO, JIAQIANG YAN, BRIAN SALES, JAIME FERNANDEZ-BACA, Oak Ridge National Laboratory — (NH4)2[FeCl5(H2O)] is a new organic multiferroic material that exhibits a very rich magnetic field versus temperature (B vs. T) phase diagram. The material undergoes two successive magnetic transitions at 7.3K and 6.8K, with the onset of ferroelectricity at 6.8K at B =0T. Applying magnetic field with B//a-axis or B//c-axis induces transitions to different ferroelectric phases, and the electric polarization direction rotates from P//a-axis at B =0T to P//c-axis at B =5T. Here we report single crystal neutron diffraction results studied with B//a-axis that elucidate the field evolution of magnetism associated with different ferroelectric phases in (NH4)2[FeCl5(H2O)].

3:54PM V6.00008 Mueller matrix ellipsometry studies of the optical phonons and crystal field excitations in multiferroic orthoferrites RFeO3 (R=Tb,Dy), V.A. MARTINEZ, T.N. STANISLAVCHUK, A.A. SIRENKO, Department of Physics, New Jersey Institute of Technology, Newark, New Jersey 07102, USA, A.P. LITVINCHUK, Texas Center for Superconductivity and Department of Physics, University of Houston, Texas 77204, USA, YAHONG WANG, CHEN-WEI CHEONG, Rutgers Center for Emergent Materials and Department of Physics and Astronomy, Rutgers University, Piscataway, New Jersey 08854, USA — Optical properties of multiferroic orthoferrites RFeO3 (R=Tb,Dy) bulk crystals have been studied in the far-infrared range from 50 to 1000 cm-1 and temperatures from 7 K to 300 K. Mueller matrix and rotating analyzer ellipsometry measurements were carried out at the U4IR beamline of the National Synchrotron Light Source at Brookhaven National Lab. Optical phonon spectra and crystal field excitations were measured for all three orthorhombic axes of RFeO3. In the experimental temperature dependencies of the phonon frequencies we found non-Grneisen behavior caused by the electron-phonon and spin-phonon interactions. We determined the symmetries and selection phonon spectra and crystal field excitations were measured for all three orthorhombic axes of RFeO3. In the experimental temperature dependencies of the phonon frequencies we found non-Grneisen behavior caused by the electron-phonon and spin-phonon interactions. We determined the symmetries and selection

4:06PM V6.00009 Unusual ferroelectricity induced by the Jahn-Teller effect: A case study on lacunar spinel compounds, KE XU, HONGJUN XUANG, Fudan Univ — The Jahn-Teller effect refers to the symmetry-lowering geometrical distortion in a crystal (or nonlinear molecule) due to the presence of a degenerate electronic state. Usually, the Jahn-Teller distortion is not polar. Recently, GaV3S8 with a lacunar spinel structure was found to undergo a Jahn-Teller distortion from a cubic to ferroelectric rhombohedral structure at TJT = 38 K. Here, we carry out a general group theory analysis to show how and when the Jahn-Teller effect gives rise to ferroelectricity. On the basis of this theory, we find that the ferroelectric Jahn-Teller distortion in GaV3S8 is due to the noncentrosymmetric nature of the parent phase and a strong electron-phonon interaction related to two low-energy T2 phonon modes. Interestingly, GaV3S8 is not only ferroelectric, but also ferromagnetic with a magnetic easy axis along the ferroelectric direction. This suggests that GaV3S8 is a multiferroic material in which an external electric field may control its magnetization direction. Our study not only explains the Jahn-Teller physics in GaV3S8, but also paves a way for searching and designing different ferroelectrics and multiferroics.
Proper multiferroic Ca$_3$Mn$_{0.9}$Ti$_{0.1}$O$_7$, FENG YE, Oak Ridge National Lab, JINCHEN WANG, Remmin University of China, JAIME FERNANDEZ-BACA, ANTONIO DOS SANTOS, Oak Ridge National Lab, BIN GAO, SANG-WOOK CHEONG, Rutgers University — A novel microscopic mechanism has been proposed to search for ferroelectric material for realistic application. The instability of the polar phonon mode is driven by the simultaneous condensation of two nonpolar lattice modes associated with oxygen octahedral rotation and tilt modes, and is responsible for the polar symmetry observed in the Ruddlesden-Popper compounds. We have used single crystal neutron diffraction to investigate the temperature and pressure dependence of these oxygen octahedral distortions in Ca$_3$Mn$_{0.9}$Ti$_{0.1}$O$_7$ which has a structural transition at 365 K and antiferromagnetic order at 120 K. We observed a strong interplay between magnetism and the local oxygen distortion near the magnetic transition. The control of the magnetism through octahedral rotation is also discussed.

Research at ORNL was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U.S. Department of Energy.

Dynamics of the Ho$^{+3}$ magnetism in the multiferroic compound HoMnO$_3$ investigated via time domain terahertz spectroscopy, N.P. ARMITAGE, N.J. LAURITA, Johns Hopkins University, RONGWEI HU, S-W CHEONG, Rutgers University — The multiferroic insulator HoMnO$_3$ possesses a diverse array of magnetism due to both magnetically active Mn$^{3+}$ and Ho$^{3+}$ moments. The latter of which sit at two distinct sites within its non-inversion symmetric hexagonal crystal structure. While previous studies have focused on the ordering of the Mn$^{3+}$ moments, little is known about the magnetic structure below $5 K$ where it is believed that there is at least partial ordering of the Ho$^{3+}$ ions. In principle, magnetic phase interactions exist between both distinct Ho$^{3+}$ and Mn$^{3+}$ ions, resulting in a complex phase diagram with as many as five distinct phases found below $T = 5K$ and $H = 3T$. While previous infrared studies have focused on the Ho$^{3+}$ crystal field levels, the spin excitations in the low frequency end of the far infrared remain unknown. We report the finding of new infrared absorptions via time domain terahertz spectroscopy which we attribute to the Ho$^{3+}$ moments. The corresponding field dependence is studied.

Electric Field Effect on the Magnetic Order in Multiferroic LuMnO$_3$, CHUNRUO DUAN, JUNJIE YANG, Univ of Virginia, LEAND HARRIGER, NIST Center for Neutron Research, DESPINA LOUCA, Univ of Virginia — LuMnO$_3$ belongs to the family of hexagonal multiferroics in which ferroelectric and magnetic orders coexist and compete. The Mn$^{3+}$ ions reside on a triangular lattice that is geometrically frustrated but undergoes a Néel transition at $T_N = 90K$. Neutron experiments under electric field were carried out on a single crystal of LuMnO$_3$ at SPINS to investigate the coupling of the electric field to the magnetic order. The elastic and inelastic scattering around the commensurate ($101$) magnetic peak and the Mn trimerization induced ($100$) peak with and without electric field were investigated. When applying an E-field of 13.3 kV/cm along the (001) direction on an unpoled sample, an increase in ($101$) peak as well as a shift of the inelastic excitation near ($100$) to higher $\Delta E$ have been observed. Once the sample is polarized, these effects exist without the field. On the other hand, an E-field along (110) direction shows almost no effect. The spin arrangement of the magnetic order is within the ab-plane, thus the Dzyaloshinskii-Moriya interaction explains why a polarization perpendicular to the magnetic moment gives a larger effect. The implication will be discussed.

First-principles studies of magneto-electric coupling in hexagonal LuFeO$_3$ under applied electric fields, YUBO ZHANG, HONGWEI WANG, PRATIKKUMAR DHUVAD, Temple Univ, XIAOSHAN XU, University of Nebraska, MASSIMILIANO STENGEL, Instituto de Cincia de Materials de Barcelona, XIFAN WU, Temple Univ — The recently stabilized hexagonal LuFeO$_3$ thin-film provides an opportunity for the investigation of multiferroic materials in which the weak ferromagnetism due to Dzyaloshinski-Moriya interaction was found to be closely associated with the trimerization ($K_s$) mode. Here, we performed first-principles calculations in hexagonal LuFeO$_3$ and studied the variations of weak ferromagnetic moment under applied electric fields. It is found that the weak ferromagnetism is a property that can be directly tuned by the external electric fields. As an imperfect ferroelectric material, such a magneto-electric coupling is realized by the strong interaction between the trimerization mode and ferroelectric mode. Under the electric field poling, ferroelectric mode will respond. A change in ferroelectric distortion will in turn affect the amplitude of trimerization mode, and therefore, the weak ferromagnetism. Interestingly, the magneto-electric coupling in LuFeO$_3$ shows a strong nonlinear behavior originating again from the coupling between the trimerization and ferroelectric modes due to its improper nature.

Energetics of Intrinsic Defects in hexagonal LuFeO$_3$, TULA R. PAUDEL, EVGENY Y. TSYMBAŁ, Department of Physics and Astronomy & Nebraska Center for Materials and Nanoscience, University of Nebraska — The hexagonal Lutetium Ferrite (h-LuFeO$_3$) is one of the few multiferroic materials where the spontaneous ferroelectric and magnetic ordering are simultaneously present at room temperature. Here, we investigate energetics of the intrinsic defects h-LuFeO$_3$ using the first-principles supercell approach in the dilute limit. We find the possibility of intermixing, i.e., Lu replacing Fe when h-LuFeO$_3$ is grown at the Lu rich conditions, and Fe replacing Lu when this compound is grown at the Fe rich conditions. In addition, our calculations predict the formation of a large number of oxygen vacancies when h-LuFeO$_3$ is grown in the reducing conditions. We find that even when the concentration of oxygen vacancies is large, they do not create as much free charge as they form relatively deep localized defect states. Cation vacancies are predicted to have shallow transition levels and the large formation energy, which makes them unlikely in this compound. The electronic structure of all these defects and their effect on the magnetic and polarization properties of h-LuFeO$_3$ are discussed.

5:18PM V6.00015 Magneto-electric control of toroidic moments in multiferroic LiCoPO$_4$, JUDIT ROMHNYI, Max Planck Institute for Solid State Research, Heisenbergstrasse 1, D-70569 Stuttgart, Germany, KARLO PENC, Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O.B. 49, H-1525 Budapest, Hungary — In addition to the three widely known forms of ordering, elastic, electric and magnetic orders, a new so called ferrotoroidic phase has been recently observed.[1] The toroidic moment is asymmetric under both time reversal and space inversion symmetries allowing ferrotoroidic materials to exhibit intrinsic magneto-electric effect. Possibility to control magnetic properties using electric field makes such materials desirable for applications. We discuss the magneto-electric control of toroidic moments in the multiferroic material, LiCoPO$_4$. Based on symmetry arguments we derive microscopic model for induced polarization and ‘toroidization’. Using multiboson approach we investigate the experimentally observed magnon absorption spectrum following different magneto-electric poling processes. We reproduce the macro-domain ferrotoroidic state established by magneto-electric poling, as well as unconventional optical properties, such as the unidirectional light transmission, emerging in magnon spectrum of LiCoPO$_4$. [1] Bas B. Van Aken et al, Nature 449, 702-705 (11 October 2007), Anne S. Zimmermann et al, Nature Communications 5, Article number: 4796

Thursday, March 17, 2016 2:30PM - 5:30PM –
Session V13 GMAG DMP: Heat Current Effects on Magnetization Dynamics

309 - Jean-Philippe
Ansermet, Ecole Polytechnique Federale de Lausanne, Switzerland
2:30PM V13.00001 Giant thermal spin torque assisted magnetic tunnel junction switching
Aakash Pushp, IBM Almaden Res Ctr — Spin-polarized charge-currents induce magnetic tunnel junction (MTJ) switching by virtue of spin-transfer-torque (STT). Recently, by taking advantage of the spin-dependent thermoelectric properties of magnetic materials, novel means of generating spin-currents from temperature gradients, and their associated thermal-spin-torques (TSTs) have been proposed, but so far these TSTs have not been large enough to influence MTJ switching. Here we demonstrate significant TSTs in MTJs by generating large temperature gradients across ultrathin MgO tunnel barriers that considerably affect the switching fields of the MTJ. We attribute the origin of the TST to an asymmetry of the tunneling conductance across the zero-bias voltage of the MTJ. Remarkably, we estimate through magneto-Seebeck voltage measurements that the charge-currents that would be generated due to the temperature gradient would give rise to STT that is a thousand times too small to account for the changes in switching fields that we observe. Reference: A. Pushp*, T. Phung*, C. Rettner, B. P. Hughes, S.-H. Yang, S. S. P. Parkin, 112, 6585-6590 (2015).

3:06PM V13.00002 Picosecond Spin Caloritronics, David G. Cahill, Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign — The coupling of spin and heat, i.e., spin caloritronics, gives rise to new physical phenomena in nanoscale spin devices and new ways to manipulate local magnetization. Our work in this field takes advantage of recent advances in the measurement and understanding of heat transport at the nanoscale using ultrafast lasers. We use a picosecond duration pump laser pulses as a source of heat and picosecond duration probe laser pulses to detect changes in temperature, spin accumulation, and spin transfer torque using a combination of time-domain thermoreflectance and time-resolved magneto-optic Kerr effect. Our pump-probe optical methods enable us to change the temperature of ferromagnetic layers on a picosecond time-scale and generate enormous heat fluxes on the order of 100 GW m⁻² that persist for ~ 30 ps. Thermally-driven ultrafast demagnetization of a perpendicular ferromagnetic layer leads to spin accumulation in a normal metal and spin transfer torque in an in-plane ferromagnet. The data are well described by models of spin generation and transport based on differences and gradients of thermodynamic parameters. The spin-dependent Seebeck effect of a perpendicular ferromagnetic layer converts a heat current into spin current, which in turn can be used to exert a spin transfer torque (STT) on a second ferromagnetic layer with in-plane magnetization. Using a [Co,Ni] multilayer as the source of spin, an energy fluence of \( \approx 4 \, J \, m^{-2} \) creates thermal STT sufficient to induce \( \approx 1 \, % \) tilting of the magnetization of a 2 nm-thick CoFeB layer.

3:42PM V13.00003 Ultrafast spin-transfer torque driven by femtosecond pulsed-laser excitation, Bert Koopmans, Eindhoven Univ of Tech — A hot topic in the field of ultrafast laser-induced manipulation of the magnetic state is that of the role and exploitation of laser-induced spin currents. Intense debate has been triggered by claims that such a spin-transfer, e.g. in the form of superdiffusive spin currents over tens of nanometers, might be a main contributor to the demagnetization process in ferromagnetic thin films after femtosecond laser excitation. In this presentation the underlying concepts will be introduced and recent developments reviewed. Particularly we demonstrate the possibility to apply a laser-induced spin transfer torque on a free magnetic layer, using a non-collinear multilayer configuration consisting of a free in-plane layer on top of a perpendicularly magnetized injection layer, as separated by a nonmagnetic spacer. Interestingly, this approach allows for a quantitative measurement of the amount of spin transfer. Moreover, it might provide access to novel device architectures in which the magnetic state is controlled by fs laser pulses. Careful analysis of the resulting precession of the free layer allows us to quantify the applied torque, and distinguish between driving mechanisms based on laser-induced transfer of hot electrons versus a spin Seebeck effect due to the large thermal gradients. Further engineering of the layered structures in order to gain fundamental understanding and optimize efficiencies will be reported. A simple model that treats local non-equilibrium magnetization dynamics to spin transport effects via a spin-dependent chemical potential will be introduced.

4:18PM V13.00004 Magnetization dynamics under heat current in metallic spin valves and in insulators, HaiMing Yu, Beihang University — Spin caloritronics, an emerging branch of spintronics, studying the addition of thermal effects to the electrical and magnetic properties of nanostructures, has recently seen a rapid development. It has been predicted by Hatami et al. that a heat current can exert a spin torque on the magnetization in a nanostructure, analogous to the well-known spin-transfer torque induced by an electrical current. We provided the experimental evidence for the thermal spin-transfer torque effect in spin valves, showing the switching field change with heat current. I will present measurements of the second harmonic voltage response of Co-Cu-Co pseudo-spinvalves deposited in the middle of Cu nanowires. Both the magnitude of the second harmonic response of the spin valve and the field value of the maximum response are found to be dependent on the heat current. Both effects show that the magnetization dynamics of the pseudo-spinvalves is influenced by the heat current. Thus, the data provide a quantitative estimate of the thermal spin torque exerted on the magnetization of the Co layers. In addition, I will present recent study on the magnetization dynamics in a magnetic insulator YIG film under in-plane heat current. The ferromagnetic resonance linewidth is found to be tuned by the applied temperature gradient, i.e., narrowing and broadening. This suggests that the Gilbert damping parameter is compensated or reinforced by the applied temperature gradient in respective direction. These observations can be understood as a heat-driven spin torque in magnetic insulators.

4:54PM V13.00005 Magnetic equivalent of the Seebeck effect, Sylvain Brechet, EPFL — Spin caloritronics seeks to investigate the effect of a thermal gradient on the electronic charge and spin degrees of freedom. In a conductor, a thermal gradient leads a transport of the conduction electrons that in turn generate an electric field along the temperature gradient, which is the well-known Seebeck effect. In an insulator, there are no conduction electrons. Thus no electronic charge transport takes place. However, the electronic spins can reorient themselves in the presence of a temperature gradient as they precess around an external field oriented along the temperature gradient. In fact, the temperature gradient generates a magnetic induction field in the plane orthogonal to the temperature gradient. The effect is the magnetic analog of the Seebeck effect and is thus referred to as the magnetic Seebeck effect. It has been observed for the propagation of spin waves along and against a temperature gradient in a YIG slab. The propagation of spin waves against the temperature gradient lead to a positive thermal damping and the propagation along the temperature gradient leads to the opposite effect, namely a negative thermal damping. Thus, the magnetic Seebeck effect generate of heat driven spin torque that can generate a positive or a negative thermal damping. The magnetic Seebeck effect has been recently established using a fundamental variational approach. In many experimental situations, the system can be treated as a classical continuum with magnetisation on the scale of interest where the quantum fluctuations average out and the underlying microscopic structure is smoothed out. For the propagation of magnetisation waves in a stationary state, the system is slightly out of equilibrium but the magnetic kinetic energy is constant. In such a case, the action of the system is a functional of the magnetisation and the magnetisation current. Since the magnetisation is a function of the temperature, the action variation yields an explicit expression for the magnetic induction field generated by the temperature gradient. This field lead to a heat driven spin torque that has the same geometry in an insulator than the spin transfer torque proposed by Berger and Slonczewski in a conductor.
2:30PM V18.00001 Room-temperature creation and spin-orbit torque-induced manipulation of skyrmions in thin film. GUOQIANG YU, PRAMEY UPADHYAYA, XIANG LI, WENYUAN LI, Electrical Engineering, UCLA, SE KWON KIM, Physics and Astronomy, UCLA, YABIN FAN, KIN L. WONG, Electrical Engineering, UCLA, YAROSLV TSEKOVNYAK, Physics and Astronomy, UCLA, PEDRAM KHALILI AMIRI, KANG L. WANG, Electrical Engineering, UCLA — Magnetic skyrmions, which are topologically protected spin texture, are promising candidates for ultra-low energy and ultra-high density magnetic data storage and computing applications. To date, most experiments on skyrmions have been carried out at low temperatures. The choice of materials available is limited and there is a lack of electrical means to control of skyrmions. Here, we experimentally demonstrate a method for creating skyrmion bubbles phase in the ferromagnetic thin film at room temperature. We further demonstrate that the created skyrmion bubbles can be manipulated by electric current. This room-temperature creation and manipulation of skyrmions in thin film is of particular interest for applications, being suitable for room-temperature operation and compatible with existing semiconductor manufacturing tools.


2:42PM V18.00002 Spin Torque induced anti-vortex excitations. KAAN OBZOZDUMAN, VEDAT KARAKAS, SEVENDUR ARPACI, ALI TAHAN HABIBIOGLU, AISHA GOKCE, Bogazici Univ, ANNA GIORDANO, University of Messina, FEDERICA CELEGATO, Institute of Materials for Electronics and Magnetism, PAULA TIBERTO, Istituto Nazionale di Ricerca Metrologica, GIOVANNI FINOCCHIO, University of Messina, GULEN AKTAS, OZBAN OZATAY, Bogazici Univ — Nanodevices that are designed to stimulate the formation of unique magnetic configurations (vortex, anti-vortex, skyrmion etc.) are applicable to spin based technologies, namely, microwave oscillators and magnetic sensors. In this talk, we report the observed dynamic behavior of an anti-vortex, which had not been thoroughly studied due to the complexity in stabilization of the structure, by analyzing its interaction with magnetic field and DC current. Permalloy (Ni81Fe19) based 2x2m2 asteroid geometry devices, consisting of four tangent circles of equal radii, facilitate the nucleation of an anti-vortex pair at the center with the application of an in-plane AC demagnetizing field and an out of plane magnetic saturation field. Magnetic force microscopy (MFM) data shows that an external magnetic field can rearrange the positions of diagonally located anti-vortex pair. Spin torque effect induces an anti-vortex pair circular motion, known as gyration. The resulting RF signal is measured using the anisotropic magneto-resistance effect (AMR) which indicates a ~250-300 mΩ change in the resistance of our samples. This study will help develop our understanding of the anti-vortex, current and magnetic field interactions for practical on-chip microwave oscillator applications.

2:54PM V18.00003 Observation of spin transfer torques in the transverse magnetic susceptibility of the Skyrmion lattice phase of MnSi. FELIX RUCKER, CHRISTOPH SCHNARR, ANDREAS BAUER, CHRISTIAN PFLEIDERER, Lehrstuhl für Topologie Korrelierter Systeme, Technische Universität München, Garching, Germany — In the Skyrmion lattice phase of MnSi the observation of sizeable spin transfer torques [1-3] promises easy experimental access to the precise qualitative and quantitative form of the Landau Lifshitz Gilbert equation. We report measurements of the transverse magnetic susceptibility, with increasing current density around the critical current density \( j_c \). We further find a sizeable dissipative part of \( \chi_{\perp} \) evolving above \( j_c \). We discuss the broader implications of our experimental findings, which provide, for the first time, a direct link between a thermodynamic property and the effects of spin transfer torques in skyrmion lattices.


3:06PM V18.00004 Chiral Skyrmion Hall effect in Antiferromagnets. MATTHEW DANIELS, RAN CHENG, Carnegie Mellon University, JIANG XIAO, Fudan University, DI XIAO, Carnegie Mellon University — We study the interaction between magnetic skyrmions and spin wave currents in antiferromagnetic (AFM) insulators. Micromagnetic simulations reveal that magnon-skyrmion scattering in AFMs is dependent on the chirality of the spin wave, a degree of freedom unique to easy-axis AFMs. We also find nontrivial dynamical differences between circularly and linearly polarized waves incident upon AFM skyrmions in simulation. We characterize the resulting chiral magnon Hall effect using the O(3) nonlinear sigma model, and we elucidate the corresponding chiral skyrmion Hall effect as arising from certain magnon spin currents.

3:18PM V18.00005 Ratchet Effects, Negative Mobility, and Phase Locking for Skyrmions on Periodic Substrates. CHARLES REICHHARDT, DIPANJAN RAY, CYNTHIA OLSON REICHHARDT, Los Alamos National Laboratory — We examine the dynamics of skyrmions interacting with 1D and 2D periodic substrates in the presence of dc and ac drives. We find that the Magnus term strongly affects the skyrmion dynamics and that new kinds of phenomena can occur which are absent for overdamped ac and dc driven particles interacting with similar substrates. We show that it is possible to realize a Magnus induced ratchet for skyrmions interacting with an asymmetric potential, where the application of an ac drive can produce quantized dc motion of the skyrmions even when the ac force is perpendicular to the substrate asymmetry direction. For symmetric substrates it is also possible to achieve a negative mobility effect where the net skyrmion motion runs counter to an applied dc drive. Here, as a function of increasing dc drive, the velocity-force curves show a series of locking phases that have different features from the classic Shapiro steps found in overdamped systems. In the phase locking and ratcheting states, the skyrmions undergo intricate 2D orbits induced by the Magnus term.

3:30PM V18.00006 FMR study of thin film FeGe skyrmionic material. VIDYA P. BHALLAMUDI, MICHAEL R. PAGE, JAMES GALLAGHER, CAROLA PURSER, JOSEPH SCHULZE, FENGYUAN YANG, P. CHRIS HAMMEL, Ohio State Univ - Columbus — Magnetic Skyrmions have attracted intense interest due to their novel topological properties and the potential for energy efficient computing. Magnetic dynamics play an important part in enabling some of these functionalities. Understanding these dynamics can shed light on the interplay of the various magnetic interactions that exist in these materials and lead to a rich magnetic phase diagram, including the Skyrmion phase. We have grown phase-pure FeGe epitaxial films on Si (111) and studied them using ferromagnetic resonance (FMR). FeGe has one of the highest recorded skyrmion transition temperatures, close to room temperature, and thin films are known to further stabilize the Skyrmion phase in the magnetic field-temperature space. We have performed cavity-based single frequency FMR from liquid nitrogen to room temperature on 120 nm thick films in both in-plane and out-of-plane geometries. The resulting complex spectra are consistent with those reported in literature for the bulk material and can be understood in terms of a conical model for the magnetism. Variable temperature broadband spectroscopy and measurements on thinner films, to better identify the various magnetic phases and their dynamic behavior, are ongoing and their progress will be discussed.

