Tuesday Afternoon, October 20, 2015

Magnetic Interfaces and Nanostructures
Room: 230A - Session MI+SA-TuA

Spin Currents, Spin Textures and Hybrid Magnetic Structures

Moderator: Greg Szulczewski, The University of Alabama

2:20pm **MI+SA-TuA1 Spin Hall Effect in Metallic Multilayers**, ***Georg Woltersdorf***, Martin Luther University Halle-Wittenberg, Germany, *M. Obstbaum, M. Decker, D. Wei, C.H. Back,* University of Regensburg **INVITED**

The discovery of the spin pumping effect and the Spin Hall Effect (SHE) has stimulated the research on dynamics in metallic magnetic nanostructures. Here a comprehensive study of the SHE in metallic multilayers will be presented. We study the direct as well as the inverse SHE. In the case of the direct SHE a dc charge current is applied in the plane of a ferromagnet/normal metal layer stack and the SHE creates a spin polarization at the surface of the normal metal leading to the injection of a spin current into the ferromagnet [1,2]. This spin current is absorbed in the ferromagnet and causes a spin transfer torque. Using time and spatially resolved Kerr microscopy we measure the transferred spin momentum and compute the spin Hall angle. In a second set of experiments using identical samples pure spin currents are injected by the spin pumping effect from the ferromagnet into the normal metal [3]. The spin current injected by spin pumping has a large ac component transverse to the static magnetization direction and a very small dc component parallel to the magnetization direction. The inverse SHE converts these spin current into charge current [4,5]. The corresponding inverse SHE voltages induced by spin pumping at ferromagnetic resonance (FMR) are measured in permalloy/platinum and permalloy/gold multilayers in various excitation geometries and as a function of frequency in order to separate the contributions of anisotropic magnetoresistance and SHE. In addition, we present experimental evidence for the ac component of inverse SHE voltages generated by spin pumping [6,7].

[1] - K. Ando et al., Phys. Rev. Lett. **101**, 036601, (2008)

[2] - V. E. Demidov et al., Phys. Rev. Lett. **107**, 107204 (2011)

[3] - Y. Tserkovnyak, A. Brataas, and G.E.W. Bauer, Phys. Rev. Lett. **88**, 117601 (2002)

[4] - E. Saitoh et al., Appl. Phys. Lett. **88**, 182509 (2006)

[5] - O. Mosendz, et al., Phys. Rev. Lett. **104**, 046601 (2010)

[6] - H. Jiao and Gerrit E. W. Bauer, Phys. Rev. Lett. **110**, 217602 (2013)

[7] - D. Wei et al. Nat. Comm. **5**, 3768 (2014)

3:00pm **MI+SA-TuA3 Chiral Spin Textures in Ultrathin Ferromagnets**, ***Geoffrey Beach***, Massachusetts Institute of Technology **INVITED**

Spin orbit coupling at interfaces in ultrathin magnetic films can give rise to chiral magnetic textures such as homochiral domain walls and skyrmions, as well as current-induced torques that can effectively manipulate them [1-3]. This talk will describe the statics and dynamics of chiral spin textures in thin-film nanowires stabilized by the Dzyaloshinskii-Moriya interactions (DMI) at a heavy metal/ferromagnet interface. We show that the DMI depends strongly on the heavy metal, differing by a factor of ~20 between Pt and Ta [2], and describe the influence of strong DMI on domain wall dynamics [1,2] and spin Hall effect switching [3]. We present high-resolution magnetic imaging of static magnetic textures that directly reveal the role of DMI and allow its strength to be quantified [4]. Finally, we will describe how a gate voltage can be used to control interfacial magnetism and magnetic domain walls in nanowires by manipulating interfacial oxygen coordination and magnetic anisotropy at a ferromagnet/oxide interface [5].

[1] S. Emori, et al., Nature Mater. 12, 611 (2013).

[2] S. Emori, et al., Phys. Rev. B 90, 184427 (2014).

[3] N. Perez, et al., Appl. Phys. Lett. 104, 092403 (2014).

[4] S. Woo, et al., arXiv:1502.07376 (2015).

[5] U. Bauer, et al., Nature Mater. 14, 174 (2015).

4:20pm **MI+SA-TuA7 Indirect Modification of Magnetic Surface States by Organic Semiconductor Adsorbates**, ***Daniel Dougherty***, *J. Wang,* North Carolina State University **INVITED**

The spin-dependent electronic coupling of organic molecules to magnetic electrode surfaces is now widely acknowledged to be a crucial factor controlling direct spin injection in organic spintronic devices. This suggests the application of known surface chemisorption principles can guide new developments in this field. However, the kinds of interactions possible at metal-organic semiconductor interfaces are diverse and direct orbital coupling is not always guaranteed even when chemical intuition favors it. In this talk I will report on an unusual observation of indirect orbital coupling at a metal-organic interface even when direct coupling is geometrically plausible. We have observed that adsorption of the organic semiconductor perylene tetracarboxylic acid dianhydride onto Cr(001) decreases the metal *d*-derived surface state lifetime without causing a shift in its energy. This suggests an indirect electronic interaction that contrasts sharply with expectations of *p-d* electronic coupling based on direct chemisorption. Lifetime changes are measured with scanning tunneling spectroscopy as a function of temperature and quantified as arising from a molecule-induced increase in electron-electron scattering rate into bulk bands. Adsorbate-induced effects extend far beyond the adsorption site of the molecule, decaying exponentially away with a characteristic length scale of ~2.4 nm, similar to the carrier mean free path in Cr .

5:00pm **MI+SA-TuA9 Transitioning into the Ga-rich Regime of Ferromagnetic Manganese Gallium Films Grown on Gallium Nitride: Structure and Magnetism**, ***Andrada-Oana Mandru****, *J.P. Corbett, A.L. Richard,* Ohio University, *J.M. Lucy,* Ohio State University, *D.C. Ingram,* Ohio University, *F. Yang,* Ohio State University, *A.R. Smith,* Ohio University

Depositions of magnetic atoms such as Mn onto wide-gap semiconducting GaN surfaces give rise to various MnGa alloyed nanostructures, some having promising magnetic properties. Co-depositions of Mn and Ga result in ferromagnetic alloys that grow with high epitaxial quality on GaN. