Magnetic Interfaces and Nanostructures
Room: 311 - Session MI+MG-TuA

Development of Multiferroic Materials (2:20- 5:00PM)
MIND Panel Discussion (5:00-6:30 pm)
Moderator: Peter Fischer, Lawrence Berkeley National Laboratory

2:20pm **MI+MG-TuA1 Versatile Abilities of Lattice Instabilities: New Design Strategies for Emergent Ferroics**, ***James Rondinelli***, Drexel University **INVITED**

I describe in this talk the design methodology and theoretical discovery of a new class of "rotation-induced" ferroelectric materials. By tailoring the instabilities of the BO_6 octahedral rotations common to ABO_3 perovskites oxides, I show these lattice distortions provide a new structural "sand box" from which to design and discover such ferroic phases. Bottom-up engineering of the transition metal octahedra at the unit cell level, is applied to realize ferroelectricity in artificial perovskites superlattices formed by interleaving two bulk materials with no tendency to such behavior. This emergent, chemistry-independent, form of ferroelectricity – octahedral rotation-induced ferroelectricity – offers a reliable means to externally address and achieve deterministic electric-field control over magnetism. I discuss the required crystal-chemistry criteria, which are obtained from a combination of group theoretical methods and electronic-structure computations, to select the compositions and stoichiometries giving polarizations comparable to the best known ferroelectric oxides. Much rarer in crystalline materials with an electric polarization, however, is the appearance of a ferri-electric (FiE) state, vis-à-vis ferrimagnetism, where local electric dipoles of different magnitude are anti-aligned to yield a net non-zero electric polarization. The underlying reason is that the long-range Coulomb forces in oxide-based dielectrics favor the cooperative alignment of all electric dipoles in the crystal through cation displacements that occur against an oxygen ligand framework. I conclude by describing our recent discovery of a first-order, isosymmetric, transition between a ferrielectric (FiE) and ferroelectric (FE) state in A-site ordered perovskite superlattices and offering new areas for ferroic discovery

3:00pm **MI+MG-TuA3 Voltage-controlled Exchange Bias and Exchange Bias Training**, ***Christian Binek***, *W. Echtenkamp*, University of Nebraska-Lincoln **INVITED**

Voltage-controlled exchange bias (EB) is a seminal achievement in nanomagnetism. It enables dissipationless electric control of interface magnetic states with major implications for room temperature spintronic applications. Numerous prototypical solid-state spintronic devices rely on switchable interface magnetism, enabling spin-selective transmission or scattering of electrons. Controlling magnetism at thin-film interfaces, preferably by purely electrical means, i.e. in the absence of electric currents, is a key challenge to better spintronics. Currently, most attempts to voltage-control magnetism focus on potentially large magnetoelectric (ME) effects of multiferroics.

Here, we report on the use of antiferromagnetic (AF) ME Cr_2O_3 (chromia) for voltage-controlled magnetism [1,2]. Electrically switchable boundary magnetization (BM) can overcome the weak linear ME susceptibility of room temperature bulk ME antiferromagnets. BM is a roughness insensitive equilibrium property of ME antiferromagnets which is in sharp contrast to the surface magnetic properties of conventional antiferromagnets. Voltage-controlled BM is the key property enabling isothermal voltage-controlled switching of exchange bias (EB) which emerges at the interface of adjacent ferromagnetic (FM) and the ME antiferromagnetic (AF) thin film. The inter-layer exchange alters the magnetization reversal shifting the FM hysteresis loop along the magnetic field axis. In this presentation I introduce voltage-control of EB and EB training [2]. Electric switching between stable EB fields is investigated in heterostructures based on single crystal Cr_2O_3(0001)/PdCo heterostructures and compared with recent results in MBE grown all thin film EB heterostructures. In addition to voltage-switching of EB we electrically and isothermally tune chromia into distinct AF multi-domain states. As a result, EB training, which originates from triggered rearrangements of the AF interface magnetization during consecutively cycled hysteresis loops, is tuned between zero and sizable effects. We quantify and interpret the peculiar voltage-controlled training effect in Cr_2O_3(0001)/PdCo by adapting our recently developed theory which is based on a discretized Landau-Khalatnikov dynamic equation [3].