Funding for this research was provided by the Center for Emergent Materials: an NSF MRSEC under award number DMR-1420451.

3:42PM V18.00007 Antiferromagnetic skyrmions. PEDRAM KHALILI AMIRI, KANG L. WANG, Electrical Engineering, UCLA — Magnetic skyrmions, which are topologically protected spin texture, are promising candidates for ultra-low energy and ultra-high density magnetic data storage and computing applications. To date, most experiments on skyrmions have been carried out at low temperatures. The choice of materials available is limited and there is a lack of electrical means to control of skyrmions. Here, we experimentally demonstrate a method for creating skyrmion bubbles phase in the ferromagnetic thin film at room temperature. We further demonstrate that the created skyrmion bubbles can be manipulated by electric current. This room-temperature creation and manipulation of skyrmions in thin film is of particular interest for applications, being suitable for room-temperature operation and compatible with existing semiconductor manufacturing tools.


4:18PM V18.00008 Magnetic skyrmions and topological materials. PEDRAM KHALILI AMIRI, KANG L. WANG, Electrical Engineering, UCLA — Magnetic skyrmions, which are topologically protected spin texture, are promising candidates for ultra-low energy and ultra-high density magnetic data storage and computing applications. To date, most experiments on skyrmions have been carried out at low temperatures. The choice of materials available is limited and there is a lack of electrical means to control of skyrmions. Here, we experimentally demonstrate a method for creating skyrmion bubbles phase in the ferromagnetic thin film at room temperature. We further demonstrate that the created skyrmion bubbles can be manipulated by electric current. This room-temperature creation and manipulation of skyrmions in thin film is of particular interest for applications, being suitable for room-temperature operation and compatible with existing semiconductor manufacturing tools.

3:42PM V18.00007 Magnetic excitations of the skyrmion host Cu2OSeO3

A. Fert et al., Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, J 5 WHITE, Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, J ROMHANYI, Institute for Theoretical Solid State Physics, IFW Dresden, D SZALLER, I KEZSMARKI, Department of Physics, Budapest University of Technology and Economics, B ROESSLI, U STUHR, Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, A MAGREZ, Laboratory for Crystal Growth, Ecole polytechnique federale de Lausanne, F GROITL, Laboratory for Quantum Magnetism, Ecole polytechnique federale de Lausanne & Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, P BABKEVICH, P HUANG, I ZIVKOVIC, H MR NOWNOW, Laboratory for Quantum Magnetism, Ecole polytechnique federale de Lausanne — Inelastic neutron scattering (INS) has been used to measure the magnetic excitation spectrum along high-symmetry directions of the first Brillouin zone of the magnetic skyrmion host compound Cu2OSeO3. The INS data are mostly consistent with the predictions of a recently proposed model for the magnetic excitations in Cu2OSeO3, for which best-fit parameters will be reported. As will be shown, differences exist between the model predictions and the experimental findings in the form of two energy scales that likely arise due to neglected anisotropic interactions. Thus highlighting the need for the inclusion of anisotropy in future theoretical works aimed at a full microscopic understanding of the emergence of the skyrmion state in this material.

3:54PM V18.00008 Staggered magnetization and low-energy magnon dispersion in the multiferroic skyrmion host Cu2OSeO3

GUY G. MARCUS, BENJAMIN A. TRUMP, JONAS KINDERVATER, Institute for Quantum Matter and Jons Hopkins University, LACY L. JONES, MATTHEW B. STONE, Quantum Condensed Matter Division, Oak Ridge National Laboratories, TYREL M. MCQUEEN, Institute for Quantum Matter and Jons Hopkins University, COLLIN L. BROHOLM, Institute for Quantum Matter, Jons Hopkins University, and Quantum Condensed Matter Division, Oak Ridge National Laboratories — We present neutron diffraction and inelastic scattering of the insulating helimagnet, Cu2OSeO3, which provide evidence for staggered magnetization and elucidate the associated low-energy magnon spectrum. The modulation wavelength of approximately λ ≈ 50 nm detected at antiferromagnetic Bragg points is of the same length scale as previously reported for the skyrmion lattice. This superstructure exhibits the composite nature of the spin-1 tetrahedra that form the topological magnetic structure of the material. To understand the interplay of ferrimagnetism and long wavelength modulated magnetism, we have performed inelastic neutron scattering on a co-aligned sample of chemical vapor transport grown single crystals. We shall present the low-energy magnon dispersion and infer an effective spin Hamiltonian to account for the long-wavelength, low-energy magnetism of Cu2OSeO3.

The work at IQM was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences and Engineering, under Grant No. DEFG02-08ER46544. GGM also acknowledges support from the NSF-GRFP Grant No. DGE-1232825.

4:06PM V18.00009 Neutron scattering study of the field-induced tricritical point in MnSi

J. KINDERVATER, A. BAUER, Physik-Department, Technische Universitat Miinchen, Garching, Germany, M. GARST, Institute for Theoretical Physics, Universitaet zu Koeln, Koeln, Germany, M. JANOSCHEK, Los Alamos National Laboratory, Los Alamos, USA, N. MARTIN, S. MUEHLBAUER, W. HAUSSER, Heinz Maier-Leibnitz Zentrum, Technische Universitaet Miinchen, Garching, Germany, P. BONI, C. PFLEIDERER, Physik-Department, Technische Universitaet Miinchen, Garching, Germany — The intermetallic compound MnSi attracts great scientific interest due to two unusual phase transitions, namely the transition from the conical phase to a skyrmion lattice in small fields and the transition from the helical to the paramagnetic phase without external magnetic field that was recently identified to be a fluctuation induced first-order transition, i.e. a so called Brazovskii-transition. Recent measurements of the specific heat provide striking evidence for a tricritical point (TCP), where the first order transition alters to second order. We report neutron spin echo measurements using the MIEZE technique. The recorded quasi elastic linewidth shows a change of the characteristic spin fluctuations at the TCP. The combination with additional SANS measurements and a generalized Brazovskii theory establishes a consistent picture of the statics and dynamics of the transition.

4:18PM V18.00010 Controlling and imaging chiral spin textures


4:54PM V18.00011 Observation of room-temperature skyrmion Hall effect

W. JIANG, Argonne National Laboratory, X. ZHANG, University of Hong Kong, P. UPADHYAYA, UCLA, W. ZHANG, Argonne National Laboratory, G. YU, UCLA, M. JUNGFLIECHS, F. FRADIN, J. PEARSON, Argonne National Laboratory, Y. TSEKOVNYAK, K. WANG, UCLA, O. HEINONEN, Argonne National Laboratory, Y. ZHOU, University of Hong Kong, SUZANNE TE VELTHUIS, A. HOFFMANN, Argonne National Laboratory — The realization of room-temperature magnetic skyrmions is key to enabling the implementation of skyrmion-based spintronics. In this work, we present the efficient conversion of chiral stripe domains into Néel skyrmions through a geometrical constriction pattern in a Ta/CoFeB/TaOx trilayer film at room temperature. This is enabled by an interfacial Dzyaloshinskii-Moriya interaction, and laterally divergent current-induced spin-orbit torques [1]. We further show the generation of magnetic skyrmions solely by the divergent spin-orbit torques through a nonmagnetic point contact. By increasing the current density, we observe the skyrmion Hall effect — that is the accumulation of skyrmions at one side of the device. The related Hall angle for skyrmion motion is also revealed under an ac driving current. Financial support for the work at Argonne came from Department of Energy, Office of Science, Basic Energy Science, Materials Sciences and Engineering Division, work at UCLA was supported by TANMS. Reference: [1] W. Jiang, et al., Science, 349, 283 (2015).
5:06PM V18.00012 Controlling skyrmion helicity via engineered Dzyaloshinskii-Moriya interaction  
SEBASTIAN DIAZ, Department of Physics, University of California, San Diego, ROBERTO TRONCOSO, Departamento de Física, Universidad Técnica Federico Santa María, Chile — Single magnetic skyrmion dynamics in chiral magnets with a spatially inhomogeneous Dzyaloshinskii-Moriya interaction (DMI) is considered. Based on the relation between DMI and skyrmion helicity, it is argued that the latter must be included as an extra degree of freedom in the dynamics of skyrmions. An effective description of the skyrmion dynamics for an arbitrary inhomogeneous DMI coupling is obtained through the collective coordinates method. The resulting generalized Thiele’s equation[1] is a dynamical system for the center of mass position and helicity of the skyrmion. It is shown that the dissipative tensor and hence the Hall angle becomes helicity dependent. The skyrmion position and helicity dynamics are fully characterized by our model in two particular examples of engineered DMI coupling: half-planes with opposite sign DMI and linearly varying DMI. In light of a recent experiment[2] on the magnitude and sign of the DMI, our results constitute the first step toward a more complete understanding of the skyrmion helicity as a new degree of freedom that could be harnessed in future high-density magnetic storage and logic devices.


5:18PM V18.00013 Quantum Anomalous Hall effect in a Topological Insulator coupled to a Skyrmion Lattice.  
TONMAY BHOWMICK, YAFIS BARLAS, GEN YIN, ROGER LAKE, Univ of California - Riverside — A Skyrmion is a topologically protected spin texture characterized by a topological charge that has been experimentally observed in both bulk B20 compounds and thin films. In a quantum anomalous Hall phase, a material develops a topologically nontrivial electronic structure giving rise to quantized hall conductivity without any external magnetic field. We predict that a conventional bulk topological insulating material (e.g. Bi2Se3, Bi2Te3, Sb2Te3) in proximity with a Skyrmion crystal, with a weak exchange coupling, will be driven into an anomalous Hall insulating phase characterized by a nonzero integer Chern number in the gap. We have calculated band structure, identified the gaps, and calculated the Chern number at those gaps. The calculations show that the non trivial topological properties of the Skyrmion spin texture can be imprinted on the Dirac electrons of the topological insulator.

We acknowledge support from the NSF (ECCS-1408168). Micromagnetic simulations were supported by SHINES Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under Award DE-SC0012670.
3:30PM V19.00004 Temperature dependences of magnetic anisotropy and longitudinal spin Seebeck effect in Y$_3$Fe$_5$O$_{12}$

VIJAYANKAR KALAPPATIL, RAJA DAS, MANH-HUONG PHAN, HARIHARAN SRIKANTH, Department of Physics, University of South Florida, Tampa FL 33620 — Spin caloritronics is an emerging, exciting research area in condensed matter owing to its potential use in advanced spintronics devices. Pure spin current without having charge current has been achieved though spin Seebeck effect (SSE). Over the last 7 years SSE has been observed in ferromagnetic metals, insulators, and semiconductors using longitudinal and transverse SSE measurement configurations. In this work, we have carried out an experimental study to understand the effect of magnetic anisotropy on the temperature evolution of longitudinal spin Seebeck effect (LSSE) in a single crystalline yttrium iron garnet (YIG). The effective anisotropy field ($H_K$) and inverse spin Hall (ISH) voltage ($V_{ISH}$) were measured using the radio-frequency transverse susceptibility (TS) and LSSE configuration, respectively. The $V_{ISH}$ of a 15 nm Pt strip on (001) YIG slab with a temperature gradient of 3 K was measured in the temperature range of 120 to 300 K. The observed values of $V_{ISH}$ vary from 1 microV for 120 K to 0.5 microV for 300 K. These values fall within the previously reported theoretical and experimental results. The temperature evolution of $H_K$ has been compared with that of $V_{ISH}$ to gain better fundamental understanding.

1Work is supported by ARO through Grant No. W911NF-15-1-0626

3:42PM V19.00005 Investigation of the timescale of the spin-Seebeck effect in yttrium iron garnet from pico to nanoseconds

JOHN JAMISON, ZHIHAO YANG, ROBERTO MYERS, Ohio State Univ - Columbus — We investigate the timescale of the spin-Seebeck effect (SSE) in yttrium iron garnet (YIG) by exciting transient thermal gradients with 150-fs laser heating pulses. The transient thermal gradient generates a spin current which is measured by a Pt top contact via the inverse spin Hall-effect (ISHE). A pulse selection system is used to lower the repetition rate of the laser to low frequencies (e.g. 10 kHz) such that the transient thermal gradient decays completely before the arrival of the next pulse. Lock-in detection, referenced at the laser repetition rate, is used to measure ISHE as a function of magnetic field, verifying that SSE is generated from the individual ultrafast laser pulses. Next, utilizing an optical delay line we vary the time delay between two equal fluence pulses. The correlated ISHE signal is measured with lock-in detection as a function of delay time with 0.1 ps resolution out to 1 ns to examine the characteristic decay times of the ultrafast laser pulse induced spin-Seebeck effect.

1Work supported by ARO MURI W911NF-14-1-0016

3:54PM V19.00006 Heat Transport between Antiferromagnetic Insulators and Normal Metals

EIRIK LOHAGEN FJÆRBU, HANS SKARSAVÅG, ERLEND G. TVETEN, ARNE BRATAAS, Norwegian University of Science and Technology (NTNU) — Antiferromagnetic insulators can become active spintronics components by controlling and detecting their dynamics via spin currents in adjacent metals. This cross-talk occurs via spin-transfer and spin-pumping, phenomena that have been predicted to be as strong in antiferromagnets as in ferromagnets. In a recent article we demonstrate that a temperature gradient drives a significant heat flow from magnons in antiferromagnetic insulators to electrons in adjacent normal metals. The same coefficients as in the spin-transfer and spin-pumping processes also determine the thermal conductance. In contrast to ferromagnets, the heat is not transferred via a spin Seebeck effect which is absent in antiferromagnetic insulator-normal metal systems. Instead, the heat is proportional to a large staggered spin Seebeck effect.


4:06PM V19.00007 Spin Nernst and torque effects in Dzyaloshinskii-Moriya ferromagnets

ALEXEY A. KOVALEV, VLADIMIR ZYUZIN, University of Nebraska-Lincoln — We predict that a temperature gradient can induce a magnon-mediated intrinsic torque and a transverse spin current in ferromagnets with non-trivial magnon Berry curvature. With the help of a microscopic linear response theory of nonequilibrium magnon-mediated torques and spin currents we identify the interband and intraband components that manifest in ferromagnets with Dzyaloshinskii–Moriya interactions and magnetic textures. In addition to the torque and spin current, we also identify the mechanical torque effect in accordance with the conservation of angular momentum. To illustrate and assess the importance of such effects, we apply our theory to the magnon-mediated spin Nernst and torque responses in a kagome lattice ferromagnet.

Doe Early Career Award DE-SC0014189, NSF under Grants Nos. Phy1415600, PHY11-25915, DMR-1420645

4:18PM V19.00008 Spin-Hall magnetoresistance and spin Seebeck effect in Pt/CoCr$_2$O$_4$ bilayer system

AISHA AQEEL, NYNKE VLIETSTRA, JEROEN A. HEUVER, Zernike Institute for Advanced Materials, University of Groningen, The Netherlands, GERRIT E. W. BAUER, Institute for Materials Research and WPI-AIMR, Tohoku University, Sendai, Miyagi 980-8577, Japan, BEATRIZ NOHEDA, BART J. VAN WEES, THOMAS T. M. PALSTRA, Zernike Institute for Advanced Materials, University of Groningen, The Netherlands — Recently, the spin-Hall magnetoresistance (SMR) and the spin Seebeck effect (SSE) have attracted much interest in the field of spintronics. However, these effects have been studied only for collinear magnetic systems. The nature and sensitivity of these effects in non-collinear magnets is still unknown. Here, we investigate the SMR and the SSE in the Pt/CoCr$_2$O$_4$ heterostructure, by using a lock-in detection technique[1]. CoCr$_2$O$_4$ (CCO) is a spinel with a collinear ferrimagnetic state below $T_C = 94$ K and non-collinear magnetic phases at lower temperatures. We investigated the SMR and the SSE at different temperatures (5K-300K). We observe a large enhancement in SMR and SSE in the non-collinear phase of the CCO. Moreover, finite SMR and SSE signals are also observed above $T_C$, where CCO is in the paramagnetic state. Our results show that SMR and SSE are very sensitive to the different magnetic phases of the CCO. [1] N. Vlietstra et al., Phys. Rev. B 90, 174434 (2014)

4:30PM V19.00009 Spin Seebeck Effect Signals from Antiferromagnets

ARATI PRAKASH, JACK BRANG-HAM, FENGYUAN YANG, JOSEPH HEREMANS, The Ohio State University — The Longitudinal Spin Seebeck Effect (LSSE), in which a heat current stimulates spin propagation across an interface between a magnetic material and a normal metal, is well established and observed in ferromagnetic systems [1]. Data have been presented indicating that antiferromagnetic systems could also give rise to LSSE signals [2]. We report here on LSSE signal measured on the Pt/NIO/YIG structure, where NIO is an antiferromagnet. This system is reported to exhibit antiferromagnonic transport [3]. We explore the dependence of the signal on the thickness of the NIO and YIG layers. We also report its temperature dependence, which was not explored before [3]. The results are interpreted in terms of the temperature dependence of the magnon density of states. It appears that magnon modes with energies below about 40 K are most involved in the process, as was the case to the LSSE on YIG itself [4]. Preliminary results using other antiferromagnets and other inverse spin-Hall layers look promising and will also be reported. [1] S. R. Boona et al., Energy Environ. Sci. 7 885-910 (2014) [2] Y. Ohnuma et al. Phys. Rev. B 87 014423 (2012) [3] H. Wang, Phys. Rev. Lett. 113, 097202 (2014) [4] Y. Jin et al., Phys. Rev. B Phys. Rev. B 92, 054436 (2015)

3Work supported by ARO- MURI W911NF-14-1-0016

3:54PM V19.00006 Heat Transport between Antiferromagnetic Insulators and Normal Metals
4:42PM V19.00010 Effects of thermal magnetic fluctuations on spin transport in Pt.1 - RYAN FREEMAN, ANDREI ZHOLUD, RONGXING CAO, SERGEI URAZHDIN, Emory University — Despite extensive studies and applications of Pt as a spin Hall material in spintronic devices, its spin-dependent transport properties are still debated. We present a comprehensive experimental study of spin transport in Pt, utilizing measurements of giant magnetoresistance (GMR) in nanoscale Permalloy (Py)-based spin valves with Pt inserted in the nonmagnetic spacer. The spin diffusion length and the interfacial spin flipping coefficients are extracted from the dependence of MR on the Pt thickness. For samples with Pt separated from Py by Cu spacers of 1 nm, the spin diffusion length is about 8.2 μm at room temperature. The interfacial spin flipping decreases with increasing temperature, resulting in nonmonotonic temperature dependence of MR in samples with thin Pt. In contrast, in samples with Pt in direct contact with Py, we do not observe such a nonmonotonic dependence, and the spin diffusion length is significantly larger than in samples with Pt surrounded by Cu spacers. Our results indicate a large effect of the giant paramagnetic fluctuations in the nearly ferromagnetic Pt. These fluctuations are suppressed due to the proximity magnetism when Pt is in contact with Py, resulting in enhanced spin diffusion length and reduced spin flipping at the Pt interfaces. These observations indicate the need for a critical revision of spin transport and spin Hall-related properties of Pt-based structures.

1supported by NSF ECCS-1305586

5:06PM V19.00012 Time-domain measurement of spin-Seebeck effect as a function of temperature: interface magnon effect , ZIHAO YANG, Department of Electrical and Computer Engineering, The Ohio State University, Columbus, Ohio, USA, JOHN JAMISON, Department of Material Science and Engineering, The Ohio State University, Columbus, Ohio, USA, ROBERTO MYERS, Department of Electrical and Computer Engineering, The Ohio State University, Columbus, Ohio, USA — Time-resolved longitudinal spin Seebeck effect (LSSE) measurements allow a means to separate the influence of thermally excited electrons, phonons and magnons on the detected spin current. In this study, we measured the time dependence of the LSSE signal in Pt/YIG structures using a high bandwidth oscilloscope and a modulated CW laser from 20 K to 300 K. The rise of the LSSE signal is sharp and not truncated indicating that the measurement is not limited by the bandwidth of the setup. The temporal profile of the LSSE signal consists of two distinct components, a fast rise (200 ns) and a slow rise. The fast component is temperature independent and roughly on par with the rise time of the modulated laser intensity, while the slow component does not saturate up to 50 μs. We model the temporal evolution of the LSSE signal by carrying out three-temperature 3D time domain heat diffusion finite element modeling of the magnon temperature gradient profile in YIG to determine the electron, magnon, and phonon temperature profile versus time. It is found that the magnon temperature gradient near the YIG interface exhibits the same fast rise time that is measured in the LSSE signal. We discuss implications for this measurement on the existing models of LSSE.

5:18PM V19.00013 Non-local thermal spin injection to study spin diffusion in yttrium iron garnet1, BRANDON GILES, Dept. of Materials Science and Engineering, The Ohio State University, ZIHAO YANG, JOHN JAMISON, Dept. of Electrical and Computer Engineering, The Ohio State University, ROBERTO MYERS, Dept. of Materials Science and Engineering, The Ohio State University — Understanding the generation, detection, and manipulation of spin current is critical for the development of devices that depend on spin transport for information processing and storage. Recent studies have shown that spin transport over long distances is possible in the magnetic insulator yttrium iron garnet (YIG) through the diffusion of non-equilibrium magnons. Electrically excited magnons have been shown to diffuse up to 40 μm at room temperature [1], while thermally injected magnons were detected at ranges greater than 125μm at 23K [2]. However, much work is still required to fully understand the processes responsible for magnon diffusion. Here, we present an in-depth study of the diffusion of magnons in YIG. By using the non-local thermal spin detection method [2], we analyze spin transport as a function of temperature. Spin diffusion maps, which can be used to experimentally determine the spin diffusion length in YIG as a function of temperature, are presented. [1] L. J. Cornelissen, et al. Nat Phys (2015). [2] B. L. Giles, et al. arXiv:1504.02808 [cond-Mat] (2015).

3Work supported by the Army Research Office MURI W911NF-14-1-0016

4:42PM V19.00011 Magnon-drag contribution to the Nernst effect of single-crystal iron. SARAH WATZMAN, The Ohio State University, HYUNGYU JIN, Stanford University, JOSEPH HEREMANS, The Ohio State University — The thermopower of single-crystal iron has recently been proven to be dominated by magnon-drag [1]. Experimental results align with hydrodynamic and microscopic theories [2] that underline the similarity between the magnon-drag charge Seebeck effect and the spin-Seebeck effect. Here, the results are expanded to the Nernst effect. The Nernst coefficient of iron is shown to be quite large and is expected to contain a contribution similar to the spin-Seebeck effect. In this case, it is present in the absence of a ferromagnet-normal metal interface or spin-orbit interactions. This talk will present a new model based on ambipolar transport. Spin-up and spin-down electrons are considered as charge carriers with separate magnon-drag Seebeck coefficients. The difference between these partial Seebeck coefficients leads to a large magnon-drag Nernst coefficient in the absence of a skew force. Furthermore, methods to increase the thermopower of iron while maintaining its magnon-drag effects will be presented with preliminary results. 1. S. J. Watzman et al., San Antonio APS March Meeting talk (2015) 2. M. E. Lucassen et al., Appl. Phys. Lett. 99 262506 (2011)

Friday, March 18, 2016 8:00AM - 10:24AM — Session X1 DCMP GMAG: Complex Oxide Interfaces at the Nanoscale: Electronic, Magnetic and Superconducting Properties Ballroom I - Chang-Beom Eom, University of Wisconsin-Madison

8:00AM X1.00001 Electron pairing without superconductivity1 — JEREMY LEVY, University of Pittsburgh — Strontium titanate (SrTiO3) is the first and best known superconducting semiconductor. It exhibits an extremely low carrier density threshold for superconductivity, and possesses a phase diagram similar to that of high-temperature superconductors—two factors that suggest an unconventional pairing mechanism. Despite sustained interest for 50 years, direct experimental insight into the nature of electron pairing in SrTiO3 has remained elusive. Here we perform transport experiments with nanowire-based single-electron transistors at the interface between SrTiO3 and a thin layer of lanthanum aluminate, LaAlO3. Electrostatic gating reveals a series of two-electron conductance resonances—paired electron states—that bifurcate above a critical pairing field Bp of about 1–4 tesla, an order of magnitude larger than the superconducting critical magnetic field. For magnetic fields below Bp, these resonances are insensitive to the applied magnetic field; for fields in excess of Bp, the resonances exhibit a linear Zeeman-like energy splitting. Electron pairing is stable at temperatures as high as 900 millikelvin, well above the superconducting transition temperature (about 300 millikelvin). These experiments demonstrate the existence of a robust electronic phase in which electrons pair without forming a superconducting state. Key experimental signatures are captured by a model involving an attractive Hubbard interaction that describes real-space electron pairing as a precursor to superconductivity.

1Support from AFSOR, ONR, ARO, NSF, DOE and NSSEFF is gratefully acknowledged.
LaMnO₃/LaNiO₃ superlattices, JEAN-MARC TRISCONE, DQMP, University of Geneva — Perovskite nickelates (RNiO₃, RE = Rare Earth) are fascinating materials, well known for their metal to insulator transition (MIT) and unique antiferromagnetic (AFM) ground state [1]. In this presentation, I will first discuss how one can control the MIT and the magnetic properties of high quality epitaxial nickelate films through a variety of techniques [2-6].

I will then describe our work on heterostructures containing LaNiO₃ — the only member of the family that is metallic and paramagnetic in the bulk down to low temperature — and ferromagnetic LaMnO₃. In this system we observed an unusual exchange bias in [111] oriented (LaNiO₃)/(LaMnO₃) superlattices [7] and an antiferromagnetic interlayer exchange coupling above the blocking temperature of the exchange biased state specifically in 7 unit cells LaMnO₃/7 unit cells LaNiO₃ superlattices. The antiferromagnetic coupling is attributed to the presence of a (1/4, 1/4, 1/4) wavelength AFM structure in LaNiO₃. The complex exchange bias observed in this (LaNiO₃)/(LaMnO₃) system is explained in this context also considering the presence of two types of interfaces [8].


View this abstract online.
9:00AM X5.00004 Structure and Physical Properties of SrNiRu$_5$O$_{11}$ Single Crystals: A New Frustrated R-type Ferrite Based on Ordered Kagome Nets$^1$. LANCE DE LONG, University of Kentucky, Department of Physics and Astronomy, LARYSA SHLYK, RAINER NIEWA, Universität Stuttgart, Institut für Anorganische Chemie — Single crystals of the R-type ferrite SrNiRu$_5$O$_{11}$ were grown from a chloride flux. The hexagonal crystal structure contains ruthenium located on Kagome nets, distorted due to formation of Ru–Ru dumbbells via metal-metal bonding. SrNiRu$_5$O$_{11}$ does not show long-range magnetic order down to 4.5 K. The low-temperature magnetic susceptibilities, $\chi_{\perp}$ and $\chi_{\parallel}$, diverge as $T^{-0.3}$, and the electric resistivity varies as $T^{1.6}$ below 40 K, which is typical of non-Fermi liquid materials. This anomalous behavior might originate from the competition between residual magnetic interactions among Ni$^{2+}$ ($S = 1/2$) spins and geometrical frustration on the two-dimensional Kagome lattice of Ru$^{3+}$ ($S = 1/2$) spins. The transverse magnetoresistivity $\rho_{\perp}$, of a SrNiRu$_5$O$_{11}$ single crystal at constant temperature $T = 5$ K for current-magnetic-field configurations, $\mathbf{J} \parallel \mathbf{H}$ [$c$-axis] and $\mathbf{J} \perp \mathbf{c}$-axis, reveals no anomalous contribution, which is typical for non-magnetic materials. Fits of the heat capacity data below 10 K require a dominant, but unusual electronic term of the form $C_\text{L} = \gamma T^{2}$, which is expected for massless Dirac fermion states in topological insulators or spin liquid phases.

$^1$Research at University of Kentucky supported by U.S. Department of Energy grant no. DE-FG02-97ER-45653.

9:12AM X5.00005 Local probe study of Sr-Veseginite. AIM VERRIER, JEFFREY QUILLIAM, Université de Sherbrooke, FABRICE BERT, PHILIPPE MENDELS, Laboratoire de physique des solides, Université Paris-Sud XI, DAVID BOLDRIN, ANDREW WILLS, University College London — We discuss the results of local probe measurements (NMR and $\mu$SR) on a powder sample of SrCu$_{11}$V$_2$O$_{12}$ (SrVeseginite) [D. Boldrini and A. S. Wills, J. Mat. Chem. C 3, 4308(2015)], a spin-1/2 kagome lattice with antiferromagnetic interactions. NMR and $\mu$SR data reveal static magnetism at low temperatures and allow us to measure the intrinsic local susceptibility of the kagome lattice. Spin rotation ($\mu$SR) experiments also demonstrate static magnetism at low $T$. We discuss the possible role of the Dzyaloshinsky-Moriya interaction and the proximity of this material to a quantum critical point between ordered and quantum spin liquid phases.

9:24AM X5.00006 Hidden Order in Spin-Liquid Gd$_3$Ga$_9$O$_{12}$, JOSEPH PADISON, School of Physics, Georgia Institute of Technology, USA, and Department of Chemistry, University of Oxford, UK, and STFC-ISIS, UK, HENRIK JACOBSEN, Nanoscience Center, University of Copenhagen, Denmark, and European Spallation Source, Sweden, OLEG PETRENKO, Department of Physics, University of Warwick, UK, MARIA TERESA FERNÁNDEZ-DÍAZ, Institut Max von Laue - Paul Langevin, France, PASCALE DEEN, Nanoscience Center, University of Copenhagen, Denmark, and European Spallation Source, Sweden, ANDREW GOODWIN, Department of Chemistry, University of Oxford, UK — Frustrated magnetic materials are promising candidates for new states of matter because lattice geometry suppresses conventional magnetic dipole order, potentially allowing non-dipole (“hidden”) order to emerge in its place. However, an atomic-scale model of a hidden-order state has been difficult to obtain because microscopic probes are not directly sensitive to hidden order. We use a combination of neutron-scattering experiments and reverse Monte Carlo refinements to develop a model of the spin-liquid state in the canonical frustrated magnet Gd$_3$Ga$_9$O$_{12}$. We show that this state exhibits a hidden order which has three unusual properties. First, it is a collective phenomenon, in which multiplets are formed from ten-spin loops. Second, it is long-range, with a diverging correlation length. Third, it is a consequence of the interplay between antiferromagnetic spin correlations and local planar magnetic anisotropy, which allows it to be indirectly observed in our neutron-scattering experiments.

9:36AM X5.00007 Topologically non-trivial electronic and magnetic states in doped copper Kagome lattices$^3$. DANIEL GUTERDING, HARALD O. JESCHKE, ROSER VALENTI, Institute for Theoretical Physics, University of Frankfurt, Frankfurt am Main, Germany — We present a theoretical investigation of doped copper kagome materials based on natural minerals Herbstsmithite [ZnCu$_{11}$OH$_6$Cl$_2$] and Barlowite [Cu$_6$(OH)$_3$FBr]. Using ab-initio density functional theory calculations we estimate the stability of the hypothetical compounds against structural distortions and analyze their electronic and magnetic properties. We find that materials based on Herbstsmithite present an ideal playground for investigating the interplay of non-trivial band-topology and strong electronic correlation effects. In particular, we propose candidates for the Quantum Spin Hall effect at filling 4/3 and the Quantum Anomalous Hall effect at filling 2/3. For the Barlowite system we point out a route to realize a Quantum Spin Liquid.

$^3$This work was supported by Deutsche Forschungsgemeinschaft under Grant No. SFB/TR 49 and the National Science Foundation under Grant No. PHY11-25915.

9:48AM X5.00008 DMRG studies of the frustrated kagome antiferromagnets and the application to volborthite$^1$. SHOU-SHU GONG, National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32310, USA, D. N. SHENG, Department of Physics and Astronomy, California State University, Northridge, California 91330, USA, KUN YANG, Department of Physics and National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32306, USA — Motivated by the recent magnetization measurements on the high-quality single crystals of the kagome antiferromagnet volborthite, we study the ground state and magnetization properties of two kagome models proposed from the electronic structure simulations, which treat the volborthite as either the coupled trimers or the coupled frustrated chains on the kagome lattice. We study the models using density-matrix renormalization group on the cylinder geometry with the system width up to 4 legs. We find a quantum phase diagram of the models with changing couplings, and identify the magnetic properties of each phase. In the antiferromagnetic phases, we also study the magnetization curve and the different phases in the magnetic field. Finally, we compare the magnetization properties of the models with the experimental observations of volborthite.

$^1$NSF DMR-1157490, DMR-1408560, and the State of Florida

10:00AM X5.00009 Spin-wave analysis of a broad magnetization plateau in volborthite, EDWARD PARKER, LEON BALENTS, Univ of California - Santa Barbara — Volborthite (Cu$_4$V$_2$O$_7$(OH)$_2$· 2H$_2$O) is a system comprised of spin-1/2 ions forming quasi-2D layers of Kagomé lattices. It displays two striking experimental features: strong geometric frustration (with a magnetic ordering temperature more than two orders of magnitude below its Curie temperature), and an extremely broad $T_c$ of the magnetization plateau extending over a range of more than 100 K. Density functional theory calculations suggest that it has a complicated anisotropic spin coupling structure with both ferromagnetic and antiferromagnetic first- and second-nearest-neighbor bonds. We present results for the classical phase diagram for this system, focusing on how the upper and lower critical fields of the magnetization plateau depend on the exchange couplings. We also present a semiclassical large-$S$ expansion, and show how including the leading quantum corrections in 1/$S$ gives a magnon self-energy that shifts the classical values for the plateaus’ critical fields.
10:12AM X5.00010 Changing the Electron Count in Spin Liquids\(^1\)  
ZACHARY KELLY, TYREL MCQUEEN,  
Johns Hopkins Univ — Materials which possess the resonating valence bond (RVB) "spin-liquid" state have been long sought after by scientists due to their predicted exotic properties. Several materials have been identified as potential spin liquid candidates and laboratory studies have only just begun to provide insight into the properties of these materials and their theoretical description. Recently theoretical calculations predict doping of a spin liquid could lead to a rich and unique phase diagram including complex magnetic states, Dirac metal behavior, and superconductivity. We report the results of structural and physical property characterizations of newly synthesized doped candidate spin liquids.

\(^1\)This work was supported by a Cottrell Scholar Award

10:24AM X5.00011 A Kagome Map of Spin Liquids\(^1\), KARIM ESSAFI, OWEN BENTON, LUDOVIC D. C. JAUBERT,  
Okinawa Inst of Sci & Tech — Competing interactions in frustrated magnets prevent ordering down to very low temperatures and stabilize exotic highly degenerate phases where strong correlations coexist with fluctuations. We study a very general nearest-neighbour Heisenberg spin model Hamiltonian on the kagome lattice which consist of Dzyaloshinskii-Moriya, ferro- and antiferromagnetic interactions. We present a three-fold mapping which transforms the well-known Heisenberg antiferromagnet (HAF) and XXZ model onto two lines of time-reversal Hamiltonians. The mapping is exact for both classical and quantum spins, i.e. preserves the energy spectrums of the HAF and XXZ model. As a consequence, our three-fold mapping gives rise to a connected network of quantum spin liquids extended around the Ising antiferromagnet. We show that these quantum disordered stages order under an extended region of the phase diagram in spin wave theory, which overlaps with the parameter region of Herbertsmithite ZnCu$_2$(OH)$_6$Cl$_4$. At the classical level, all the phases have an extensively degenerate ground-state which present a variety of properties such as ferromagnetically induced pinch points in the structure factor and spontaneous scalar chirality which was absent in the original HAF and XXZ models.

\(^1\)This work was supported by the Okinawa Institute of Science and Technology Graduate University.

10:36AM X5.00012 Nature of Possible Z\(_6\) symmetry breaking magnetic phases in frustrated hyperkagome iridate. RYUICHI SHINDOU, School of Physics, Peking University — To obtain a comprehensive understanding of classical magnetism possible in frustrated hyperkagome iridate Na$_3$Ir$_2$O$_8$ (Na-438), we postulated additional lattice symmetries other than an exact crystal symmetry, and introduced a relatively simpler effective spin model for Na-438. Using Monte Carlo simulation and Luttinger-Tisza analysis, we derived a classical magnetic phase diagram for Na-438. We show that a Z\(_6\) symmetry breaking magnetic phase is stabilized by the thermal order by disorder. Our finite-size scaling analysis reveals that the criticality of the ordering temperature of the Z\(_6\) phase is characterized by the 3D XY universality class, where the system acquires effectively a higher symmetry than high-T disorder phase (dubbed as emergent U(1) symmetry). For a finite size system, an intermediate temperature regime appears below the ordering temperature, where the spin anisotropy term becomes effectively irrelevant and spin ordering develops in the U(1) symmetric way. We showed that this crossover phenomena can be well accounted for in terms of the 3-d ferromagnetic Z\(_6\) Potts model. Based on this crossover behavior, we introduced a possible phenomenology of low-temperature magnetic behaviors of polycrystalline Na-438. Reference: arXiv.1509.01002

10:48AM X5.00013 Competing phases of S=1 XXZ model on Kagome lattice\(^1\), ZHENYUE ZHU, STEVEN WHITE, UC Irvine — We numerically study the S=1 XXZ model on the Kagome lattice with the Density matrix renormalization group. We focus on the two types of expected magnetic order, \(Q = 0\) and \(\sqrt{3} \times \sqrt{3}\). As a function of the coupling \(\Delta\) for the \(S_z\) terms, we find two possible phase transitions. For \(\Delta < \Delta_2\) we find that the \(\Delta = 0\) state is the ground state. For \(\Delta > \Delta_2\) we find that the magnetic ordered phases disappears, entering a magnetic disordered phase. We find a close competition between a trimerized phase and a hexagon single phase, which is consistent with recent numerical studies of S=1 Heisenberg model on the Kagome lattice.

\(^1\)We acknowledge support from the NSF under grant DMR-1505406 and from the Simons Foundation through the Many Electron collaboration.

Friday, March 18, 2016 8:00AM - 11:00AM –  
Session X6 GMAG DMP: Nanoparticles, Nanowires, and Clusters 302 - Deepak Singh, Univ. of Missouri

8:00AM X6.00001 Using Magnetic Proximity Effects to Stabilize Magnetic Nanoparticles\(^1\). JOSE A. DE TORO, Instituto Regional de Investigacion Cientifica Aplicada (IRICA) and Departamento de Fisica Aplicada, Universidad de Castilla-La Mancha — The current miniaturization trend in magnetic applications has led to a quest to suppress spontaneous thermal fluctuations (superparamagnetism) in ever-smaller nanostructures, which constitutes a clear example of the fundamental efforts of condensed matter physics to meet technological challenges (e.g., the continued growth of magnetic recording density). We have demonstrated that ferromagnetic (FM) Co nanoparticles with blocking temperature below 70 K become magnetically stable above 400 K when embedded in a high Neel temperature antiferromagnetic (AFM) NiO matrix [1]. This remarkable stabilization is due to a magnetic proximity effect between a thin CoO shell (with low Neel temperature and high anisotropy) surrounding the Co nanoparticles and the NiO matrix (with high Neel temperature but low anisotropy). This proximity effect yields an effective antiferromagnet with an apparent ordering temperature beyond that of bulk CoO, and an enhanced anisotropy compared to NiO. In turn, the Co core FM moment is stabilized against thermal fluctuations via core-shell exchange-bias coupling, leading to the observed increase in blocking temperature. A mean-field model, corrected for thermal activation effects, closely reproduces the experimental exchange-bias data, corroborating the above interpretation and providing a semi-quantitative understanding of the nature of the proposed proximity effect. The results presented in this study constitute a striking illustration of how a subtle combination of interactions may permit the occurrence of unique magnetic properties by exploiting proximity effects in magnetism. 1. J. A. De Toro, D. P. Marques, P. Muniz, V. Skumryev, J. Sort, D. Givord, and J. Nogues, Phys. Rev. Lett. 115, 057201 (2015).

\(^1\)This work has been supported by projects from the Junta de Comunidades de Castilla-La Mancha [PEII11-0226-8769] and from the Generalitat de Catalunya (2014-SGR-1015)
8:36AM X.6.00002 Emergent 1/f noise in collections of individually oscillating magnetic dots

BARRY COSTANZI, E DAN DAHLBERG, Univ of Minnesota – Twin Cities — We experimentally demonstrate an emergent 1/f spectrum from a superposition of the noise from random telegraph noise (RTN) oscillators. The system consists of individual square magnetic permalloy dots with dimensions on the order of 200 nm x 200 nm x 10 nm that exhibit RTN in their magnetization at appropriate applied fields. The magnetization fluctuations are measured by the anisotropic magnetoresistance (AMR). AMR is used to find applied fields necessary to exhibit RTN, which result in Lorentizan spectra in the power spectral density of the measurement. A composite AMR measurement of multiple oscillating dots at once, however, shows an emergent 1/f spectrum in the power spectral density. This agrees with the prediction of Van Der Ziel [1] that, for an appropriate distribution of oscillators showing Lorentizan spectra, the composite spectrum will have a 1/f character. This experimental demonstration of 1/f noise from a system of two-state oscillators indicates a possible mechanism for the origin of 1/f spectra observed in both other magnetic systems, and potentially in other, more disparate systems. [1] A. van der Ziel, Physica 16, 359 (1950).

8:48AM X.6.00003 Magnetic and Structural Properties of Mn5Ge3 Nanoparticles

MOHAMMAD SALEHI-FASHAMI, GEORGE C. HADJIPANAYIS, Univ of Delaware, DAVID J. SELLMYER, Balamurugan Balasubramanian, Univ of Nebraska-Lincoln, UNIV OF DELAWARE TEAM, UNIV OF NEBRASKA-LINCOLN COLLABORATION — Magnetic nanoparticles have unique and interesting properties which are scientifically important and attractive for numerous advanced technologies. In this work, we have used the cluster beam deposition technique to synthesize Mn5Ge3 nanoparticles with different size. The composition, crystal structure and magnetic properties of the nanoparticles have been characterized by energy dispersive x-ray spectroscopy (EDS), X-ray diffraction, high-resolution transmission electron microscopy (HR-TEM) and magnetometry, respectively. Particles made with 1.7 Torr Argon pressure, and power of 80 W had an average size of 14 nm. Selected area electron diffraction showed that the particles had a hexagonal Mn5Si3-type structure with space group P63/mmc which is the same as in bulk. Magnetic measurements showed that the nanoparticles are ferromagnetic with a Curie temperature near room temperature. The effects of particle size and temperature on the magnetic properties are currently being studied and the results will be reported and discussed.

9:00AM X.6.00004 Computational Atomicistic Modeling of Bi-Magnetic Core-Shell Nanoparticles

RAHUL SAHAY, Sacred Heart Academy and Department of Physics, Central Michigan University, Mount Pleasant, MI, JUAN PÉRALTA, Department of Physics, Central Michigan University, Mount Pleasant, MI, 48859, GABRIEL CARUNTU, Department of Chemistry, Central Michigan University, Mount Pleasant, MI, 48859 — Since its discovery, there has been an increasing interest in the modeling of magnetic phenomena found in materials that present exchange bias. In particular, ferro-antiferromagnetic core-shell nanoparticles are an interesting case in which the magnetic properties of the nanostructure can be altered by adjusting their size, shape, and composition. Here we present a computational scheme that efficiently models the magnetic behavior of bi-magnetic core-shell nanostructures. Using a Heisenberg-Dirac-van Vleck Hamiltonian in combination with a continuous spin model, we simulate a wide range of hysteresis diagrams displaying exchange bias. Furthermore, we will demonstrate our efforts towards improving the efficiency of the simulation algorithms, aiming to afford magnetic atomistic simulations of large nanostructures by using a method based on a tessellated unit sphere to account for spin orientations. Our results allow for further semi-quantitative comparisons with existing experimental data and provide a means to discover new phenomena associated with these core-shell nanoparticles and other nanostructures.

9:12AM X.6.00005 Angular dependence of magnetization in single crystalline cobalt nanowires

KINJAL NANDHA, KEVIN ELKINS, NÁRAYAN PODYUAL, J. PING LIU, University of Texas at Arlington — In this work, the magnetization behavior of Co nanowires has been investigated by applying the Stoner-Wohlfarth model. The single crystalline cobalt nanowires with a diameter of about 15 nm and a mean length of 200 nm were synthesized via a solvothermal chemical process that have high coercivity up to 12.5 kOe. It is found that the c-axis (002) or the easy magnetization direction of the single-crystalline wires is along the long axis of the nanowires. Particular attention has been paid to the angular dependence of magnetic properties on the applied magnetic field orientation with respect to the c-axis. The angular dependence of coercivity has been modeled and it was revealed that the coherent mode rotation gives the best fitting with the experimental observations. In addition, surface oxidized Co nanowires have also been studied that provided us a unique opportunity to understand the exchange bias in the aligned Co/CoO core-shell nanostructures. Ferromagnetic nanowires of this type are ideal building blocks for future bonded, consolidated and thin film magnets with high energy density and high thermal stability.

9:24AM X.6.00006 Chalcogenide Cobalt telluride nanotubes

BISHNU DAHAL, RAJENDRA DULAL, IAN L. PEGG, JOHN PHILIP, The Catholic University of America — Cobalt telluride nanotubes are grown using wet chemical and hydrothermal syntheses. Wet chemical synthesized nanotubes display nearly 1:1 Co to Te ratio. On the other hand, CoTe nanotubes synthesized using hydrothermal method show excess Co content leading to the compound Co5Te12. Both CoTe and Co5Te12 display magnetic properties, but with totally different characteristics. The Curie temperature of CoTe is higher than 400 K. However, the Curie temperature of Co5Te12 is below 50 K. Transport properties of cobalt telluride (CoTe) nanotube devices show that they exhibit p-type semiconducting behavior. The magnetoresistance measured at 10 K show a magnetoresistance of 54%.

9:36AM X.6.00007 Effect of Bi Substitution on the FCC to Li0 Phase Transformation in CoPt(Bi) Nanoparticles

FRANK ABEL, Physics and Astronomy, University of Delaware, VASILIS TZITZIOS, Institute of Nanoscience and Nanotechnology, NCSR, DAVID SELLMYER, Physics and Astronomy and NCMN, University of Nebraska, GEORGE HADJIPANAYIS, Physics and Astronomy, University of Delaware — The transformation from the fcc to fct structure Li0 in CoPt requires annealing at temperatures over 600°C, as compared to FePt which can occur at 550°C. In the past, similar attempts to lower the transformation temperature in CoPt have been unsuccessful. In this work, we report for the first time a decrease in the phase transformation temperature of chemically synthesized CoPt nanoparticles by the addition of a small amount of bismuth. Our studies have shown that the phase transformation occurs in as-made CoPt(Bi) nanoparticles at refluxing temperatures as low as 330°C, which is significantly lower than previously reported values in CoPt nanoparticles and thin films. The as-made CoPt nanoparticles with 5% atomic weight Bi show partial Li0 ordering with an average size of 11.7 nm, as measured by TEM imaging, and have a coercivity of 1 kOe and saturation magnetization of 32 emu/g. Annealing of the CoPt(Bi) nanoparticles produced maximum coercivities of 12.4 kOe when annealed at 700°C for 1 hour. The effect of amount of Bi addition on the formation and ordering of Li0 structure will be discussed.
9:48AM X6.00008 Magnetic and Structural Properties of Co5Ge3 Nanoparticles,  MOHAMMAD SALEHI-FASHAMI, VIMAL DEEPCHAND, University of Delaware, RALPH SKOMSKI, DAVID J. SELLMYER, University of Nebraska-Lincoln, GEORGE C. HAJDIPANAYIS, University of Delaware — Magnetic semiconductor alloy nanostructures play a crucial role in advanced technologies due to their tunable band gaps and electronic properties. Among these magnetic semiconductor alloys, Co-Ge is important both scientifically and technologically. In this work, we studied the magnetic and transport properties of Co5Ge3 nanoparticles (NPs) fabricated by cluster-beam deposition. The NPs were characterized by X-ray powder diffraction and the results demonstrated that they had the same hexagonal structure P63/mmm-type as in bulk. Transmission-electron-microscope observations revealed that the particles have a single crystalline structure with an average size of 8 nm. Selected-area electron diffraction (SAED) confirmed the XRD data, showing clearly that the particles have the hexagonal structure mentioned above. High-resolution electron microscopy images show lattice fringes with spacing of 1.99A and 2.02A which correspond to the (102) and (110) superlattice reflections of the hexagonal ordered Co5Ge3 structure. Magnetic properties showed that these nanoparticles are ferromagnetic at room temperature as compared to bulk samples that are paramagnetic at all temperatures. This magnetic behavior in Co-Ge nanoparticles indicates new size-controlled spin structures in confined nanosize systems.