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4:20pm **MI+MG-TuA7 Multiferroic Z_6 Vortices in Hexagonal $ErMnO_3$**, *Y. Geng, X.-Y. Wang, S.-W. Cheong,* ***Weida Wu***, Rutgers University

Multiferroics are materials with coexisting magnetic and ferroelectric orders, where inversion symmetry is also broken [1-5]. The cross-coupling between two ferroic orders can result in strong magnetoelectric coupling. Therefore, it is of both fundamental and technological interest to visualize cross-coupled topological defects in multiferroics. Indeed, topological defects with six interlocked structural antiphase and ferroelectric domains merging into a vortex core were revealed in multiferroic hexagonal manganites [6, 7]. Numerous Z_6 vortices are found to form an intriguing self-organized network, and may be used to test Kibble-Zurek model of early universe [8, 9]. Many emergent phenomena, such as enhanced conduction and unusual piezoelectric response, were observed in charged ferroelectric domain walls protected by these topological defects [10, 11]. In particular, alternating uncompensated magnetic moments were discovered at coupled structural antiphase and ferroelectric domain walls in hexagonal manganites using cryogenic magnetic force microscopy (MFM) [12], which demonstrates the coupling between ferroelectric and spin orders (B_2 phase). The appearance of correlated net moments at the coupled domain walls is in excellent agreement with a phenomenological Landau theory [13], suggesting that the 120° antiferromagnetic order (B_2 phase) rotates 4pi in each Z_6 vortex. This is further corroborated by the magnetic field dependence of domain wall moments.

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Reference

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4:40pm **MI+MG-TuA8 Two-Dimensional Manganese Gallium Quantum Height Islands on Wurtzite GaN (000-1)**, ***Jeongihm Pak***, *A. Mandru, A.R. Smith*, Ohio University

We describe the spontaneous formation of five and six-monolayer quantum height manganese gallium islands on gallium-rich, nitrogen polar GaN($000\underline{1}$). From ex-situ MOKE measurements at room temperature, we expect these MnGa islands to be ferromagnetic. The structural evolution is followed from the beginning of growth using reflection high energy electron diffraction, in which a dotted 2× pattern is observed to form. In-situ scanning tunneling microscopy is also used to investigate the islands' structures with atomic resolution. Based on all the observations, we propose the possible bulk and surface models for the islands. A possible bonding structure at the substrate/island interface is also discussed in which Mn atoms substitute for Ga atoms on the Ga adlayer thus making the MnGa islands bonded to the GaN substrate. Atomic chains are observed only on the six-layer island surface and the model for the chains is also discussed. STM observations of atomic-chain interconnection on the six-layer island surface indicate a dynamic system at room temperature. The models presented here should serve as useful starting points for theoretical calculations.

5:20pm **MI+MG-TuA10 Current Topics in Magnetism: The Importance of Interfaces**, ***Mark Stiles***, National Institute of Standards and Technology

Interfaces play a crucial role in many magnetic systems. As magnetoelectronic devices shrink, this role is becoming more and more important. Unfortunately, many times these interfaces are not well enough characterized to allow measurements to constrain physical models of the behavior in these systems. In this talk, I give several examples from my own experience of systems of both historical and current interest in which the interfaces play a dominant role but for which very little is known. A historical example is exchange bias, the study of systems in which the behavior of a ferromagnetic film is modified by coupling to it to an antiferromagnet. In spite of decades of study on a wide variety of systems, structural characterization of the interfaces has only been done several times on model systems, despite the fact that all of the coupling occurs at this interface. A topic of recent interest is the study of current induced torques in magnetic bilayers consisting of ferromagnetic thin films coupled to non-magnetic materials with strong spin-orbit coupling. The spin orbit coupling dramatically affects the current induced torques in these systems. An outstanding question is what role the interfacial spin-orbit coupling plays. This can be addressed theoretically by first-principles calculations, but these necessarily assume ideal interfaces between perfectly coherent lattices for material pairs with lattice mismatch on the order of ten percent. Without real characterization of the structure of these interfaces, it is almost impossible to definitively determine which parts of the system are playing important roles. Both of these topics are useful or potentially useful for applications, a characteristic that tends to drive research focused on achieving dramatic results rather than doing the time intensive work necessary to characterize the samples adequately to support a deeper understanding of the underlying physics.

5:40pm **MI+MG-TuA11 Optical Spectroscopy of Nanomaterials within Magnetic Fields**, ***Angela Hight Walker***, NIST

Transition-metal dichalcogenides are a new system in which to study the effect of temperature and magnetic field on optical properties. Recent experiments will be discussed from a novel set up which couples a confocal optical microscope into fields up to 9 Tesla and temperatures down to 3.5 K, with several laser sources throughout the visible range. As these dichalengenides or 2D materials are certainly under study for use in nanoelectronic devices they are of general interest to the Magnetic Interfaces and Nanostructures (MIN or MI) Division. Other areas where MIND members see as future foci will be explored. Methods to ensure that the Division draw upon the widest possible spectrum of talented individuals from all segments of society will also be discussed.

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