1Work supported by DOE DE-FG02-04ER46126 and DE-FG02-04ER46152.

10:00AM X6.00009 Evolution of Magnetic Moments in Cobalt and Nickel Clusters, MAZAHIRO SAKURAI, JAIME SOUTO-CASARES, JAMES CHELIKOWSKY, University of Texas at Austin — Ferromagnetism in transition-metal clusters has attracted much interest owing to their enhanced magnetic moments as compared to those of bulk phases. Here, we investigate the stability and the magnetism of Co and Ni clusters with various structures using a real-space formalism of pseudopotentials within the spin-polarized density-functional theory, i.e., the PARSEC code. We will discuss how the calculated magnetic moments evolve as a function of cluster size and compare them to experiment.

We acknowledge support by the National Science Foundation Grant No. DMR 14-35219.

10:12AM X6.000010 Spin Moments and Stability of VCun+ Clusters: The curious case of VCu1+, VCu2+, and VCu3+, WILLIAM BLADES, ARTHUR REBER, SHIV KHANNA, VCU, LUIS SOSA, PATRIZIA CALAMINICI, ANDREAS KOSTER, Civestav — The atomic structures, bonding characteristics, magnetic spin moments, and stability of VCun+ clusters have been examined within density functional theory. Our studies show that at small sizes, the spin moments of the vanadium atom (3d⁶ 4s²) due to 3d electrons are unquenched as the bonding is primarily through 4s electrons. As the cluster grows, the 3d orbitals of the vanadium atom start to participate in hybridized bonding with the copper atoms, resulting in a quenching of the magnetic moment. Upon closer examination of the electronic structures, we observe that our results differ from previous theoretical analyses and simulations that explain the origin of ferromagnetic behavior from super exchange mechanism and model the temperature dependent magnetic behavior of these superatomic solids. [1] X. Roy et al., Science, 341, 157, 2013. [2] C.H. Lee et al., J. Am. Chem. Soc. 136, 16926, 2014.

10:24AM X6.000011 Model for ferromagnetic behavior of metal cluster-fullerene superatomic solids, PALLABI SUTRADHAR, VIKAS CHAUHAN, SHIV KHANNA, JAYASIMHA ATULASIMHA, Virginia Commonwealth Univ — Recent work has explored the precise assembly of binary superatomic solids from metal clusters and fullerenes [1] as well as experimentally demonstrated ferromagnetic behavior in such assemblies at low temperatures (less than 10K). However, the origin of this behavior is not yet completely understood and modeled rigorously. We report theoretical analyses and simulations that explain the origin of ferromagnetic behavior from super exchange mechanism and model the temperature dependent magnetic behavior of these superatomic solids. [1] X. Roy et al., Science, 341, 157, 2013. [2] C.H. Lee et al., J. Am. Chem. Soc. 136, 16926, 2014.

10:36AM X6.000012 Transition metal doped semiconductor quantum dots: Optical and magnetic properties, YURI DHANOVSKY, VITALY PROSHCHENKO, ARTEM PIMACHEV, Department of Physics & Astronomy, University of Wyoming — We study optical and magnetic properties of CdSe and Cd-Mn-Se quantum dots (QD). We find that there are two luminescence lines, one is fast and another is slow (Tₐ₈s). The increase of a QD diameter the slow luminescence disappears at some critical QD size, thus only one line (fast) remains. Using the SAC Si computational method we find that D = 3.2 nm and D = 2.7 nm if the Mn impurity is located inside a QD or on a QD surface, respectively. For two or four Mn atoms in the quantum dot, normal absorption takes place because the transition is spin-allowed. The DFT calculations of the magnetic state reveal that these Mn dopants increase the band gap and also removes the exciton peak. This effect is different to the other quantum dots.

10:48AM X6.000013 Anomalous Hall Effect and Electron Transport in Co₅Si Nanocluster Films, BALAMURUGAN BALASUBRAMANIAN, TOM GEORGE, BHASKAR DAS, RALPH SKOMSKI, DAVID SELLMYER, Nebraska Center for Materials and Nanoscience and Department of Physics and Astronomy, University of Nebraska — Magnetic nanoparticles or clusters are of fundamental and technological importance, since they exhibit entirely different and/or improved magnetic and electronic properties as compared to bulk alloys. Our recent research shows large average magnetic moments of up to 0.70µB/Co at 10K and 0.49µB/Co at 300K for cluster-deposited Co₅Si nanoparticles, in sharp contrast to the nearly vanishing bulk magnetization. In this talk, we present interesting electron-transport properties in Co₅Si nanoparticle films. The film shows a room-temperature negative magnetoresistance (MR) of 0.14% at to kOe, which become as high as 1.8% at low temperatures. We also observed anomalous field-dependent Hall resistivities (ρₓᵧ) in the nanoparticle film, which corroborate the magnetic hysteresis loops. Interestingly, the longitudinal metallic resistivity (ρₓₓ) shows a resistivity minimum at around 10K, similar to Kondo effects observed in the case of non-magnetic metals due to dilute magnetic impurities. The transport properties will be discussed in terms of the spin correlations in the Co₅Si nanoparticle films. This work is supported by the U.S. DOE-BES-DMSE (Grant No. DE-FG02-04ER46126) and NCMN.
8:00AM X8.00001 Organometal Trihalide Perovskite Spintronics 1, DALI SUN, University of Utah — The family of organometal trihalide perovskite (OTP), CH3NH3PbX3 (where X is halogen) has recently revolutionized the photovoltaics field, and shows promise in applications such as solar energy harnessing, light emitting diodes, field effect transistors and laser action. The OTP spin characteristic properties are directly related to experimental measurable properties. Here we construct a 8-band Hamiltonian for tetragonal perovskites from both perturbation and group theories and determine the parameters from first-principles band-structure calculations and experiments. This Hamiltonian is then used to study conduction- and valence-band states as well as excitons under an arbitrary magnetic field. The calculated electron and hole g-factors can explain the exciton g-factors measured by magneto-absorption and magneto-luminescence and the field-dependent exciton energies are consistent with the high-field magneto-absorption experiment, which has been used to accurately determine the exchange coupling.

8:08AM X8.00002 Magneto-optical properties of hybrid organic-inorganic perovskite bilayers investigated by broadband ferromagnetic resonance 1, MATTHEW GROESBECK, DALI SUN, RYAN MCLAUGHLIN, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, University of Utah Dept. of Physics and Astronomy — Organo-metal trihalide perovskites (OTP) have recently been suggested as promising candidates for spintronics applications, motivated by the presence of strong spin-orbit coupling, and recent studies of spin dynamics in CH3NH3PbI3. To help elucidate the spin transport properties in these materials, we have studied the Gilbert magnetization damping parameter in NiFe ferromagnetic films related to spin-pumping into adjacent OTP layers under ferromagnetic resonance (FMR) excitation conditions, using a broadband FMR detection system. We found an increase of the damping parameter associated with spin-pumping into the OTP. The obtained thickness-dependent results are compared to those of NiFe/Cu and NiFe/Pt bilayer structures, where spin transport characteristics are well-known.

8:12AM X8.00003 Studies of Gilbert magnetization damping in NiFe/organometallic trihalide perovskite bilayers investigated by broadband ferromagnetic resonance 1, MATTHEW GROESBECK, DALI SUN, RYAN MCLAUGHLIN, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, University of Utah Dept. of Physics and Astronomy — Organo-metal trihalide perovskites (OTP) have recently been suggested as promising candidates for spintronics applications, motivated by the presence of strong spin-orbit coupling, and recent studies of spin dynamics in CH3NH3PbI3. To help elucidate the spin transport properties in these materials, we have studied the Gilbert magnetization damping parameter in NiFe ferromagnetic films related to spin-pumping into adjacent OTP layers under ferromagnetic resonance (FMR) excitation conditions, using a broadband FMR detection system. We found an increase of the damping parameter associated with spin-pumping into the OTP. The obtained thickness-dependent results are compared to those of NiFe/Cu and NiFe/Pt bilayer structures, where spin transport characteristics are well-known.

8:36AM X8.00002 Magneto-optical properties of hybrid organic-inorganic perovskites, ZHI-GANG YU, Washington State University — In semiconductors the k.p Hamiltonian played a central role in understanding material properties because the model parameters are directly related to experimental measurable properties. Here we construct a 8-band k.p Hamiltonian for tetragonal perovskites from both perturbation and group theories and determine the parameters from first-principles band-structure calculations and experiments. This Hamiltonian is then used to study conduction- and valence-band states as well as excitons under an arbitrary magnetic field. The calculated electron and hole g-factors can explain the exciton g-factors measured by magneto-absorption and magneto-luminescence and the field-dependent exciton energies are consistent with the high-field magneto-absorption experiment, which has been used to accurately determine the exchange binding energy.

8:48AM X8.00003 Studies of Gilbert magnetization damping in NiFe/organometallic trihalide perovskite bilayers investigated by broadband ferromagnetic resonance 1, MATTHEW GROESBECK, DALI SUN, RYAN MCLAUGHLIN, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, University of Utah Dept. of Physics and Astronomy — Organo-metal trihalide perovskites (OTP) have recently been suggested as promising candidates for spintronics applications, motivated by the presence of strong spin-orbit coupling, and recent studies of spin dynamics in CH3NH3PbI3. To help elucidate the spin transport properties in these materials, we have studied the Gilbert magnetization damping parameter in NiFe ferromagnetic films related to spin-pumping into adjacent OTP layers under ferromagnetic resonance (FMR) excitation conditions, using a broadband FMR detection system. We found an increase of the damping parameter associated with spin-pumping into the OTP. The obtained thickness-dependent results are compared to those of NiFe/Cu and NiFe/Pt bilayer structures, where spin transport characteristics are well-known.

9:00AM X8.00004 Optical Generation of Ballistic and Diffusive Spin Currents in Organic- Inorganic Lead Halide Perovskites, JUNWEN LI, PAUL HANEY, National Institute of Standards and Technology — Organic-inorganic halide perovskite solar cells have attracted enormous attention in recent years due to their remarkable photovoltaic power conversion efficiency. These materials should exhibit interesting spin-dependent properties as well, owing to the strong spin-orbit coupling and the broken inversion symmetry present at room temperature. In this work, we consider the spin-dependent optical response of CH3NH3PbI3 on two distinct time scales. We first use density functional theory to compute the ballistic spin current injected by optical polarization light. This spin current persists on a time scale of the momentum relaxation time. We then consider diffusive transport of photogenerated charge and spin for a thin perovskite layer with a passivated surface and an Ohmic, non-selective back contact. The spin densities and spin currents are evaluated by solving the drift-diffusion equations for a 3-dimensional Rashba model. We comment on the applications of optically excited spin densities and spin currents in these materials.

9:12AM X8.00005 Exciton spin dynamics in MAPbI3 measured by Hanle effect, WILLIAM TALMADGE, University of Utah Department of Physics and Astronomy, RUIZHI WANG, University of Utah Department of Physics and Astronomy, Nanjing University of Science and Technology, PATRICK ODENTHAL, NATHAN GUNDLACH, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, YAN (SARAH) LI, University of Utah Department of Physics and Astronomy — The organic-inorganic hybrid perovskites have emerged as a highly promising class of semiconductors for photovoltaic applications. The properties responsible for the high conversion efficiency are under extensive investigation. There have, however, been few investigations of spin-dependent effects in this class of materials. We present energy dependent photoinduced Faraday rotation in polycrystalline thin film CH3NH3PbI3, which benefit from the band structure and optical selection rules. The Faraday rotation spectrum follows the exciton absorption band at low temperatures, indicating its excitonic origin. Through the Hanle effect, based on Faraday rotation, we found the coexistence of two spin components at 4 K, which was confirmed through time resolved measurements.

9:24AM X8.00006 Photoexcited carrier spin dynamics in CH3NH3PbI3 1, PATRICK ODENTHAL, NATHAN GUNDLACH, WILLIAM TALMADGE, University of Utah, RUIZHI WANG, Nanjing University of Science and Technology, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, YAN (SARAH) LI, University of Utah — Metal halide perovskites have shown great promise for the field of spintronics due to their large tunable spin-orbit coupling, spin dependent optical selection rules and predicted electrically tunable Rashba band. The spin sensitive optical transitions allow optical spin orientation of carriers using circularly polarized light, and detection of the spin polarization via optical Faraday rotation measurement. We study carrier spin dynamics on solution-processed polycrystalline CH3NH3PbI3 films using time-resolved Faraday rotation (TRFR). TRFR reveals unexpected long spin lifetimes exceeding 1ns at 4K. This is significant given that Pb and I exhibit large spin-orbit coupling, which usually lead to fast spin relaxation.

9:36AM X8.00007 Composition, Temperature, and Electric Field Dependence of Magneto-Optical Properties of Lead Halide Perovskites 1, RYAN MCLAUGHLIN, CHUANG ZHANG, DALI SUN, Z. VALY VARDENY, University of Utah — Organometal Perovskites have received much attention in recent years due to their remarkable efficiency in photovoltaic cells, along with their highly tunable optical and electrical properties. It is an important goal to quantify and understand the effects of Spin-Orbit Coupling in Perovskite-based optoelectronic devices, which can be characterized by magneto-optical properties such as Kerr rotation and Faraday rotation. Here we use the Verdet constant to investigate the tunability of the Spin-Orbit coupling parameters of Organometal Perovskites as a function of chemical composition, temperature, and electric field.

9:48AM X8.00008 ABSTRACT WITHDRAWN —
10:00AM X8.00009 Neutron and X-Ray Scattering Studies of Hybrid Perovskites for Photovoltaic Applications, MICHAEL CRAWFORD, DuPont Company, PAMELA WHITFIELD, NIINA JALARVO, GEORG EHLERS, SNS, Oak Ridge National Laboratory, MADHUSUDAN TYAGI, NIST Center for Neutron Research, NORMAN HERRON, LYNDA JOHNSON, DuPont Company, WILLIAM GUSE, DuPont Company and APS, Argonne National Laboratory, IVAN MILAS, DuPont Company, YONGQIANG CHENG, LUKE DAEMEN, ANIBAL RAMIREZ-CUESTA, KATHARINE PAGE, XIAOPING WANG, FENG YE, SNS, Oak Ridge National Laboratory — Hybrid perovskites (ABX$_3$) have attracted a great deal of attention recently as light absorbers for photovoltaics. In these materials the A site is occupied by organic cations, for example methyl ammonium (MA) or formamidinium (FA) cations, the B site is occupied by metals, for example Pb or Sn, and the X anions are halogens (I, Br, or Cl). Typical of perovskites, these materials exhibit a series of structural phase transitions involving rotations or tilts of the BX$_6$ octahedra, but with the added complexity that the inorganic framework is coupled to order-disorder transitions of the organic cations. We have used neutron scattering techniques to characterize the structures and dynamics of several of these compounds as a function of temperature. In addition, high resolution synchrotron x-ray diffraction measurements have been performed to investigate the structural phase transitions. These studies yield a detailed picture of the structures, dynamics, and structural phase transitions of these compounds, and provide a firm basis for understanding their excellent photovoltaic properties.

10:12AM X8.00010 Electric Field Effects on Photoconductivity and Photoluminescence in MAPbI$_3$ Perovskite, CHUANG ZHANG, DALI SUN, ZEEV VALY VARDENY, Department of Physics & Astronomy, University of Utah — The origin of “hysteresis behavior” in I-V response of MAPbI$_3$ perovskite devices is still under debate. We characterized this electric field induced hysteresis by monitoring the changes of photoconductivity (E-PC) and photoluminescence (E-PL) from the MAPbI$_3$ film deposited on inter-digital electrodes. Interestingly, we observed a “sign change” in both E-PC and E-PL effects, depending on the applied field and temperature. The E-PC/E-PL could be “frozen” when cooling the device under external field to lower temperature. These results reveal multiple possible reasons for the intrinsic hysteresis behavior in MAPbI$_3$ perovskite devices. This work was supported by the Utah NSF-MRSEC program DMR 1121252.

1 Electric Field Effects on Photoconductivity and Photoluminescence in MAPbI$_3$ Perovskite

10:24AM X8.00011 Nanoimprinting Perovskite by Hot Stamping for Improved Crystallinity and Morphology, BALASUBRAMANIAM BALACHANDRAN, ROSS HAROLDSON, YIXIN REN, ANVAR ZAKHIDOV, WENCHUANG HU, JULIA CHAN, Univ of Texas - Dallas, UTD NANOIMPRINT TEAM — We present an innovative approach of using thermal nanoimprinting lithography (NIL by hot embossing) to pattern hybrid perovskites into ordered micro and nanostructures with improved crystallinity and morphology. The spin-coated thin films of organic-inorganic perovskite CH$_3$NH$_3$PbI$_3$ have been embossed by large area stamps of highly periodic nanopatterns at the scale of 200 to 600 nm. XRD shows the larger and aligned grains, while SEM reveals much improved film morphology with no pin-holes and much less grain boundaries. The obtained ordered periodic micro- and nanostructures show iridescent coloration due to Bragg scattering in planar perovskite photonic crystals.

10:36AM X8.00012 Spatially resolved optoelectronic characterization of perovskite lead iodide nanostuctures, RUI XIAO, XINGYU PENG, YASEN HOU, DONG YU, Univ of California - Davis — The high power conversion efficiency of organo-lead halide perovskite-based solar cells has attracted worldwide attention over the past few years. The high efficiency was believed to originate from the unusual properties including long carrier lifetimes and consequent long carrier diffusion lengths in these materials. Ion drift, ferroelectricity, and charge traps have been proposed to account for the efficient charge separation and photocurrent hysteresis. However, it remains unclear which mechanism is dominating. We fabricate field effect transistors (FETs) incorporating single nanoplates/nanowires of organic perovskite and perform scanning photocurrent microscopic (SPCM) measurements to extract carrier diffusion lengths as a function of gate voltage, source-drain bias. Spatially resolved optoelectronic investigations of single crystalline perovskite nanostuctures provide valuable information and key evidence on distinguishing the dominating charge transport/separation mechanism.

Friday, March 18, 2016 8:00AM - 11:00AM — Session X13 GMAG DMP: Hall-Bar Structure for the Detection of Spin/Valley Hall Effect 309 - Wei Han, Peking University

8:00AM X13.00001 Topological Superconductivity in HgTe-based Devices, LAURENS MOLENKAMP, Wuerzburg University — Suitably structured HgTe has been shown to be a topological insulator in both 2- (a quantum well wider than some 6.3 nm) and 3 (an epilayer grown under tensile strain) dimensions with favorable properties for quantum transport studies, i.e. a good mobility and a complete absence of bulk carriers. In this talk I will summarize the results of our efforts (in collaboration with colleagues all over the globe) to induce superconductivity in the topological surface states of these materials. Special emphasis will be given to recent results on the ac Josephson effect. We will present data on Shapiro step behavior that is a very strong indication for the presence of a gapless Andreev mode in our Josephson junctions.

8:36AM X13.00002 Origins of Nonlocality Near the Neutrality Point in Graphene, JOSHUA FOLK, University of British Columbia — Nonlocal measurements are an effective experimental tool for probing non-charged characteristics of carriers using a (charge) transport measurement. For example, nonlocal signals in a Hall bar geometry can indicate spin currents, or valley currents, or heat currents flowing through a sample without an accompanying charge current. We present an experimental study of nonlocal electrical signals near the Dirac point in graphene, with the goal of disentangling the various types of current that might give rise to nonlocality. The in-plane magnetic field dependence of the nonlocal signal confirms the role of spin in this effect, as expected from predictions of the Zeeman spin Hall effect in graphene, but our experiments show that thermo-magneto-electric effects also contribute to nonlocality, and the effect is sometimes stronger than that due to spin.

9:12AM X13.00003 Spin Hall effect and spin transport in graphene and 2D heterostructures, BARBAROS OEZYLMAZ, National University of Singapore — Semiconducting 2D materials offer new opportunities in both alternative technologies and fundamental discoveries by using the spin degree of freedom of electrons. One of the main challenges in this field is to identify new materials which allow the control of spin currents by means of the electric field effect. This requires either a sizeable spin-orbit coupling strength or a sizeable bandgap or both. Unfortunately, pristine graphene has a negligibly small spin-orbit coupling strength. Recently we have addressed this problem in three distinct ways. First we have used chemical functionalization to introduce locally sp3 type bonding. Next we used metal ad-atoms to increase spin-orbit coupling via local enhancement of the spin-orbit coupling strength due to resonant scattering. Finally, I will show that the proximity of graphene on transition metal dichalcogenides can also lead to a significant enhancement of the spin-orbit coupling strength. I will complete my talk with a brief discussion on the possibility of all electrical spin injection into complementary 2D crystals such as WS2, MoS2 or black phosphorus.

1Membership Pending in the abstract Special Instructions field
Electron transport nonlocality in monolayer graphene modified with hydrogen silsesquioxane polymerization. 

ALEXEY KAVERZIN, Univ of Groningen — Physical properties of electrons in graphene offer not only functionality in terms of conventional charge transport, but also allow to explore spin and valley degrees of freedom. The presence of internal coupling between the nontrivial current states and normal charge current provides the effective mechanism for studying these properties. At the same time a nonlocal geometry of the transport experiments allows to separate the useful signal associated with either spin or valley degree of freedom from trivial charge contribution. In this work we studied an interface between a ferromagnetic (FM) and a nonmagnetic (NM) material, which would inevitably produce some complications in the analysis. Here, we report a new method using simply nanoscale H-pattern of gold, which is free from any interface between FM/NM, to obtain the small-sized skyrmion in gold thin films. A spin Hall angle around 0.1 is obtained for 10nm gold film but negligibly small for 60 nm gold. This result has not only clarified the controversy about the spin hall angle in gold thin film, but also proved the feasibility of using H-pattern to measure SHE in metallic system.

10:24AM X13.0005 Spin Hall Angle in Gold thin films: large or small? . XIAOFENG JIN, Fudan University

Most of the methods so far adopted to determine the spin Hall angle are involved with the interface between a ferromagnetic (FM) and a nonmagnetic (NM) material, which would inevitably produce some complications in the analysis. Here, we report a new method using simply nanoscale H-pattern of gold, which is free from any interface between FM/NM, to obtain the spin Hall angle in gold thin films. A spin Hall angle around 0.1 is obtained for 10nm gold film but negligibly small for 60 nm gold. This result has not only clarified the controversy about the spin hall angle in gold thin film, but also proved the feasibility of using H-pattern to measure SHE in metallic system.

Friday, March 18, 2016 8:00AM - 11:00AM

Session X18 GMAG DMP: Bulk and Artificial Skyrmions

8:00AM X18.00001 Emergence of skyrmions from rich parent phases in the molybdenum nitrides . JIADONG ZANG, Univ of New Hampshire, WEI LI, Shanghai Institute of Microsystem and Information Technology, CAS, CHIMING JIN, High Magnetic Field Laboratory, CAS, RENCHAO CHE, Fudan University, JENSSEN WEI, LANGSHENG LIN, LEI ZHANG, HAIFENG DU, MINGLIANG TIAN, High Magnetic Field Laboratory, CAS — We report a new family of skyrmion materials originated from the antisymmetric Dzyaloshinskii-Moriya (DM) interactions. Based on the symmetric tensor technique, the molybdenum nitrides with the $\beta$-manganese structure, $A2Mn3N$ with $A=Fe$, Co, Rh, are predicted to support the skyrmion phase. This predication is directly proved in doped $FeCo_{1-x}Rh_{x}Mo_{2}N$ components by high resolution Lorentz transmission electron imaging. Interestingly, the parent compounds $Fe2Mo3N$, $Co2Mo3N$, and $Rh2Mo3N$ exhibit ferromagnetic, anti-ferromagnetic, and even superconducting orderings respectively. Magnetism in these parent phases is theoretically clarified by the first-principle calculations, where the corrected nature of the magnetism is revealed.

8:12AM X18.00002 Magnetic phase diagram of doped MnSi . CHETAN DHITAL, MOJAMMEL KAHHN, ADAM P. PHELAN, DAVID P. YOUNG, RONGYING JIN, JOHN DITUSA, Louisiana State University — The noncentrosymmetric chiral structure of cubic B20 compound MnSi favors Dzyaloshinskii-Moria (DM) interaction ($D$) where the broken inversion symmetry determines direction of $D$ and the strength of spin-orbit coupling determines the magnitude of $D$. This relatively weak DM interaction $D$ competes against the exchange interaction $J$ resulting in rather unusual long wavelength helimagnetism with the period set by the ratio $(J/D)$. Previous work has shown that both helimagnetic period ($\lambda$) and the transition temperature ($T_C$) are reduced as a result of either $Fe$ or $Co$ substitutions on Mn site [1, and references therein]. Recently we have started to investigate the effect on the helimagnetic/Skyrmion structure and the transition temperature by chemical substitutions on the Si site. We will present our preliminary magnetization and neutron scattering results where we have found clear evidence of increase in both $T_C$ and helimagnetic period as a result of doping. The possible connection between carrier doping and the strength of DM interaction strength will be discussed.


8:24AM X18.00003 First-principles simulation and low-energy effective modeling of three-dimensional skyrmion in MnGe. HONGCHUL CHOI, YUAN-YEN TAI, JIAN-XIN ZHU, Los Alamos National Laboratory, T-4 TEAM — The skyrmion spin textures are mostly observed in two-dimensional (2D) space, which can be topologically mapped onto the surface of the sphere with an integer multiple of topological winding number. Recently, MnGe has been reported as a candidate of 3D skyrmion crystal, showing the variation of the skyrmion size along the $z$-direction [1,2]. We have performed the first-principles simulation and constructed a tight-binding model with calculated electronic-structure information to investigate the 3D skyrmion phase in MnGe. Our first-principles study within density functional theory shows that the calculated magnetic moment is larger than that for MnSi (with different lattice constant), implying the possibility of a multiple magnetic transition under pressure [3]. We have also found that the small-sized skyrmion could be stabilized in a 2D structure. Such a high density of the skyrmion is in good agreement with the experimental finding of large topological Hall effect [1]. Finally, we will extend our study to consider the 3D skyrmion structure based on the constructed tight-binding model. [1] Y. Shiomi et al., Phys. Rev. B 88, 064409 (2013); [2] T. Tanigaki et al., Nano Lett. 15, 5438 (2015); [3] M. Deutsch et al., Phys. Rev. B 89, 180407 (2014).

This work was carried out under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at Los Alamos National Laboratory (LANL) under Contract No. DE-AC52-06NA25396, and was supported by the LANL LDRD Program.

8:36AM X18.00004 Study of topological spin texture in B20 crystalline FeGe films. EMRAH TURGUT, ALBERT PARK, KAYLA NGUYEN, ROBERT HOVĐEN, School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853 USA, LENA KOURKOUTIS, DAVID MULLER, GREGORY FUCHS, School of Applied and Engineering Physics & Kavli Institute at Cornell for Nanoscale Science, Cornell University, Ithaca, NY 14853 USA — The possibility of efficient and robust information storage in B20-helimagnet systems has been attributed significant interest. Although there have been promising transmission electron microscopy (TEM) and transport studies on bulk B20 crystalline materials, the development of applications motivates study of thin-film samples grown with scalable techniques such as magnetron sputtering. Here we report transport and characterization measurements of FeGe thin films grown on Si <111> by magnetron co-sputtering. We obtain well-oriented but polycrystalline FeGe films with the B20 crystalline phase after post-growth annealing. Low temperature TEM imaging reveals that the lattice mismatch between the Si substrate and FeGe film introduces disordered helical magnetic phases. In addition, bulk susceptibility measurements of a continuous film and AMR measurements of micron-size wires indicate helical, conical, and ferromagnetic phases, but not an obvious skyrmion phase. Similar to recent reports, our measurements confirm that the observations of additional contributions to Hall effect measurements in B20 materials are not necessarily proof of magnetic skyrmion phase, and that more careful experimental studies are needed to understand thin-film properties of B20 materials.
Skyrmion domains in Cu2OSeO3: Short-Range Order and Domain Wall Formation.

SHILEI ZHANG, Department of Physics, University of Oxford, ANDREAS BAUER, Physik Department, Technische Universität München, HELMUTH BERGER, Ecole Polytechnique Federale de Lausanne (EPFL), STAVROS KOMINEAS, Department of Mathematics and Applied Mathematics, University of Crete, DAVID BURN, Diamond Light Source, CHRISTIAN PFLEIDERER, Physik Department, Technische Universität München, GERRIT VAN DER LAAN, Diamond Light Source, THORSTEN HESJEDAL, Department of Physics, University of Oxford — Cu2OSeO3 is a chiral ferrimagnetic insulator carrying a long-range order magnetic skyrmion phase. Here, we report a short-range ordered equilibrium skyrmion state on the surface of Cu2OSeO3 single crystal, studied by resonant soft x-ray scattering. Soft x-ray scattering at the L3-edge of 3d compounds is an ideal tool to probe the magnetic order, and is only sensitive to 60-70 unit cells in depth of Cu2OSeO3. Our results show that under the arbitrary magnetic field directions that deviate from the cubic main axes, the six-fold-symmetric skyrmion order breaks into domains, and the initial, anisotropy-governed pinning of propagation directions is completely unwound. We show that uniform 360° Bloch domain walls form between the skyrmion domains. Our findings provide a new way to manipulate and engineer the skyrmion state locally, or even individually, on the surface which will enable applications in the future.

WIEBE, Institute for Nanostructure and Solid State Research, Hamburg University, A. A. KHAJETOORIANS, Institute for Molecules and Materials, Radboud University Nijmegen, M. STEINBRECHER, Institute for Nanostructure and Solid State Research, Hamburg University, M. TERNES, Max Planck Institute for Solid State Research, Stuttgart, M. BOUHAISSEUNE, M. DOS SANTOS DIAS, S. LOUNIS, Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, R. WIESENDANGER, Institute for Nanostructure and Solid State Research, Hamburg University — Chiral magnets are a promising route toward dense magnetic storage technology due to their inherent nano-scale dimensions and energy efficient properties. Engineering chiral magnets requires atomic-level control of the magnetic exchange interactions, including the Dzyaloshinskii-Moriya interaction, which defines a rotational sense for the magnetization of two coupled magnetic moments. Here we show that the indirect conduction electron mediated Dzyaloshinskii-Moriya interaction between two individual magnetic atoms on a metallic surface can be manipulated by changing the interatomic distance with the tip of a scanning tunneling microscope. We quantify this interaction by comparing our measurements to a quantum magnetic model and ab-initio calculations yielding a map of the chiral ground states of pairs of atoms depending on the interatomic separation. The map enables tailoring the chirality of the magnetization in dilute atomic-scale magnets.

Acknowledgements: SFB668, GrK1286, SFB767, LO 1659 5-1, Emmy Noether Program of the DFG, FOM of NWO, VNS-NG-717
10:00AM X18.00011 Collapse and control of the MnAu$_2$ spin spiral state through pressure and dopin. JAMES GLASBRENNER, National Research Council/Naval Research Lab — MnAu$_2$ is a spin spiral material with ferromagnetic Mn layers that rotate from plane to plane. The spiral angle $\theta$ decreases with pressure and collapses to a ferromagnetic state above a critical threshold, although different experiments do not agree on whether the collapse is first or second order. To resolve this contradiction, we employ density functional theory to calculate magnetic energies in the spin spiral state under both pressure and charge doping and fit the results to the $J_z - J_x - J_y$ Heisenberg model, which predicts either first or second order phase transitions depending on the set of exchange parameters. At ambient pressure, MnAu$_2$ sits very close to a dividing line separating first and second order transitions, if the system is at the second order region of parameter space. Our findings show how variations in material quality can impact how the spiral state collapses, which resolves the contradiction in pressure experiments. Our results also suggest that MnAu$_2$ is amenable to engineering via chemical doping and to controlling $\theta$ using pressure and gate voltages, which holds potential for integration in spintronic devices.

10:12AM X18.00012 Neutron Study of Spiral Magnetism in Au$_2$Mn$_x$. I-LIN LIU, MARIA PASCALE, University of Maryland, College Park, NICHOLAS BUTCH, NIST - Natl Inst of Std & Tech — The binary compound Au$_2$Mn$_x$ is known to order magnetically with a spiral structure. The pitch of the spiral has been previous shown to be dependent upon temperature and pressure. We will discuss the results of neutron diffraction measurements, in which we study the low temperature behavior of the spiral to higher pressure.

10:24AM X18.00013 Chiral Magnets Under a Tilted Magnetic Field: Noncircular Skyrmions. AVADH SAXENA, SHI-ZENG LIN, Los Alamos National Lab — The equilibrium and dynamical properties of skyrmions in thin films of chiral magnets are studied in the presence of oblique magnetic fields. The shape of an individual skyrmion is found to be noncircular and the skyrmion density decreases with the tilt angle (from the normal of the film). Consequently, the interaction between two skyrmions depends on the relative angle between them besides their separation. Under a perpendicular magnetic field a triangular lattice of skyrmions is formed which is distorted into a centered rectangular lattice when the magnetic field is tilted. For low skyrmion densities a chainlike structure of skyrmions is formed. The dynamical response (including the Hall angle of motion) of the noncircular skyrmions is found to depend on the direction of external currents.

10:36AM X18.00014 Anisotropy of Skyrmion Lattice in Mn$_{0.9}$Fe$_{0.1}$Si probed by magnetic field orientation dependence of the topological Hall effect and magnetoresistance. PETER SIEGFRIED, ANDREW TREGLIA, ALEXANDER BORNSTEIN, University of Colorado Boulder, THOMAS WOLF, Karlsruhe Institute of Technology, MINHYEAA LEE, University of Colorado Boulder — We report the magnetic field orientation dependence of the topological Hall effect (THE) and magnetoresistance (MR) of Mn$_{0.9}$Fe$_{0.1}$Si in the $\Lambda$-phase within the applied magnetic field ($H$) temperature ($T$) phase diagram. In the $\Lambda$-phase a two dimensional Skyrmion lattice is formed in the plane perpendicular to the direction of $H$, which is responsible for the observed THE signal. At a given $T$ within the $\Lambda$-phase, we investigated the angular dependence of THE and MR at a fixed $H$ to probe the boundaries of the $\Lambda$-phase region. We find the MR signal exhibits a unique $H$-direction dependence at the entering and exiting of the $\Lambda$-phase, whereas, in the middle $H$ range, i.e. in the core of $\Lambda$-phase, the angular dependence is consistent with what is expected from a perfect 2D Skyrmion lattice. However, THE signals show extreme sensitivity upon entering the $\Lambda$-phase and unexpected angular dependence, yet did not leave any trace through exiting. The discrepancy between the angular dependence of MR and THE signals at the $\Lambda$-phase boundaries indicates a crucial role of Fe impurities as pinning centers for the Skyrmions. We will discuss further our $H$-orientation dependence of the THE, compared to sweeping $H$ at a fixed angle in Fe doped MnSi.

3Work at the University of Colorado was supported by the US DOE Basic Energy Sciences under Award No. DE-SC0006888.

10:48AM X18.00015 Critical phenomena of emergent monopoles in a chiral magnet. XIAO-XIAO ZHANG, Univ. of Tokyo, NAOTO NAGAOSA, Univ. of Tokyo and RIKEN CEMS — A three-dimensional cubic Skyrmion crystal in the bulk, which is simultaneously a lattice of monopole-antimonomopole pairs predicted theoretically, has been recently identified experimentally in MnGe. Adopting appropriate temperature Green’s function technique for optical conductivity and devising a solvable phonon-magnon interaction, we systematically developed the theory of coupling spin-waves to both itinerant electrons and mechanical degrees of freedom in this chiral magnet, describing the latest experimental observations including anomalies and critical phenomena in magnetotransport and magnetoelasticity, which are identified as hallmarks of fluctuations of the emergent monopolar fields upon the nontrivial monopole dynamics and especially a topological phase transition signifying strong correlation. As a whole, they speak for a crucial role played by the monopole defects and hence the real-space spin topology in this material.

Friday, March 18, 2016 8:00AM - 11:00AM — Session X19 GMAG DMP: Magnetic Oxide Thin Films and Heterostructures: Electrostatic, Ionic, and Magnetoelectric Coupling 316 - Philip Ryan, Argonne National Laboratory

8:00AM X19.00001 Electric-Field Coupling to Spin Waves in a Centrosymmetric Ferrite. TIANYU LIU, Optical Science and Technology Center and Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa 52242, USA — A systematic control of spin waves via external electric fields has been a long standing issue for the design of magnonic devices, and is of fundamental interest. One way to attain such control is to use multiferroics [1], whose electric and magnetic polarizations are inherently coupled. The lack of electric polarization in a centrosymmetric ferrite, however, makes direct coupling of its magnetization to external electric fields a challenge. Indirect electric control of spin waves has been accomplished by hybridizing yttrium iron garnet (YIG), a centrosymmetric ferrite, with a piezoelectric material [2]. Here, we predict direct control of spin waves in YIG by a flexoelectric interaction, which couples an electric field to the spatial gradient of the magnetization, and thus the spin waves [3]. Based on a superexchange model, which describes the antiferromagnetic coupling between two nearest neighbor iron ions through an oxygen ion, including spin-orbit coupling, we estimate the coupling constant and predict a phase shift linear in the applied electric field [4]. The theory is then confirmed by experimental measurement of the electric-field-induced phase shift in a YIG waveguide [5]. In addition to the flexoelectric effect, another electric effect is observed, which couples the electric field directly with the magnetization of YIG. We call this a magnetoelectric effect. By adjusting the direction of the electric field, the two effects can be well separated. Experimental results agree quantitatively with the theoretical prediction. A phenomenological coupling constant for the magnetoelectric effect is also obtained. Our findings point to an important avenue for manipulating spin waves and developing electrically tunable magnonic devices. [1] P. Rovillain et al., Nat. Mater. 9, 975 (2010). [2] M. Bao et al., Appl. Phys. Lett. 101, 022409 (2012). [3] T. Liu and G. Vignale, J. Appl. Phys. 111, 083907 (2012). [4] T. Liu and G. Vignale, Phys. Rev. Lett. 106, 247203 (2011). [5] X. Zhang et al., Phys. Rev. Lett. 111, 037202 (2014). [6] The author gratefully acknowledges collaborations with G. Vignale, M.E. Flattery, X. Zhang and H. X. Tang. This work is supported by DARPA Meso and an ARO MURI.
8:36AM X19.00002 Enhanced magneto-ionic switching of interface anisotropy in Pt/Co/GdOx films, AIK JUN TAN, MAX MANN, UWE BAUER, GEOFFREY BEACH, MIT — Voltage control of magnetic anisotropy is of great interest for reducing the switching energy barrier in spintronic devices. It has recently been shown that electric field-driven oxygen ion migration near the interface of ferromagnet/nitride bilayers can lead to very large changes in magnetic anisotropy at elevated temperature. Here, we examine magneto-ionic switching in ultrathin Pt(3nm)/Co(0.9nm)/GdOx(t/oxide) bilayers. We find that for optimally oxidized GdOx, a positive bias voltage applied to the Au electrode results in a transition from PMA to in-plane magnetization, and at zero bias, the single phase system returns. The rate of this transition depends on the thickness of the Au gate which suggests that the rate-limiting step is removal and reintroduction of oxygen by gate voltage. This toggling of PMA under positive bias does not require oxidation of the Co layer, in contrast to earlier work by Uwe et al. We demonstrate that by optimizing the electrode materials, extremely fast room-temperature switching can be achieved in these devices.

8:48AM X19.00003 Giant enhancement of magnetocrystalline anisotropy in ultrathin magnetite films via nanoscale 1D periodic depth modulation, ANIL RAJAPITAMAHIUNI, LE ZHANG, VIJAY SINGH, JOHN BURTON, MAK KOTEN, JEFFREY SHIELD, EVGENY TSYMBA, XIA HONG, University of Nebraska-Lincoln — We report a unusual giant enhancement of in-plane magnetocrystalline anisotropy (MCA) in ultrathin colossal magnetoresistive oxide films due to 1D nanoscale periodic depth modulation. High quality epitaxial thin films of La0.67Sr0.33MnO3 (LSMO) of thickness 6 nm were grown on (001) SrTiO3 substrates via off-axis radio frequency magnetron sputtering. The top 2 nm of LSMO films are patterned into periodic nano-stripes using e-beam lithography and reactive ion etching. The resulting structure consists of nano-stripes of 2 nm height and 100-200 nm width on top of a 4 nm thick continuous base layer. We employed planar Hall effect measurements to study the in-plane magnetic anisotropy of the patterned and unpatterned films. The unpatterned films show a biaxial anisotropy with easy axis along [110]. The extracted anisotropy energy density is “1.1 x 10^6 erg/cm^3, comparable to previously reported values. In the nanopatterned films, a strong uniaxial anisotropy is developed along one of the biaxial easy axes. The corresponding easy anisotropy energy density is “5.6 x 10^6 erg/cm^3 within the nano-striped volume, comparable to that of Co. We attribute the observed uniaxial MCA to MnOx octahedral rotations/tilts and the enhancement in the anisotropy energy density to the strain gradient within the nano-stripes.

9:00AM X19.00004 Magnetoelectric Dead Layer and Uncompensated Spins in Magnetic/Ferroelectric Heterostructures, MIKEL HOLCOMB, CHIH-YEH HUANG, GUERAU CABRERA, West Virginia University, YING-HAO CHU, National Chiao Tung University, WEST VIRGINIA UNIVERSITY TEAM, NATIONAL CHIAO TUNG UNIVERSITY TEAM — Interfacial magnetoelectricity across a multilayer system is known to result in sometimes result in much larger coupling between electric and magnetism than between two separate systems. We compare the magnetic domains in LaSrMnO3 films, ferroelectric domains in PbZrTiO3 and observed uncompensated spin at the interface. Several techniques to quantify image contrast switching between left and right circularly polarized x-ray absorption spectra of magnetic domains and uncompensated spin were developed and gave similar results. Not surprisingly, the magnetic domain switching increased with magnetic film thickness, but the uncompensated spin did as well. This results suggests that there may be an effective magnetoelectric dead layer at the interface between coupled magnetic and ferroelectric layers, which is likely to limit the at least the magnetic dead layer in the magnetic film. These measurements were taken L-edge spectromicroscopy at the PEE3 beamline of the Advanced Light Source.

9:12AM X19.00005 Magnetoelectric Coupling Characteristics of the La0.67Sr0.33MnO3/PbZr0.2Ti0.8O3 (001) Interface1, MAHMOUD HAMMOURI, DMITRY KARPOV, New Mexico State University, EDWIN FOHTUNG, New Mexico State University and Los Alamos National Laboratory, IGOR VASILIEV, New Mexico State University — Multiferroic heterostructures are attracting considerable attention in recent years. We apply ab initio computational methods based on density functional theory to study the characteristics of the magnetoelectric coupling at the (001) interface between La0.67Sr0.33MnO3 (LSMO) and PbZr0.2Ti0.8O3 (PZT). The calculations are carried out using the Quantum ESPRESSO electronic structure code combined with Vanderbilt ultrasoft pseudopotentials. Our study shows that the interfacial interaction between LSMO and PZT and the polarization of PZT have a strong influence on the distribution on magnetization in the LSMO layer. A significant change in the magnetization of the LSMO layer adjacent to PZT is observed after reversal of the direction of polarization of PZT.

1Supported by NMSU GREG award. EF is funded by the DoD-AFOSR under award No FA9550-14-1-0363.

9:24AM X19.00006 Large enhancement of magnetic anisotropy and laser induced resistive switching effect in La0.7Sr0.3MnO3 films due to strain from BaTiO3 substrates1, V KALAPPATTIL, R DAS, H SKEKANTH, M.K PHAN, Department of Physics University of North Florida, X MOYA, Department of Materials Science, University of Cambridge, UK — Multiferroic oxide materials are interesting for their fundamental physical properties and technological applications. Epitaxial films of La0.7Sr0.3MnO3 (LSMO) on BaTiO3 (BTO) show intriguing properties such as a giant magnetoelectric effect due to strain from BTO substrate. The LSMO film shows sharp jumps in magnetization (M(T)) and resistance (R(T)) at first-order structural phase transitions of BTO (Tc=200K and Tm=270 K) due to strain coupling from BTO. A temperature evolution of effective in-plane anisotropy field (Hx) measured using the radio-frequency transverse susceptibility (TS) shows a sharp increase in Hx around Tc, which vanishes around TO-T. The in-plane magnetic anisotropy plays an important role in changing the magnetic and resistive states around TO-T. A switchable laser-induced resistive change of up to 300 %, which is about 10 times greater than those of conventional oxide systems, has been achieved in LSMO films using a 0.5 W violet laser just below the TO-T. The repeatability and scalability of the laser-induced resistive switching effect reveal potential applications of LSMO/BTO heterostructures in developing new type of temperature sensors and memory devices.

1Work at USF supported by ARO Grant No. W911NF-15-1-0626

9:36AM X19.00007 Reversible Control of Magnetism in La0.67Sr0.33MnO3 through Chemically-Induced Oxygen Migration, ALEXANDER GRUTTER, DUSTIN GILBERT, BRIAN MARANVILLE, JULIE BORCHERS, BRIAN KIRBY, National Institute of Standards and Technology, ELKE ARENHOLZ, Lawrence Berkeley National Lab, URUSA ALAA, YURI SUZUKI, Stanford University, KAI LIU, University of California, Davis — There has been a surge of interest in controlling magnetism through oxygen migration for applications in hybridionic/magnetoelectric device architectures. With a rich magnetic and electronic phase diagram, the colossal magnetoresistive perovskite (La,Sr)MnO3 (LSMO) is an ideal candidate for achieving large modulations in magnetic properties with small changes in oxygen content. We demonstrate reversible control of magnetism in LSMO films through interfacial oxygen migration. Gd metal capping layers deposited onto LSMO leach oxygen from the film to form porous Gd2O3. X-ray absorption and polarized neutron reflectometry measurements show Mn valence alterations consistent with high oxygen vacancy concentrations, resulting in suppressed magnetization and increased coercive fields. Oxygen migration is observed both at the interface and also throughout the majority of a 40 nm thick film, suggesting extensive oxygen vacancy diffusion. After Gd-capped LSMO is exposed to atmospheric oxygen for a prolonged period of time, oxygen diffuses through the Gd2O3 layer and the magnetization of the LSMO returns to the uncompensated state. These findings showcase perovskite heterostructures as ideal candidates for developing functional interfaces through chemically-induced oxygen migration.
9:48AM X19.00008 Detecting interfacial defects at magnetic/non-magnetic junctions¹, NICHOLAS HARMON, MICHAEL FLATTÉ, University of Iowa — Recent three terminal (3T) measurements in Co/LaAlO3/SrTiO3 show that spin-dependent transport through an interfacial defect is occurring instead of Hanle dephasing [1]. We propose extending 3T measurements into a coherent regime where single defects are detected by their local fields. The setup involves defects being situated between biased non-magnetic (NM) and ferromagnetic (FM) contacts. Spin torque on the FM drives an AC magnetization. Due to the large exchange interaction, the ability for charge to enter the FM depends on its spin and FM’s relative orientation. As the FM precesses, the spin is dynamically filtered and a precessing spin accumulation remains at the defect. Local fields also precess the defect spin and interfere with the dynamic spin filtering. If the AC and local field are resonant, the spin accumulation is locked anti-parallel to the FM and leads to a dip in current. By adjusting the AC frequency, information on the local field is ascertainted which, for hyperfine local fields, tells which nuclei are present at the defect and aids in identifying the defect. In the DC limit, defect spin accumulation leads to modifications in Hanle signals. [1] H. Inoue, A.G. Swartz, N.J. Harmon, M.E. Flatté, T. Tachikawa, Y. Hikita, and H.Y. Hwang. In press at Phys. Rev. X.

¹This material is based on work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Award Number DE-SC0014336.

10:00AM X19.00009 Electronic and Magnetic Properties of Transition-Metal Oxide Nanocomposites: A Tight-Binding Modeling at Mesoscale,¹ YUAN-YEN TAI, Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA, JIAN-XIN ZHU, Theoretical Division and Center for Integrated Nanotechnologies, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — Transition metal oxides (TMOs) exhibit many emergent phenomena ranging from high-temperature superconductivity and giant magnetoresistance to magnetism and ferroelectricity. In addition, when TMOs are interfaced with each other, new functionalities can arise, which are absent in individual components. In this talk, I will present an overview on our recent efforts in theoretical understanding of the electronic and magnetic properties TMO nanocomposites. In particular, I will introduce our recently developed tight-binding modeling of these properties arising from the interplay of competing interactions at the interfaces of planar and pillar nanocomposites. Our theoretical tool package will provide a unique capability to address the emergent phenomena in TMO nanocomposites and their mesoscale response to such effects like strain and microstructures at the interfaces, and ultimately help establish design principles of new multifunctionality with TMOs.

¹This work was carried out under the auspices of the National Nuclear Security Administration of the U.S. Department of Energy at LANL under Contract No. DE-AC52-06NA25396, and was supported by the LANL LDRD Program.

10:12AM X19.00010 Direct measurement of voltage-controlled reversal of the antiferromagnetic spin structure in magnetoelectric Cr₂O₃¹, JUNLEI WANG, CHRISTIAN BINEK, University of Nebraska-Lincoln — The frequency dependence of the electric field induced magneto-optical Faraday effect is investigated in the magnetoelectric antiferromagnet chromia. Two electrically induced Faraday signals superimpose in proportion to the linear magnetoelectric susceptibility and the antiferromagnetic order parameter. The relative strength of these contributions is determined by the frequency of the probing light beam. It allows tuning the Faraday signal between extreme characteristics which follow the temperature dependence of the magnetoelectric susceptibility or solely that of the antiferromagnetic order parameter. The frequency dependence is analyzed in terms of electric dipole transitions of perturbed Cr³⁺ crystal-field states. The results lead to a table-top set-up allowing to measure voltage-controlled selection and temperature dependence of the antiferromagnetic order parameter. The Faraday rotation per applied voltage is independent of the sample thickness making the method scalable and versatile for thin film investigations. Scalability, compactness, and simplicity of the data analysis combined with low photon flux requirements make the Faraday approach advantageous for the investigation of the otherwise difficult to access voltage-controlled switching of antiferromagnetic domain states in magnetoelectric thin films.

¹This project is supported by NRI via CNFD through tasks SRC 2398.001 and 2587.001, by C-SPIN, a SRC program, sponsored by MARCO and DARPA, and by NSF through Nebraska MRSEC DMR-1420645.

10:24AM X19.00011 Voltage Control of Exchange Bias in a Chromium Oxide Based Thin Film Heterostructure¹, WILL ECHTENKAMP, MIKE STREET, AHER MAHMOOD, CHRISTIAN BINEK, Univ of Nebraska - Lincoln — Controlling magnetism by electrical means is a key challenge in the field of spintronics, and electric control of exchange bias is one of the most promising routes to address this challenge. Isothermal electric control of exchange bias has been achieved near room temperature using bulk, single crystal, magnetoelectric Cr₂O₃ [1,2]. In this study the electrically-controlled exchange bias is investigated in an all thin film Cr₂O₃/PdCo exchange bias heterostructure where an MBE grown ferromagnetic and perpendicular anisotropic Pd/Co multilayer has been deposited on a PLD grown (0001) Cr₂O₃ thin film. Prototype devices are fabricated using lithography techniques. Using a process of magnetoelectric annealing, voltage control of exchange bias in Cr₂O₃ heterostructures is demonstrated with significant implications for scalability of ultra-low power memory and logical devices. In addition, the dependence of the exchange bias on the applied electric and magnetic fields are independently studied at 300K and isothermal voltage-controlled switching is investigated. [1] Xi He, et al., Nature Mater. 9, 579-585 (2010). [2] W. Echtenkamp and Ch. Binek, Phys. Rev. Lett. 111, 187204 (2013).

¹This project was supported by SRC through CNFD, an SRC-NRI Center, by C-SPIN, part of STARnet, and by the NSF through MRSEC DMR-0820521.

10:36AM X19.00012 Eliminating leakage current in voltage-controlled exchange-bias devices¹, AHER MAHMOOD, WILL ECHTENKAMP, MICHAEL STREET, CHRISTIAN BINEK, Univ of Nebraska - Lincoln, MAGNETIC HETEROSTRUCTURES TEAM — Manipulation of magnetism by electrical field has drawn much attention due to the technological importance for low-power devices, and for understanding fundamental magnetoelectric phenomena. A manifestation of electrically controlled magnetism is voltage control of exchange bias (EB). Robust isothermal voltage control of EB was demonstrated near room temperature using a heterostructure of Co/Pd thin film and an exchange coupled single crystal of the antiferromagnetic Cr₂O₃ (Chromia) [1,2]. A major obstacle for EB in lithographically patterned Chromia based thin-film devices is to minimize the leakage currents at high electric fields (>10 kV/mm). By combining electrical measurements on patterned devices and conductive Atomic Force Microscopy of Chromia thin-films, we investigate the defects which form conducting paths impeding the application of sufficient voltage for demonstrating the isothermal EB switching in thin film heterostructures. Technological challenges in the device fabrication will be discussed. [1] Xi He, et al., Nat. Mater. 9, 579-585 (2010) [2] W. Echtenkamp, Ch. Binek, Phys. Rev. Lett. 111, 187204 (2013)

¹This project was supported by SRC through CNFD, an SRC-NRI Center, by C-SPIN, part of STARnet, and by the NSF through MRSEC Abstract DMR-0820521.
10:48 AM X19.00013 Electromagnetic doping limits and control of magnetism in electrolyte gated LaAlO$_3$(001)/La$_{0.5}$Sr$_{0.5}$CoO$_{3-\delta}$ thin films, JEFF WALTER, HELIN WANG, CHRIS LEIGHTON, University of Minnesota — Recently developed ionic liquid/gel gating techniques have proven remarkably expedient in the study of charge density effects in a variety of conductors, ranging from organics to complex oxides. Here we present electrolyte gate control of magnetism in ultrathin (2 u.c.) La$_{0.5}$Sr$_{0.5}$CoO$_{3-\delta}$ (LSCO) films, using ion gels in electric double layer transistors. The LSCO films are initially metallic and ferromagnetic ($T_C \approx 170$ K), with anomalous Hall conductivity up to 40 S/cm, and strong perpendicular magnetic anisotropy. Based on extensive temperature and gate voltage dependences we first determined the limits for electrostatic vs. electrochemical operation, concluding that negative bias enables reversible hole accumulation, whereas positive bias irreversibly induces oxygen vacancies. Following this we demonstrated clear voltage-control of resistivity, magnetoresistance, and $T_C$. Utilizing the anomalous Hall conductivity as an exceptional probe of the magnetic order parameter in the gated surface region, a 12 K shift in $T_C$ is obtained. This compares favorably to the state-of-the-art and exhibits potential for much larger modulation in films of lower Sr content. Work supported by NSF MRSEC.

Friday, March 18, 2016 11:15AM - 1:39PM
Session Y2 DCMP DMP GMAG: Spin and Valley Pseudo-Spin Transport in Strongly Spin-Orbit Coupled Systems
Ballroom II - Kin Fai Mak, Pennsylvania State University

11:15AM Y2.00001 Transport measurements of MoS$_2$ using a van der Waals heterostructure device platform, JAMES HONE, Columbia University — No abstract available.

11:51AM Y2.00002 Theory of classical and quantum transport in monolayers of MoS$_2$, SHAFFIQUESTADAM, Yale-NUS College, 16 College Avenue West, Singapore 138527, Singapore — From the family of new van der Waals materials, the class of layered transition metal dichalcogenides has emerged as a particularly interesting system due to the inherent spin and valley degrees of freedom. In this talk we focus on the interplay between these degrees of freedom and the different types of disorder in monolayers of molybdenum disulphide. Within the semiclassical Drude-Boltzmann formalism, treating the screening of impurities with the random phase approximation, we demonstrate that different scattering mechanisms such as charged impurity scattering, intervalley scattering, and phonons differ for different signatures in electronic transport. This allows us to conclude, for example, that in CVD-grown monolayers of MoS$_2$, intervalley scattering dominates over other mechanisms at low temperatures (1). Interestingly, charged impurities generate spatial inhomogeneity in the carrier density that results in a classical disorder-induced magnetoresistance that can be observed at room temperature (2). However, at lower temperatures, in this regime of strong intervalley scattering, we predict that the quantum phase-coherent corrections to the conductivity results in a one-parameter crossover from weak localization to weak anti-localization as a function of magnetic field, where this crossover is determined only by the spin lifetime. By comparing with available experimental data (3), we show that this combined framework allows for a novel way to measure the spin-relaxation in monolayers of MoS$_2$. We find that the spin scattering arises from the Dyakonov-Perel spin-orbit scattering mechanism with a conduction band spin-splitting of about 4 meV, consistent with calculations using density functional theory. REFERENCES: [1] “Transport Properties of Monolayer MoS$_2$ Grown by Chemical Vapor Deposition”, H. Schmidt, S. Wang, L. Chu, M. Toh, R. Kumar, W. Zhao, A. H. Castro Neto, J. Martin, S. Adam, B. Özyilmaz, and G. Eda, Nano Lett. 14, 1909 (2014); [2] “Disorder induced magnetoresistance in a two dimensional electron system”, J. Ping, I. Yudhistira, N. Ramakrishnan, S. Cho, S. Adam, M. S. Fuhrer, Phys. Rev. Lett. 113, 047206 (2014); [3] “Quantum transport and observation of Dyakonov-Perel spin-orbit scattering in monolayer MoS$_2$”, H. Schmidt, I. Yudhistira, L. Chu, A. H. Castro Neto, B. Özyilmaz, S. Adam, G. Eda, arXiv:1503.00428, (2015).

1Work done in collaboration with Indra Yudhistira and the experimental groups of Gokt Eda (NUS), Michael Fuhrer (Monash) and Roland Kawakami (Ohio State), and funded by Singapore National Research Foundation and Ministry of Education.

12:27PM Y2.00003 Optical imaging of the valley Hall effect in MoS$_2$ transistors, JIEUN LEE, Penn State University — The newly emerged two-dimensional (2D) transition metal dichalcogenides (TMDs) with nonequivalent K and K’ valleys have provided an ideal laboratory for exploring the valley degree of freedom of electrons, as well as their potential applications for information processing. Valley Hall effect (VHE), in which a transverse valley current is formed under a longitudinal electrical bias in the absence of a magnetic field, has been predicted in 2D TMDs with broken inversion symmetry. The effect has recently been demonstrated in monolayer MoS$_2$ through a photo-induced anomalous Hall effect, which uses circularly polarized light to preferentially excite electrons into a specific valley. In this talk, we will present our recent results on the development of Kerr rotation microscopes to image the VHE. The valley polarizations of opposite sign accumulated on two opposing edges of MoS$_2$ transistors from the VHE are measured directly. We will also discuss the possibility of electrical control of the VHE in bilayer MoS$_2$, which possesses inversion symmetry. An application of a vertical electric field breaks the inversion symmetry and consequently yields the VHE.

1:03PM Y2.00004 Breaking time reversal symmetry, quantum anomalous Hall state and dissipationless chiral conduction in topological insulators, JAGADEESH MOODERA, MIT — Breaking time reversal symmetry (TRS) in a topological insulator (TI) with ferromagnetic perturbation can lead to many exotic quantum phenomena exhibited by Dirac surface states including the quantum anomalous Hall (QAH) effect and dissipationless quantized Hall transport. The realization of the QAH effect in realistic materials requires ferromagnetic insulating materials and topologically non-trivial electronic band structures. In a TI, the ferromagnetic order and TRS breaking is achievable in a TI, the ferromagnetic order and TRS breaking is achievable in the quantum anomalous Hall (QAH) effect and dissipationless quantized Hall transport. In close collaboration with: CuiZu Chang, 2Francis Bitter Magnet Lab, 3Plasma Science and Fusion Center

1Work supported by NSF Grant DMR-1207469, the ONR Grant N00014-13-1-0301, and the STC Center for Integrated Quantum Materials under NSF grant DMR-1231319.

2Physics Department, 2Francis Bitter Magnet Lab, 3Plasma Science and Fusion Center
11:15 AM Y3.00001 INVITED ABSTRACT WITHDRAWN

11:51 AM Y3.00002 Experimental Studies of Berry Phase Effects and Collective Excitations in Skyrmion Materials, CHRISTIAN PFLEIDERER, Physik-Department, Technische Universität München, D-85748 Garching, Germany — The emergence, stability and decay of skyrmions in chiral magnets and the associated emergent electrodynamics are reviewed. The non-zero topological winding, which corresponds to precisely one quantum of emergent magnetic flux, mediates an extremely efficient coupling between the conduction electrons and the magnetic properties. This emergent flux leads to a topological Hall signal, spin transfer torques at ultra-low current densities and emergent electric fields. Additionally skyrmions are characterised by an exceptional stability, which cannot be simply suppressed under large hydrostatic pressures or doping. In fact, measurements of the Hall effect suggest the survival of non-trivial topological winding akin that of the skyrmion lattice in a non-Fermi liquid regime at high pressures, where neutrons scattering suggests the absence of long-range magnetic order. The topological unwinding of skyrmions, which involves emergent magnetic monopoles, may be at the heart of the loss of long-range order.

12:27 PM Y3.00003 Skyrmions in chiral magnets with Rashba and Dresselhaus Spin-Orbit Coupling1, MOHIT RANDERIA, The Ohio State University — Studies of skyrmions in chiral magnets have focused largely on systems with broken bulk inversion and a Dzyaloshinskii-Moriya interaction (DMI) of the Dresselhaus form. The skyrmion crystal is then stable only in a small regime with easy-axis anisotropy. I will show how skyrmion crystal phases can be stabilized over a much larger region of field and anisotropy down to zero temperature in systems with a Rashba DMI that break surface inversion or mirror symmetry [1,2]. Increasing the ratio of Rashba to Dresselhaus DMI leads to a progressively larger domain of stability for skyrmions, especially in the easy-plane anisotropy regime. The spin texture and topological charge density then develop nontrivial spatial structures, different from conventional skyrmions, with a quantized topological charge given by a Chern number. Our theoretical results predict how tuning the Rashba spin orbit coupling and magnetic anisotropy can help stabilize skyrmion phases in thin films, surfaces, interfaces and bulk magnets with broken mirror symmetry. [1] J. Rowland, S. Banerjee, and M. Randeria, arXiv:1509.07508v2. [2] S. Banerjee, J. Rowland, O. Erten, and M. Randeria, PRX 4, 031045 (2014).

1 Supported by the NSF grant DMR-1410364 and by the CEM, an NSF MRSEC, under grant DMR-1420451.

1:03 PM Y3.00004 Skyrmions in frustrated magnets1, SHIZENG LIN, Los Alamos Natl Lab — A skyrmion in magnets or magnetic skyrmion is a stable spin texture with nontrivial topology and behaves like a particle at mesoscale. To stabilize a skyrmion, it is required to have a characteristic length scale, which can be introduced by competing interactions. Recently skyrmion lattice has been observed experimentally in chiral magnets without inversion symmetry, where the skyrmions are stabilized by the competition between the exchange and Dzyaloshinskii-Moriya interactions. The skyrmions in chiral magnets have been studied actively and have been demonstrated to be promising for applications. These skyrmions share qualitatively similar properties in metals, semiconductors and insulators and can be described by a simple universal Hamiltonian. Skyrmions can also be stabilized in frustrated magnets with inversion symmetry. In the talk, we will present a general Ginzburg-Landau theory for the skyrmions in the frustrated magnets. We will discuss their unusual properties in comparison to those in chiral magnets. Finally we will also discuss the conditions for the stabilization of skyrmions.

1 This work was carried out under the auspices of the NNSA of the US DOE at LANL under Contract No. DE-AC52-06NA25396, and was supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering.

Friday, March 18, 2016 11:15 AM - 2:03 PM

11:15 AM Y5.00001 Microscopic origin of the prolonged coherence in 4H-SiC divacancy spin qubits1, HOSUNG SEO, ABRAM FALK, PAUL KLIMOV, DAVID CHRISTLE, DAVID AWSCHALOM, GIULIA GALLI, Institute for Molecular Engineering, University of Chicago — Long coherence times of quantum bits (qubits) is a key prerequisite for quantum computing and quantum metrology. Recently, electronic spin qubits localized to divacancies in 4H-SiC were found to have a long spin coherence time (T2) exceeding 1 ms, which is longer than that of the nitrogen-vacancy (NV) center in chemically but not isotopically purified diamond. In this talk, we discuss the microscopic origin behind the prolonged divacancy coherence. By using optically detected magnetic resonance (ODMR), we show that the divacancy T2 rapidly increases as a function of magnetic field, saturating at 1.3 ms at T = 20 K. We used a quantum-bath model combined with a cluster correlation expansion technique to calculate the divacancy coherence function and found an excellent agreement between theory and experiment. We show that an effective decoupling of the 29Si and 13C nuclear spins due to their gyromagnetic ratio difference is one of the key reasons responsible for suppressing the decoherence of the divacancy qubits in SiC under magnetic fields larger than 100G.

1 We gratefully acknowledge financial support from the National Science Foundation through the University of Chicago MRSEC under award number DMR-1420709.

11:27 AM Y5.00002 Coherent population trapping of a nitrogen vacancy center induced by optical and surface acoustic waves, THEIN OO, ANDREW GOLTER, HAILIN WANG, University of Oregon — We report experimental demonstration of coherent population trapping (CPT) driven by resonant optical and mechanical coupling in a nitrogen vacancy (NV) center in diamond. A surface acoustic wave (SAW) is generated with an inter-digital transducer fabricated on a ZnO layer sputtered on diamond surface. The SAW couples resonantly to a transition between two excited states of the NV center, while a laser field couples to a corresponding resonant optical transition. The combined optical and mechanical coupling to the lambda- or ladder-type three-level system leads to CPT of the NV center. These studies open the door to exploiting strong excited-state electron-phonon coupling for applications such as laser cooling of a mechanical resonator and mechanically-mediated spin entanglement.
11:39AM Y5.00003 Quantum Control of a Nitrogen-Vacancy Center using Surface Acoustic Waves in the Resolved Sideband Limit. DAVID GOLTER, THEIN OO, MAIRA AMEZCUA, HAILIN WANG, University of Oregon — Micro-mechanical systems research is producing increasingly sophisticated tools for nanophonic applications. Such technology is well-suited for achieving chip-based, integrated acoustic control of solid-state quantum systems. We demonstrate such acoustic control in an important solid-state qubit, the diamond nitrogen-vacancy (NV) center. Using an interdigitated transducer to generate a surface acoustic wave (SAW) field in a bulk diamond, we observe phonon-assisted sidebands in the optical excitation spectrum of a single NV center. This exploits the strong strain sensitivity of the NV excited states. The mechanical frequencies far exceed the relevant optical linewidths, reaching the resolved-sideband regime. This enables us to use the SAW field for driving Rabi oscillations on the phonon-assisted optical transition. These results stimulate the further integration of SAW-based technologies with the NV center system.

11:51AM Y5.00004 Development of single-crystal diamond scanning probes with nitrogen-vacancy centers for cryogenic magnetometry with nanoscale spatial resolution. ALEC JENKINS, MATTHEW PELLICIONE, PREETI OVARTCHAIYAPONG, CHRISTOPHER REETZ, ANIA BLESZYNSKI JAYICH, University of California, Santa Barbara — Scanning probes based on the nitrogen-vacancy (NV) defect center in diamond are powerful tools for imaging magnetic phenomena at the nanoscale. In particular, extending the operation of these probes to cryogenic temperatures opens up a wide range of condensed matter systems that can be studied. In this talk, we demonstrate a variable temperature NV scanning magnetometer consisting of an atomic-force microscope housed in a closed-cycle cryostat integrated with custom confocal optics. With this microscope we have observed 6-nm spatial resolution and 3 µT/√Hz sensitivity at T = 6 K. The single-crystal diamond scanning probes that contain shallow and coherent NV centers are critical to the performance of the microscope. The probes are designed with the aim of reducing the NV-sample separation and increasing collection of NV fluorescence, both while maintaining the spin coherence properties of the defects. We describe the fabrication of these probes as well as ongoing efforts to improve their sensitivity and spatial resolution.

12:03PM Y5.00005 Scanned probe imaging of nanoscale magnetism at cryogenic temperatures with a single-spin quantum sensor. MATTHEW PELLICIONE, ALEC JENKINS, PREETI OVARTCHAIYAPONG, CHRISTOPHER REETZ, University of California, Santa Barbara, EVE EMMANUELIIDU, NI NI, University of California, Los Angeles, ANIA BLESZYNSKI JAYICH, University of California, Santa Barbara — The nitrogen vacancy (NV) defect in diamond has emerged as a promising candidate for high resolution magnetic imaging based on its atomic size and quantum-limited sensing capabilities afforded by long spin coherence times. Although the NV center has been successfully implemented as a nanoscale scanning magnetic probe at room temperature, it has remained an outstanding challenge to extend this capability to cryogenic temperatures, where many solid-state systems exhibit non-trivial magnetic order. In this talk, we present NV magnetic imaging at T = 6 K, first benchmarking the technique with a magnetic hard disk sample, then utilizing the technique to image vortices in the iron pnictide superconductor BaFe2(As0.57P0.43)2 with Tc = 30 K. In addition, we discuss other candidate solid-state systems that can benefit from the high spatial resolution and field sensitivity of the scanning NV magnetometer.

12:15PM Y5.00006 Coupling a driven magnetic vortex to individual nitrogen-vacancy spins for fast, nanoscale addressability and coherent manipulation. MICHAEL WOLF, ROBERT BADEA, JESSE BEREZOVSKY, Case Western Reserve University — The core of a ferromagnetic (FM) vortex domain creates a strong, localized magnetic field which can be manipulated on nanosecond timescales using small magnetic fields, or electrical currents. Here, we demonstrate how these FM vortex properties can be used in a room temperature, integrated device by coupling a FM vortex to nitrogen-vacancy (NV) center spins in diamond [1]. Measurements are carried out using a combined magneto-optical microscopy and optically-detected spin resonance technique. We show that the FM vortex can be driven into proximity with an NV, inducing significant NV spin splitting and sufficiently large magnetic field gradient to address spins separated by nanometer length scales. By applying a microwave-frequency magnetic field, we drive both the vortex and the NV spins, resulting in enhanced coherent rotation of the spin state. Finally we demonstrate that by driving the vortex on fast timescales, sequential addressing and coherent manipulation of spins is possible on 100 ns timescales, while driving on faster timescales results in non-trivial coherent dynamics of the coupled vortex/NV system. [1] Wolf, M.S., Badea, R., and Berezovsky, J., cond-mat/1510.07073, (2015)

13We acknowledge support from US Department of Energy, award DE-SC008148

12:27PM Y5.00007 Navigating the vortex pinning landscape for bistable coupling of a ferromagnetic vortex to individual nitrogen vacancy spins. JESSE BEREZOVSKY, MICHAEL WOLF, ROBERT BADEA, Case Western Reserve University — A ferromagnetic (FM) vortex coupled to nitrogen-vacancy (NV) spins in diamond provides an integrated platform for fast, nanoscale addressability of coherent spins [1]. The vortex moves in a complex effective potential landscape set by the geometry of the disk and the defects present in the material. As the vortex moves through this landscape, the coupling to a proximal NV varies. We use differential magneto-optical microscopy to extract the effective potential through which the vortex moves [2], and optically-detected magnetic resonance to study the coupling of the vortex to an adjacent NV spin. When multiple local minima are present in the vortex potential, the vortex/NV coupling displays bistability. We switch between these bistable states with short magnetic field pulses. This allows an NV spin transition to be switched between on-resonance and off-resonance with a driving field with the same set of external parameters, and also yields information about the mechanisms of vortex/NV coupling. [1] M.S. Wolf, R. Badea, J. Berezovsky, arXiv:1510.07073, 2015 [2] R. Badea, J. Berezovsky, arXiv:1510.07059, 2015.

13We acknowledge support from US Department of Energy, award DE-SC008148

12:39PM Y5.00008 Phonon induced two-electron relaxation in two donor qubits in silicon. YULING HSUEH, ARCHANA TANKASALA, YU WANG, GERHARD KLIMECK, Purdue University, MICHELLE SIMMONS, University of New South Wales, RAJIB RAHMAN, Purdue University — An atomistic method of calculating two-electron spin-lattice relaxation times (T1) is presented for two donor qubits in silicon. The singlet-triplet two-electron states are calculated from full-configuration interaction (FCI) method with one-electron basis states obtained from the tight-binding Hamiltonian including spin-orbit interaction. The FCI solution enables the investigation of various regimes of donor separations, including very closely separated donor pairs in which rearrangement of excited bonding and anti-bonding states change the wavefunction symmetries. Hyperfine mixing from the nuclear spins is included perturbatively into the two-electron states. To calculate the T1 times, the electron-phonon Hamiltonian is evaluated from the strain-dependent tight-binding Hamiltonian. The results show how the T1 times in donor qubits vary with magnetic field and donor separation for each of the three triplets. Moreover, the variation of T1 with the electric field controlled exchange coupling is also investigated.
Pauli spin blockade in CMOS silicon double dots probed by dual gate reflectometry

This work supported by the AFOSR, NSF MRSEC, and Argonne LDRD Program.

12:51PM Y5.00009 Pauli spin blockade in CMOS silicon double dots probed by dual gate reflectometry

1:03PM Y5.00010 Direct observation of long-distance coherent superexchange spin coupling in a quantum dot array

1:15PM Y5.00011 Decoherence of an electron spin qubit in an optically active quantum dot

1:27PM Y5.00012 Coherent control of single spins in a silicon carbide pn junction device at room temperature

1:39PM Y5.00013 Optical and Spin Signatures of Transition Metal Impurities in Silicon Carbide

1:51PM Y5.00014 Measurement of Spin Coherence Times in Proton Irradiated 4H-SiC

1:51PM Y5.00014 Measurement of Spin Coherence Times in Proton Irradiated 4H-SiC. JACOB EMBLEY, JOHN COLTON, Brigham Young University, SAM CARTER, Naval Research Lab, KYLE MILLER, Brigham Young University, MARGARET MORRIS, Brandeis University — Silicon vacancy defects in silicon carbide (SiC) have potential for use in solid-state implementations of quantum information technologies. These experiments were performed at a magnetic field strength of 0.371 T and a resonant microwave frequency of 10.5 GHz. Each sample contained silicon vacancy defects that were formed through irradiation with 2 MeV protons at unique fluences (10^{13} and 10^{14} cm^{-2}). Measurements for each sample were made across a range of temperatures, from 8 K to room temperature. While we generally observed a decrease in spin coherence time with temperature, we also observed a range of temperatures (from 60 K to 160 K) for which the overall trend was reversed.
The extreme quantum limit in lightly-doped SrTiO$_3$\(^1\). ANAND BHATTACHARYA, Materials Science Division and Nanoscience and Technology Division, Argonne National Laboratory, Lemont IL, BRIAN SKINNER, Materials Science Division, Argonne National Laboratory, Lemont IL, GURU KHALA, CNST, National Institute of Standards and Technology, Gaithersburg MD, ALEXEY SUSLOV, National High Magnetic Field Laboratory, Tallahassee FL — When a three dimensional electron gas is placed in a sufficiently strong magnetic field, it is said to be in the quantum limit when the cyclotron energy $\hbar \omega_c > > eF > > kT$, and all of the electrons occupy the lowest Landau level. Achieving this limit in a material requires a small Fermi energy relative to the applied magnetic field, and a weak disorder potential such that magnetic freezing-out is avoided. We present an experimental study of lightly-doped single crystals of SrTiO$_3$ which remain good bulk conductors in temperatures down to 25 mK and magnetic fields up to 45 T. Our measurements probe deep into the quantum limit, where $\hbar \omega_c > > eF$ and theory has long predicted that electron-electron interactions can drive the system into a charge density wave or Wigner crystal like state. A number of interesting features arise in electrical transport in this regime, including a striking reentrant nonlinearity in the current–voltage characteristics. We discuss these features in the context of possible correlated electron states, and present a picture based on magnetic field induced puddling of electrons in a disorder potential landscape.

\[^1\]U.S. DOE, BES contract No. DE-AC02-06CH11357; NIST CNST; US NSF Cooperative Agreement No. DMR-1157490; State of Florida.

Phonon-induced ultrafast band gap control in LaTiO$_3$. MINGQIANG GU, JAMES A. M. RONDINELLI, Northwestern University — We propose a route for ultrafast band gap engineering in correlated transition metal oxides by using optically driven phonons. We show that the $\Gamma$-point electron band energies can be deterministically tuned in the nonequilibrium state. Taking the Mott insulator LaTiO$_3$ as an example, we show that such phonon-assisted processes dynamically induce an indirect-to-direct band gap transition or even a metal-to-insulator transition, depending on the electron correlation strength. We explain the origin of the dynamical band structure control and also establish its generality by examining related oxides. Lastly, we describe experimental routes to realize the band structure control with impulsive stimulated Raman scattering.

The magnetic ordering in EuTiO$_3$ through doping. ZHIGANG GUI, ANDERSON JANOTTI, Univ of Delaware — EuTiO$_3$ (ETO) is a complex oxide that displays strong spin-lattice coupling, large magnetoelectric effects, and undergoes a series of structural and magnetic phase transitions when subjected to pressure or epitaxial strain. ETO adopts a cubic structure and is paramagnetic at high temperatures, while at very low temperatures it transforms to an antiferrodistortive tetragonal structure with a G-type antiferromagnetic (AFM) ordering. Several approaches have been presented to tune the magnetic ordering from the G-type antiferromagnetism to the F-type ferromagnetism, often relying on external pressure or epitaxial strain. Doping through substitution of trivalent species on the europium sites or creation of oxygen vacancies have also been proposed to lead to ferromagnetism. However, the fundamental mechanism by which excess electrons from impurities or defects lead to ferromagnetic ordering is unclear. In this study, we explore the effects of doping on the magnetic ordering in EuTiO$_3$, through first-principles calculations. We show how itinerant carriers in the Ti-der-ived conduction-band states interact with europium $f$ states, inducing an alignment of the large moments on the europium ions. The effects of doping of different types of magnetic ordering are considered, a

Point defects, impurities, and small hole polarons in GdTiO$_3$. LARS BJAALE, University of California, Santa Barbara, ANDERSON JANOTTI, University of Delaware, KARTHIK KRISHNASWAMY, CHRIS G. VAN DE WALLE, University of California, Santa Barbara — GdTiO$_3$(GTO) has become the focus of great interest because of its use in complex-oxide heterostructures that display two-dimensional electron gases with unprecedented high densities. GTO is a Mott insulator, with a band gap arising within the partially filled Ti 3d band due to strong electron-electron interactions. GTO often displays hole conductivity, likely attributed to defects or impurities, yet the cause of this unintentional conductivity has not yet been explored. We therefore used density functional theory with a hybrid functional to study their electronic structure. Among native defects, the cation vacancies have the lowest formation energies in oxygen-rich conditions, and oxygen vacancies have the lowest formation energy in oxygen-poor conditions. Among the impurities, $\text{Gd}$, $\text{Sr}$, $\text{H}$, and $\text{C}$ have the lowest formation energies. The defects and impurities are intrinsically stable only in a single “natural” charge state, to which various numbers of hole polarons can be bound, which explains the frequent observation of $\mu$-type hopping conductivity in the rare-earth titanates. These small hole polarons also lead to optical absorption and act as electron traps in devices. Work supported by NSF and by the LEAST Center.

The dynamic stripe correlations have been the subject of intense research, owing to the possible links with high-$T_c$ superconductivity. In light of a recently published, direct observation of charge-stripe fluctuations in La$_{1.75}$Sr$_{0.25}$NiO$_3$, observed with inelastic neutron scattering\(^1\), we propose a route for ultrafast band gap engineering in correlated transition metal oxides by using optically driven phonons. In light of a recently published, direct observation of charge-stripe fluctuations in La$_{1.75}$Sr$_{0.25}$NiO$_3$, unveiled the ultrafast dynamics of the crystal symmetry breaking and of local electronic arrangements. At low temperatures the folding of finite momenta vibrations due to symmetry breaking lead to the appearance of new IR-active resonances, particularly around the phonon bending mode frequency ($\approx 11$ THz). Ultrafast experiments in the multi-THz spectral range show sharp THz reflectivity modulations associated with the phonon zone-folding dynamics, while the background conductivity is reminiscent of the opening of the mid-IR pseudogap. We combine experimental data with DFT calculations of the phonon dispersion to reveal the distinct dynamics of the LO and TO phonon modes at finite momenta. This work provides new insight in the role of polar electron-phonon coupling and symmetry breaking in charge-ordered systems.

\[^1\]Work supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering.
12:27PM Y6.00007 Single crystal preparation and long-range charge fluctuations in the square-planar nickelate La$_4$Ni$_3$O$_8$.  

JUN JIE ZHANG, Argonne National Laboratory, YU-SHENG CHEN, Argonne National Laboratory/University of Chicago, HONG ZHENG, DANIEL PHELAN, JOHN MITCHELL, Argonne National Laboratory — Since the discovery of high-Tc superconductivity in cuprates, intensive effort has been focused on a search for superconductivity in related materials, with particular attention on nickelates. Bulk nickelates containing square-planar coordinated Ni$^+$ are of interest because NiI$^+$ is isoelectronic with Cu$^2+$, the building block of high-Tc cuprates. Here we report the first single crystal synthesis of La$_4$Ni$_3$O$_8$, a layered nickelate containing square-planar coordinated Ni$^+$ with crystallographic and electronic structure related to that of cuprates. Magnetic susceptibility, resistivity, and heat capacity measurements confirm the reported phase transition at $T_{N}=105$ K$^{[1]}$. Long-range charge fluctuations with $q$ $(1/3, 1/3, l)$ was observed for the first time through synchrotron X-ray single crystal diffraction. Our results challenge the current understanding of the origin of the phase transition. Availability of bulk La$_4$Ni$_3$O$_8$ single crystals is also of significant importance for unraveling its ambiguous ground-state magnetic structure, the spin state of the Ni ion, and potential for superconductivity in nickelates involving Ni$^+$ in a square-planar coordination. [1] Poltavets, V. V. et al. PRL 2010, 104, 206403.

3Work in the Materials Science Division at Argonne National Laboratory was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Division of Materials Science and Engineering.

12:39PM Y6.00008 Cooperative phonon effects in the metal-insulator transitions of manganite and nickelate perovskites, RICHARD T. BRIERLEY, Yale University, GIAN G. GUZMÉN VERRI, Universidad de Costa Rica and Argonne National Laboratory, PETER B. LITTLEWOOD, Argonne National Laboratory and The University of Chicago — Metal-insulator transitions in manganite and nickelate perovskites depend on the competition between the electron kinetic energy, which favors the metallic phase, and the electron-phonon coupling and Coulomb interaction, which favors localization. The size of the A-site cation controls the relative rotation of the octahedral structural units of the perovskite in the range of 0 - 15°. This is accompanied by changes in the metal-insulator transition temperature from 0 - 600 K. This effect is commonly attributed to modification of the electron bandwidth from changes in orbital overlap. Although previous theoretical studies of these materials include the electron-phonon interaction, they typically do not consider cooperative phonon effects. Using a phenomenological model of the perovskite structure, we show that the long-range anisotropic forces arising from inter-site phonon interactions are modulated by changes in the octahedral rotation. We demonstrate using statistical mechanical calculations that these changes in the strain interaction can capture the variation in transition temperature with tolerance factor observed in both the manganites and nickelates.

12:51PM Y6.00009 Direct proof of static charge stripe correlations in La$_2$-Ba$_x$CuO$_4$, X M CHEN, V THAMPY, C MAZZOLI, A BARBOUR, G GU, J P HILL, J M TRANQUADA, M P M DEAN, S B WILKINS, Brookhaven National Laboratory — The nature of charge stripe order in the cuprates, and in particular whether the stripes are static or dynamic, is a key issue in understanding the relationship between stripes and superconductivity. In La$_2$-Ba$_x$CuO$_4$ (LBCO) a low temperature superconducting distortion is widely believed to pin stripes into fixed, static domains, but such an assertion has never been directly verified. We performed resonant soft x-ray photon correlation spectroscopy (XPCS) to probe the charge order Bragg peak of 1/8 doped LBCO. At low temperatures, we observe time-independent x-ray speckle patterns persisting for more than three hours, proving the static nature of the stripes and we go on to discuss how stripe order melts with increasing temperature. Our results demonstrate that the combination of XPCS with diffraction limited soft x-ray sources such as the National Synchrotron Light Source II can probe the dynamics of even subtle order parameters such as stripes in the cuprates.

2Work performed at Brookhaven National Laboratory was supported by the US Department of Energy, Division of Materials Science, under Contract No.DE-AC02-98CH10886. Use of the National Synchrotron Light Source II was supported under Contract No DE-SC0012704.

1:03PM Y6.00010 Quasi-static magnetoelectric quadrupoles as the order parameter for the pseudo-gap phase in cuprate superconductors, MICHAEL FECHNER, MERLIN J. A. FIERZ, FLORIAN THÖLE, Materials Theory, ETH Zurich, Wolfgang-Pauli-Strasse 27, 8093 Zurich, URS STAUB, Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen PSI, NICOLA A. SPALDIN, Materials Theory, ETH Zurich, Wolfgang-Pauli-Strasse 27, 8093 Zurich — A characteristic of ferroic materials is the emergence of a temporally static finite expectation value of an order parameter. Here, we introduce a new mechanism [1] for ferroic order, in which a non-zero quasi-static magnetoelectric quadrupolar order parameter appears as a result of the coupling of fluctuating spin magnetic dipole moments and polar optical phonons. Using first-principles calculations within the LSDA+U method of density functional theory, we calculate the magnitude of the effect for the prototypical cuprate superconductor, HgBa$_2$CuO$_4$+$\delta$. We show that our proposed mechanism is consistent, to our knowledge, with many experimental observations for the onset of the pseudo-gap phase and therefore propose the quasi-static magnetoelectric quadrupole as a possible pseudo-gap order parameter. Finally, we show that our mechanism embraces some key aspects of previous theoretical models, in particular the knowledge of the pseudo-gap phase in terms of orbital currents. [1] M. Fechner, M. J. A. Fierz, F. Thöle, U. Staub, and N. A. Spaldin, arXiv 1510.04844, (2015).

1:15PM Y6.00011 Quantum oscillations in a bilayer with broken mirror symmetry: a minimal model for YBa$_2$Cu$_3$O$_6$, AKASH MAHARAJ, YI ZHANG, Stanford University, BRAD RAMSHAW, National High Magnetic Field Laboratory, Los Alamos National Laboratory, STEVEN KIVELSON, Stanford University — Using an exact numerical solution and semiclassical analysis, we investigate quantum oscillations (QOs) in a model of a bilayer system with an anisotropic (elliptical) electron pocket in each plane. Key features of QO experiments in the high temperature superconducting cuprate YBCO can be reproduced by such a model, in particular the pattern of oscillation frequencies (which reflect "magnetic breakdown" between the two pockets) and the polar and azimuthal angular dependence of the oscillation amplitudes. However, the requisite magnetic breakdown is possible only under the assumption that the horizontal mirror plane symmetry is spontaneously broken and that the bilayer tunneling, $t_{11}$, is substantially renormalized from its 'bare' value. Under the assumption that $t_{11} = \tilde{Z} t_{11}^{0}$, where $\tilde{Z}$ is a measure of the quasiparticle weight, this suggests that $Z_{1}/20$. Detailed comparisons with new YBa$_2$Cu$_3$O$_{6.5}$ QO data, taken over a very broad range of magnetic field, confirm specific predictions made by the breakdown scenario.

1Supported in part by the US DOE, Office of Basic Energy Sciences under contract DE-AC02-76SF00515 (A.V.M.), the US DOE Office of Basic Energy Sciences “Science at 100 T,” (B.J.R.L) and the National Science Foundation Grant No. DMR 1265959 (S.A.K., YZ)

1:27PM Y6.00012 Controlling Spin Ordering in Rare-Earth Perovskite Vanadates, NICHOLAS WAGNER, JAMES RONDINELLI, Northwestern University — We investigate the role and influence of local structure distortions on the antiferromagnetic spin ordering temperatures for large A-site radii RV03 perovskites (R=Yb-La) using a combination of data analytics (DA) and density functional theory (DFT).

First, mode crystallography is used to parameterize the structural phase space. Next, we identify the important local structural features that correlate strongly with the Neél temperatures ($T_N$) using Pearson correlation coefficients. From this data, we then formulate a regression model using gradient boosted decision trees (GBDT) that returns the relative importance of each feature in predicting $T_N$. Our analysis indicates that the amplitude of the sublattice Jahn-Teller active mode, which leads to variations in the V-O bond lengths and angles, could be used as an effective structural control parameter to modify the spin ordering temperature. We then validate this data-driven structure-property relationship in artificial vanadate structures using $T_N$ based on both our GBDT model and a model Hamiltonian using DFT energies. This combined approach allows us to gauge the accuracy of existing physical models for the antiferromagnetic ordering in vanadates and opens possible strategies to design materials with targeted $T_N$.
1:39PM Y6.00013 Giant Magnetocaloric Effect in the Double-perovskite Gd2NiMnO6\textsuperscript{2}. JAE YOUNG MOON, MI KYUNG KIM, DONG KUN OH, SANG HYUP OH, NARA LEE, YOUNG JAI CHOI, Yonsei Univ — We have synthesized single crystal of Gd\textsubscript{2}NiMnO\textsubscript{6} (GNMO) by the Bi-flux method and investigated magnetocaloric effect in them by magnetic measurements. Magnetic susceptibility of GNMO increases smoothly as temperature decrease and ferromagnetic order occurs below 135 K, and additional anomaly show at low temperature, indicative of the onset of Gd\textsuperscript{3+} spin arrangement. At the temperature, magnetic entropy change, \(\Delta S_{M}\), with the field changes of 0-9 T, calculated from isothermal M(H) data using Maxwell relation, exhibits sharp peak. This peak is gigantic and cryogenic, these make GNMO promising cryogenic magnetic refrigerant materials.

\textsuperscript{2}Giant Magnetocaloric Effect in the Double-perovskite Gd2NiMnO6

1:51PM Y6.00014 ABSTRACT WITHDRAWN

Friday, March 18, 2016 11:15AM - 2:15PM –
Session Y18 GMAG DMP: Frustrated Magnetism: Pyrochlore and Kagome Lattices 317 - Lucile Savary

11:15AM Y18.00001 Quantum spin ices and magnetic states from dipolar-octupolar doublets on the pyrochlore lattice. GANG CHEN\textsuperscript{1}, Fudan Univ, Perimeter Institute for Theoretical Physics — We consider a class of electron systems in which dipolar-octupolar Kramers doublets arise on the pyrochlore lattice. In the localized limit, the Kramers doublets are described by the effective spin1/2 pseudospins. The most general nearest-neighbor exchange model between these pseudospins is the XYZ model. In addition to dipolar ordered and octupolar ordered magnetic states, we show that this XYZ model exhibits two distinct quantum spin ice (QSI) phases, that we dub dipolar QSI and octupolar QSI. These two QSIs are distinct symmetry enriched U(1) quantum spin liquids, distinct by the lattice symmetry. Moreover, the XYZ model is absent from the notorious sign problem for a quantum Monte Carlo simulation in a large parameterspace. We discuss the potential relevance to real material systems such as Dy2Ti2O7, Nd2Zr2O7, Nd2Hf2O7, Nd2Ir2O7, Nd2Sn2O7 and Ce2Sn2O7.

\textsuperscript{1}chggst@gmail.com, Refs: Y-P Huang, G Chen, M Hermene, Phys. Rev. Lett. 112, 167203 (2014).

11:51AM Y18.00002 Layered kagome spin ice. JAMES HAMP, SIAN DUTTON, University of Cambridge, MARTIN MOURIGAL, Georgia Tech, PAROMITA MUKHERJEE, University of Cambridge, JOSEPH PADDISON, Georgia Tech, HARAPAN ONG, CLAUDIO CASTELNOVO, University of Cambridge — Spin ice materials provide a rare instance of emergent gauge symmetry and fractionalisation in three dimensions: the effective degrees of freedom of the system are emergent magnetic monopoles, and the extensively many ‘ice rule’ ground states are those devoid of monopole excitations. Two-dimensional (kagome) analogues of spin ice have also been shown to display a similarly rich behaviour. In kagome ice however the ground-state ‘ice rule’ condition implies the presence everywhere of magnetic charges. As temperature is lowered, an Ising transition occurs to a charge-ordered state, which can be mapped to a dimer covering of the dual honeycomb lattice. A second transition, of Kosterlitz-Thouless or three-state Potts type, occurs to a spin-ordered state at yet lower temperatures, due to small residual energy differences between charge-ordered states. Inspired by recent experimental capabilities in growing spin ice samples with selective (layered) substitution of non-magnetic ions, in this work we investigate the fate of the two ordering transitions when individual kagome layers are brought together to form a three-dimensional pyrochlore structure coupled by long range dipolar interactions. We also consider the response to substitutional disorder and applied magnetic fields.

12:03PM Y18.00003 Theory of quantum kagome ice\textsuperscript{1}. YI-PING HUANG, MICHAEL HERMELE, Department of Physics, University of Colorado Boulder — Some pyrochlore oxides realize novel dipolar-octupolar (DO) doublets on the sites of the pyrochlore lattice of corner-sharing tetrahedra. With magnetic field along the (111) direction, such systems can approximately be described as decoupled layers of a \(S = \frac{3}{2}\) XYZ model on Kagome planes, with perpendicular magnetic field. A recent quantum Monte Carlo study found a zero temperature disordered phase in this model, dubbed quantum kagome ice, and proposed that it is a type of \(Z_2\) quantum spin liquid (J. Carraquilla, Z. Hao and R. G. Melko, Nat. Comm., 6, 7421). We will describe an effective theory for this putative \(Z_2\) spin liquid, and present results on its symmetry fractionalization and resulting properties that may be tested in future numerical simulations.

\textsuperscript{1}the U.S. Department of Energy (DOE), Office of Science, Basic Energy Sciences (BES) under Award DE-SC0014415

12:15PM Y18.00004 Dynamics of quantum excitations in square ice\textsuperscript{1}. CLAUDIO CASTELNOVO, TCM group, Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK, STEFANOS KOURTIS, Department of Physics, Princeton University, Princeton, NJ 08544, USA — The study of emergent excitations in classical spin ice has culminated in the discovery of a condensed-matter realization of magnetic monopoles. In spin-ice materials where quantum fluctuations play an important role, excitations acquire quantum properties that promote them to more complicated and exciting objects. To understand these quantum excitations better in a relatively simple context, we construct a toy model of excited square ice and solve it both exactly by tuning it to a Rokhsar-Kivelson point and numerically for small clusters. We furthermore numerically evaluate the dynamic spin structure factor and compare it to effective free-particle theories. Our results offer a useful point of comparison for further theoretical and experimental work.

\textsuperscript{1}Supported by ICAM branch contributions, EPSRC Grant No. EP/G049394/1, the Helmholtz Virtual Institute New States of Matter and Their Excitations and the EPSRC NetworkPlus on Emergence and Physics far from Equilibrium

12:27PM Y18.00005 Magnetic monopoles in quantum spin ice. OLGA PETROVA, RODERICH MOESSNER, Max Planck Institute for the Physics of Complex Systems, SHIVAJI SONDHI, Princeton University — Typical spin ice materials can be modeled using classical Ising spins. The geometric frustration of the pyrochlore lattice causes the spins to satisfy ice rules, whereas a violation of the ice constraint constitutes an excitation. Flipping adjacent spins fractionalizes the excitation into two monopoles. Long range dipolar spin couplings result in Coulombic interactions between charges, while the leading effect of quantum fluctuations is to provide the monopoles with kinetic energy. We study the effect of adding quantum dynamics to spin ice, a well-known classical spin liquid, with a particular view of how to best detect its presence in experiment. For the weakly diluted quantum spin ice, we find a particularly crisp phenomenon, namely, the emergence of hydrogenic excited states in which a magnetic monopole is bound to a vacancy at various distances [1].

12:39PM Y18.00006 Spinon walk in quantum spin ice, YUAN WAN, JUAN CARRASQUILLA, ROGER MELKO, Perimeter Institute for Theoretical Physics — Quantum spin ice is a novel family of spin ice magnets that possess substantial quantum fluctuations. The fractional excitations are spinons, which are quantum analog of the monopoles in classical spin ice. The spinon propagates in quantum spin ice via quantum tunnelling. As opposed to a conventional quantum particle, the spinon moves in a background of disordered spins. The orientation of background spins controls the spinon motion, whereas the spinon motion in turn alters the spin background. One may naturally ask what a suitable framework for understanding the dynamics of spinon in quantum spin ice, and furthermore, whether the spinon propagation is coherent. In this talk, we address these issues by investigating a minimal model that captures the essential features of single spinon dynamics in quantum spin ice. We demonstrate that the spinon motion can be thought of as a quantum walk with entropy-induced memory. Our numerical simulation shows that the simple quasi-particle behaviour emerges out of the intricate interplay between the spinon and the background spins.

12:51PM Y18.00007 Neutron scattering in Er$_2$-$Y$Ti$_2$O$_7$, JONATHAN GAUDET, ALANNAH HALLAS, DALINI MAHARAJ, EDWIN KERMARREC, McMaster Univ, NICHOLAS P. BUTCH, NIST Center for Neutron Research, HANNA DABOWSKA, BRUCE GAULIN, McMaster Univ — Er$_2$Ti$_2$O$_7$ (ETO) is a strong candidate for ground state selection via the order by disorder mechanism. A $\psi$ magnetic ground state appears below $T_1 = 1.2$ K, where $\psi_1$ and $\psi_2$ are the two basis states of the irreducible representation $\Gamma_5$. No sample dependence has been observed in the thermodynamics properties of ETO at low temperature, and in particular on its phase transition to long range magnetic order. ETO’s ordered Neel state has been shown to be robust even to a relatively high level of magnetic dilution, as occurs with non-magnetic substitutions of $Y^{3+}$ substitution of $Er^{3+}$. However, recently two theoretical studies have predicted that ETO’s $\psi_1$ ground state should be unstable to formation of the $\psi_3$ state, in the presence of such disorder. To explore this possibility, we grew single crystals of Er$_2$-$Y$Ti$_2$O$_7$ (ETYTO) with $x = 0.2$ and $0.4$ and performed a systematic inelastic neutron scattering studies using the Disk Chopper time-of-flight spectrometer (DCS) at the National Institute of Standards and Technology (NIST). We will show elastic and inelastic neutron scattering at low temperatures and as a function of applied magnetic field for all three samples and discuss the role of such quenched disorder on the spin dynamics of ETO.

1:03PM Y18.00008 Semi-classical Theory of Quantum Spin Ice, MICHAL KWASIGROCH, CLAUDIO CASTENANOVO, University of Cambridge — The low temperature properties of quantum spin ice compounds Yb$_2$Ti$_2$O$_7$ and Pr$_2$Zr$_2$O$_7$ are described by spin-1/2 degrees of freedom associated with magnetic Yb or Pr atoms residing on vertices of corner-sharing tetrahedra. Strong Ising exchange enforces the well-known 2-in-2-out rule for each tetrahedron at low temperatures. These describe the macroscopically degenerate spin ice configurations. Recently, it has been shown [Phys. Rev. B 69, 064404 (2004)] that the addition of weak easy-plane exchange can lead to hybridisation of the classically allowed spin-ice configurations and the emergence of a gapless quantum spin liquid. We show that a semi-classical treatment of this U(1) liquid phase captures the QED-like physics and we derive quantitative estimates of the low-energy dispersion and the dynamic structure factor. These compare well with the existing Monte Carlo simulations.

1:15PM Y18.00009 From pinch points to pinch lines: a new spin liquid on the pyrochlore lattice, OWEN BENTON, LUDOVIC JAUBERT, HAN YAN, NIC SHANNON, Okinawa Inst of Sci & Tech — One of the most fascinating discoveries in the study of spin liquids has been the existence of emergent gauge fields arising out of a disordered magnetic ground state. The best known example is provided by the spin ice pyrochlores Ho$_2$Ti$_2$O$_7$ and Dy$_2$Ti$_2$O$_7$, whose underlying gauge structure is revealed by the presence of pinch-point singularities in the neutron scattering response. Here we report the discovery of a new spin liquid on the pyrochlore lattice, the low temperature fluctuations of which are naturally described by the fluctuations of a tensor field with a continuous gauge freedom. This gauge structure underpins a novel form of spin correlations, giving rise to “pinch-line” singularities- line-like analogues of the pinch-point singularity extending along the (111) directions of reciprocal space. Remarkably, our theory reproduces several otherwise unaccounted for features of neutron scattering experiments on Tb$_2$Ti$_2$O$_7$.

1:27PM Y18.00010 Numerical evidence for a chiral spin liquid in the XXZ model on the kagome lattice in a magnetic field, HITESH CHANGLANI, KRISHNA KUMAR, BRYAN CLARK, EDUARDO FRADKIN, University of Illinois Urbana Champaign — Frustrated spin systems in two dimensions provide a fertile ground for discovering exotic states of matter, often with topologically non-trivial properties. In this paper, we investigate the possible existence of a chiral spin liquid state in the spin 1/2 XXZ model on the frustrated kagome lattice in the presence of a magnetic field. This model is equivalent to a hard-core bosonic one with density-density interactions at finite filling fraction. Motivated by previous field theoretic predictions utilizing a Chern-Simons theory adapted for this lattice [1,2], we focus our attention to understanding the XY limit for the 2/3 magnetization plateau (equivalent to a system of hard-core bosons at 1/6 filling with weak nearest-neighbor repulsive interactions). Performing exact or accurate numerical computations, and based on energetics and construction of minimally entangled states and associated modular matrices, we provide evidence for such a spin liquid. We study the nature of this phase and examine its stability to additional interactions. [1] K. Kumar, K. Sun, and E. Fradkin, Phys. Rev. B 90, 174409 (2014) [2] K. Kumar, K. Sun, and E. Fradkin, Phys. Rev. B 92, 094433 (2015)

1:39PM Y18.00011 Spin liquids on an anisotropic kagome lattice, ROBERT SCHAFFER, KYUSUNG HWANG, YEJIN HUH, YONG BAEK KIM, Univ of Toronto — Much recent theoretical and experimental effort has been devoted to the search for quantum spin liquids, which arise in the presence of strong frustration of magnetic interactions. Motivated by recent experiments on the vanadium oxyfluoride material DQVOF, we examine possible spin liquid phases on an anisotropic kagome lattice of $S = 1/2$ spins, in which the $C_3$ symmetry is broken to $C_3$. Using the projective symmetry group analysis, we determine the possible phases for both bosonic and fermionic $Z_2$ spin liquids on this lattice. Using VMC, we study the Heisenberg model on this lattice, and show that a $Z_2$ spin liquid emerges as the ground state in the presence of this anisotropy.

1:51PM Y18.00012 Classification of $Z_2$ spin liquids in a hyperkagome lattice by projective symmetry groups, BIAO HUANG, Ohio State Univ - Columbus, YONG BAEK KIM, University of Toronto; Korea Institute for Advanced Study, YUAN-MING LU, Ohio State Univ - Columbus, YONG BAEK KIM, University of Toronto — Being a rare candidate material supporting 3D spin liquid states, Na$_2$Ir$_2$O$_6$ has attracted much theoretical and experimental interest in the past decade. Motivated by such developments, we give a complete classification of $Z_2$ spin liquid states in the hyperkagome lattice formed by Ir$^{4+}$ ions in the projective symmetry group approach. A list of mean field states with different fractional quasi-particle excitations are correspondingly given, and their excitation gaps are analyzed. The effects of spin-orbit coupling due to the $t_{ud}$ electrons in Ir are also discussed. This work paves the way for further variational Monte-Carlo study of the spin liquid physics in hyperkagome lattices.
2:03PM Y18.00013 Z\textsubscript{2} gauge theory for valence bond solids on the kagome lattice. KYUSUNG HWANG, YEJIN HUH, YONG BAEK KIM. Department of Physics and Centre for Quantum Materials, University of Toronto, Toronto, Toronto, Ontario M5S 1A7, Canada — We present an effective Z\textsubscript{2} gauge theory that captures various competing phases in spin-1/2 kagome lattice antiferromagnets: the topological Z\textsubscript{2} spin liquid (SL) phase, and the 12-site and 36-site valence bond solid (VBS) phases. Our effective theory is a generalization of the recent Z\textsubscript{2} gauge theory proposed for SL phases by Wan and Tchernyshyov. In particular, we investigate possible VBS phases that arise from vison condensations in the SL. In addition to the 12-site and 36-site VBS phases, there exists 6-site VBS that is closely related to the symmetry-breaking valence bond modulation patterns observed in the recent density matrix renormalization group simulations. We find that our results have remarkable consistency with a previous study using a different Z\textsubscript{2} gauge theory. Motivated by the lattice geometry in the recently reported vanadium oxyfluoride kagome antiferromagnet, our gauge theory is extended to incorporate lowered symmetry by inequivalent up- and down-triangles. We investigate effects of this anisotropy on the 12-site, 36-site, and 6-site VBS phases. Particularly, interesting dimer melting effects are found in the 36-site VBS. We discuss the implications of our findings and also compare the results with a different Z\textsubscript{2} gauge theory used in previous studies.

Friday, March 18, 2016 11:15AM - 2:15PM — Session Y19 GMAG DCMP-Correlated Electron Magnism 318 - Steven Dissing, NIST

11:15AM Y19.00001 Orbital Delocalization and Enhancement of Magnetic Interactions in Perovskite Oxidehydrides. KAI LIU, YUSHENG HOU, XINGAO GONG, HONGJUN XIANG, Fudan University, CCGM TEAM — Recent experiments showed that some perovskite oxidehydrides have surprisingly high magnetic-transition temperature. In order to unveil the origin of this interesting phenomenon, we investigate the magnetism in SrCrO\textsubscript{2}H and SrVO\textsubscript{2}H on the basis of first-principles calculations and Monte Carlo simulations. Our work indicates that the Cr-O-Cr bond angle, we reveal instead that this is mainly because the 3\textit{d} orbitals in perovskite oxidehydrides becomes more delocalized since H\textsuperscript{+} ions have weaker electronegativity and less electrons than O\textsuperscript{2\textpm}. The delocalized 3\textit{d} orbitals result in stronger Cr-O interactions and enhance the magnetic-transition temperature. This novel mechanism is also applicable to the case of SrV\textsubscript{2}O\textsubscript{4}H. Furthermore, we predict that SrFeO\textsubscript{2}H will have unprecedented high Neel temperature because of the extraordinarily strong Fe-H-Fe \textsigma-type interactions. Our work suggests the anion substitution can be used to effectively manipulate the magnetic properties of perovskite compounds.

11:27AM Y19.00002 Understanding the magnetoelectric behavior of pure and Co substituted GdNi\textsubscript{2}. DURGA PAUDYAL, Y. MUDRYK, The Ames Laboratory, Iowa State University, Ames, IA 50011, V. K. PECHARSKY, K. A. GSCHNEIDER, JR., The Ames Laboratory and Department of Materials Science and Engineering, Iowa State University, Ames, IA 50011 — Total-energy calculations employing local spin density approximation including Hubbard \textit{U} (onsite electron correlation) parameter and temperature and magnetic field dependent x-ray diffraction experiments show large anisotrophic shifts in lattice parameters and a giant linear magnetostriiction without a structural transformation and a negligible volume magnetostriiction in GdNi\textsubscript{2}. In agreement with the magnetization and heat-capacity experiments, the total-energy and band splitting results confirm that the anisotropic shape changes in GdNi\textsubscript{2} are associated with the second-order ferromagnetic to paramagnetic transformation. When the band splitting due to the ferromagnetic ordering is broken (\textit{T} = \textit{T}\textsubscript{N}), a magnetic field\textit{B} can result in a structural change in the lattice energy of the induced magnetic field\textit{H} in the competing anisotropy between magnetism and crystal structure. The positive formation energy at 0K and the nature of the density of states at the Fermi level confirm an unstable equiatomic Gd compound when Ni is fully substituted by Co. However, the enhanced effective exchange interactions with small Co substitutions increase the Curie temperature without losing the chemical stability.

11:39AM Y19.00003 Direct observation of a helical magnetic order near the superconducting state of MnP under pressure. YISHU WANG, California Institute of Technology, YEJUN FENG, Argonne National Lab, J.-G. CHENG, Chinese Academy of Sciences, T. F. ROSENBAUM, California Institute of Technology — A recent high-pressure electrical transport study of the 3d transition metal compound MnP\textsubscript{8} manifested a complex pressure-temperature phase diagram of different types of magnetism and superconductivity. However, the nature of the high-pressure magnetic phase proximate to the superconducting state was not determined. We use non-resonant X-ray magnetic diffraction to probe the magnetic order in MnP under pressure. We discover incommensurate helical order in a confined region under high pressure, and ascertain the phase boundary through the pressure evolution of the lattice. Although the antiferromagnetic and superconducting phases are separated, there is no signature of a strong first-order phase transition between them. We discuss how our direct observation of a helimagnetic order in MnP helps to better understand aspects of magnetically-modulated superconductivity.

11:51AM Y19.00004 Neutron scattering study on the magnetic and superconducting phases of MnP. SHINICHIRO YANO, NSRC, DIANE LANÇON, HENRIK RONNOW, EPFL, THOMAS HANSEN, ILL, JASON GARDNER, NSRC — We have performed series of neutron scattering experiments on MnP. MnP has been investigated for decades because of its rich magnetic phase diagram. The magnetic structure of MnP is ferromagnetic (FM) below \textit{T}_C = 291 K. It transforms into a helimagnetic structure at \textit{T}_S = 47 K with a propagation vector \textit{q} = 0.117a^*\textsuperscript{1}. Superconductivity was found in MnP under pressures of 8 GPa with a \textit{T}_C\textsubscript{SC} around 1 K by J.-G. Cheng. Since Mn-based superconductors are rare, and the superconducting phase occurs in the vicinity of FM, new magnetic and helimagnetic phases, there is a need to understand how the magnetism evolves as one approach the superconducting state. MnP is believed to be a double helix magnetic structure at \textit{T}_C = 47 K. We observed new 2\textit{\sigma} and 3\textit{\sigma} satellite peaks whose intensity are 200 ~ 1000 times smaller than those of 1\textit{\sigma} satellite peaks on the cold triple axis spectrometer SIKA under zero magnetic fields. We also found the periods of helimagnetic structure changes as a function of temperature. If time permits, we will discuss recent experiments under pressure. However, we have complete picture of magnetic structure of this material with and without applied pressure, revealing the interplay between the magnetic and superconducting phases.

12:03PM Y19.00005 Unusual behavior of uranium dioxide at high magnetic fields. Part I. K. GOFRYK, Idaho National Laboratory, M. JAIME, V. ZAPF, N. HARRISON, Aix-Marseille University, France G. RADDKE, Paris 6 University, France, J. C. LASHEY, Los Alamos National Laboratory, M. SALAMON, University of Texas, Dallas, A. D. ANDERSSON, C. STANEK, T. DURAKIEWICZ, J. L. SMITH, Los Alamos National Laboratory — UO\textsubscript{2} is a Mott-Hubbard insulator with well-localized 5f-electrons and its crystal structure is the face-centered-cubic fluorite. It experiences a first-order antiferromagnetic phase transition at 30.8 K to a non-collinear antiferromagnetic structure that remains a topic of debate. It is believed that the first order nature of the transition results from the competition between the exchange interaction and the Jahn-Teller distortion of oxygen atoms. Despite extensive experimental and theoretical efforts the nature of the competing degrees of freedom and their couplings (such as spin-phonon coupling) are still unclear. Here we present results of our extensive thermodynamic investigations, on well-characterized and oriented single crystals of UO\textsubscript{2}, focusing on magnetization M(\textit{T},\textit{H}) measurements in DC and pulsed magnetic fields to up 65 T at the NHMFL.

\textsuperscript{1} Work supported by the Department of Energy, Office of Basic Energy Sciences, Materials Sciences, and Engineering Division. The NHMFL Pulsed Field Facility is supported by the NSF, the U.S. D.O.E., and the State of Florida through NSF cooperative grant DMR.
12:15PM Y19.00006 Unusual behavior of uranium dioxide at high magnetic fields. Part II*, M. JAIME, LAML, K. GÖFRYK, INL, V. ZAPF, N. HARRISON, LAML, A. SAUL, Aix-Marseille Univ., G. RÄDTKE, Univ. Paris, J.C. LASHLEY, LAML, M. SALAMON, UT Dallas, A.D. ANDERSSON, C. STANEK, T. DURAKIEWICZ, J.L. SMITH, LAML — More than 65 years worth of unravelling experimental and theoretical research on seemingly uncomplicated UO₂, a Mott-Hubbard insulator with well-localized 5f/–electrons and a fluorite crystal structure, have not been able to elucidate some important questions such as the detailed nature of the low temperature AFM state, or the reasons behind unusual lattice properties that prevailly hint to a sizeable spin-lattice coupling via either a ferromagnetic or an antiferromagnetic coupling. Recent results from the Hall effect combined with magnetic force microscopy, have hinted to the notion that unusual spin-lattice coupling is behind the crippled thermal behavior of UO₂. Here we present results of our thermodynamic investigations, on well-characterized and oriented single crystals, focusing on fiber Bragg grating magnetostriction measurements in pulsed magnetic fields to 90T at the NHMFL PFF. Our data support a multidomain non-collinear 3–k AFM order below 30.8 kK, coupled to an oxygen-cage trigonal distortion that breaks time reversal symmetry. Work supported by the US DOE BES, Mat. Sci., and Eng. Div. The NHMFL PFF is supported by the NSF, the U.S. DOE, and the State of Florida through NSF coop. grant DMR-1157490. Work at LANL was supported by the U.S. DOE BES project “Science at 100 Tesla”.


12:39PM Y19.00008 Unexpected magnetism, and transport properties in mixed lanthanide compound*.1, ARJUN PATHAK, KARL SCHNEIDNER, JR, VITALIJ PECHARSKY, Ames Laboratory, US DOE, AMES LABORATORY TEAM — For intelligent materials design it is desirable to have compounds which have multiple functionalities such as a large magnetoresistance, ferromagnetic and ferrimagnetic states, and field-induced first-order metamagnetic transitions. Here, we discuss one such example where we have combined two lanthanide elements Pr and Er in Pr₆Ο₁₄Al₂. This compound exhibits multiple functionalities in magnetic fields between 1 and 40 kOe. It undergoes only a trivial ferrimagnetism to paramagnetism transition in a zero magnetic field, but Pr₆Ο₁₄Al₂ exhibits a large positive magnetoresistance (MR) for H>40 kOe, a small but non negligible negative MR for H<30 kOe, and a clear Griffiths-like phase behavior at <1 kOe. The compound also exhibits an asymmetry of hysteresis loop, or exchange bias (EB) effect after field cooling from the paramagnetic state. These phenomena are attributed to the competition between single-ion anisotropies of Pr and Er ions coupled with the opposite nearest-neighbor and next-nearest-neighbor exchange interactions.

1This work was supported by the US Department of Energy, Office of Basic Energy Science, Division of Material Sciences and Engineering. The research was performed at the Ames Laboratory. The Ames Laboratory is operated by Iowa State University for the US D

12:51PM Y19.00009 Magnetic and Metal-Insulator Transition in natural Transition Metal Sulfides , RENXIONG WANG, TRISTRIN METZ, I-LIN LIU, KEFENG WANG, XIAOFENG WANG, Department of Physics, University of Maryland College Park, J.R JEFFRIES, Lawrence Livermore National Laboratory, S.R. SAHA, R.L. GREENE, J. PAGLIONE, Department of Physics, University of Maryland College Park, C. C. SANTELLI , J, POST, Department of Mineral Sciences, Smithsonian Museum of Natural History — In collaboration with the Smithsonian Institution’s National Museum of Natural History, we present detailed studies of a class of natural minerals with potential to harbor correlated behavior. Transition metal sulfide minerals, such as Bornite (Cu₅FeS₄), are an important family of compounds known for their thermoelectric properties. We will present low temperature experimental studies of magnetic transitions and focus on a compound that exhibits a metal to insulator transition concurrent with entrance to an antiferromagnetic ground state, suggesting a potentially interesting system with promise for realizing new correlated states of matter in a naturally occurring mineral.

1:03PM Y19.00010 Emergent triangular structure in doped extended honeycomb Hubbard model , LUCIA F. TOCCHIO, Consiglio Nazionale delle Ricerche (CNR) and International School for Advanced Studies (SISSA), RYUI KANEKO, ROSER VALENTI, Goethe-Universitaet Frankfurt, FEDERICO BECCA, Consiglio Nazionale delle Ricerche (CNR) and International School for Advanced Studies (SISSA), CLAUDIUS GROS, Goethe-Universitaet Frankfurt — We investigate the extended honeycomb Hubbard model at 3/4 filling. By using the mean-field approach we find a transition from a normal metal to a ferromagnetic metal at large Coulomb interaction $U$’, and a transition to a charge ordered metal at large nearest-neighbor Coulomb interaction $V$‘. In the presence of both $U$’ and $V$‘, we find a metal-insulator transition, where the insulating state possesses charge and magnetic orders. The charge rich sites are nearly fully occupied, while the charge poor sites form a triangular lattice at nearly half filling. We also apply the variational Monte Carlo method to take into account quantum fluctuations beyond the mean-field treatment, and find this charge ordered state to be stable at sufficiently large $U$’ and $V$‘.

1:15PM Y19.00011 Mechanisms of finite-temperature magnetism in the three-dimensional Hubbard model , DANIEL HIRSCHMEIER, Institut fr Theoretische Physik, Universitt Hamburg , HARTMUT HAFFERMANN, Mathematical and Algorithmic Sciences Lab, France Research Center, Huawei Technologies Co, EMANUEL GULL, Department of Physics, University of Michigan, ALEXANDER I. LICHTENSTEIN, Institut fr Theoretische Physik, Universitt Hamburg, ANDREY E. ANTIPOV, Department of Physics, University of Michigan — We examine the nature of the transition to the antiferromagnetically ordered state in the half-filled three-dimensional Hubbard model using the dual-fermion multiscale approach. Consistent with analytics, in the weak-coupling regime we find that spin-flip excitations across the Fermi surface are important, and that the strong coupling regime is described by Heisenberg physics. In the intermediate interaction, strong correlation regime we find aspects of both local and non-local correlations. We analyze the critical exponents of the transition in the strong coupling regime and find them to be consistent with Heisenberg physics down to an interaction of $U/t\sim10$.

1:27PM Y19.00012 Quantum Monte Carlo study of magnetism in the Lieb Lattice*, NATANIEL COSTA, TIAGO SANTOS1, THEREZIA PAIVA, RAIMUNDO DOS SANTOS, Universidade Federal do Rio de Janeiro, RICHARD SCALETTA, UC Davis — The Hubbard model on the ‘Lieb lattice’ provides an important example of how flat band systems may lead to ferromagnetism: at half filling Lieb proved that a ferrimagnetic ground state can be achieved. Since a rigorous proof that long range order does indeed emerge is still lacking, here we report Determinant Quantum Monte Carlo (DQMC) simulations for this model. We found that the spin correlation between nearest neighbors are always antiferromagnetic, and that for small $U$' ferromagnetic long range order does set in the ground state. However, spatial spin correlations weaken as $U$ is increased, and we established that long range order is suppressed above $U_c \approx 4.5$. We obtain the dependence of the magnetization with the on-site repulsion $U$, and show that it displays a maximum at $U \approx 3$. The behavior of the compressibility and of the double occupancy across this transition is also discussed.

1Also at Department of Physics, UC Davis
Using dephasing to distinguish composite and elementary particles

Leonid P. Pryadko, University of California, Riverside, Claudio Castelnovo, University of Cambridge, Mark I. Dykman, Michigan State University, Roderich Moessner, Max-Planck-Institut für Physik komplexer Systeme, Dresden, Vadim N. Smelyanskiy, Google — Many-body topological excitations like domain walls in 1D can be treated quantum mechanically as particles. We establish limits on such a description in the presence of weak dephasing. Specifically, we compare dynamics of a particle in a tight-binding model with weak on-site dephasing, and that of a kink separating two locally distinguishable domains. In the latter case, dephasing rate of the off-diagonal matrix elements $\rho_{ab}$ of the density matrix is proportional to the distance $|a - b|$ from the diagonal, compared to a constant dephasing rate of such matrix elements for a single particle. We show that in a transport setting (quantum diffusion), with small density gradients, the dynamics of these two systems is nearly identical. The difference can only be seen when far off-diagonal matrix elements are important, as in the formation of a bound state, or in a two-path interferometer. We analyze the spectroscopic signature of a bound state of a domain wall, and suggest possible experimental signatures in spin chains.

Spontaneous symmetry breaking in correlated wave functions

Ryui Kaneko, Goethe-Universitäet Frankfurt, Luca F. Tocchio, Consiglio Nazionale delle Ricerche (CNR) and International School for Advanced Studies (SISSA), Roser Valentí, Goethe-Universitäet Frankfurt, Federico Becca, Consiglio Nazionale delle Ricerche (CNR) and International School for Advanced Studies (SISSA), Claudius Gros, Goethe-Universitäet Frankfurt — We show that Jastrow-Slater wave functions, in which a density-density Jastrow factor is applied onto an uncorrelated fermionic state, may possess long-range order even when all symmetries are preserved in the wave function. This fact is mainly related to the presence of a sufficiently strong Jastrow term (also including the case of full Gutzwiller projection, suitable for describing spin models). Selected examples are reported, including the spawning of Néel order and dimerization in spin systems, and the stabilization of density and orbital order in itinerant electronic systems.

On the magnetic structure and band gap of the double perovskite Ba2CuOsO6: Density functional analysis

Changhoon Lee, Jisook Hong, Ji Hoon Shim, Pohang University of Science and Technology, Myung-Hwan Whangbo, North Carolina State University — The ordered double-perovskite Ba2CuOsO6, consisting of 3d and 5d transition-metal magnetic ions (Cu2+ and Os6+, respectively), is a magnetic insulator. It obeys the Curie-Weiss law with $\theta = -13.3$ K. We evaluated the spin exchange interactions of Ba2CuOsO6 by performing energy-mapping analysis based on DFT+U calculations and determined the band gap of Ba2CuOsO6 by DFT+U and DFT+U+SOC calculations. The antiferromagnetic ordering of Ba2CuOsO6 is due largely to the spin exchange interactions between Cu2+ ions, which are enhanced by the empty eg orbitals of the intervening Os6+ ions. Both electron correlation and spin-orbit coupling are necessary to open a band gap for Ba2CuOsO6.

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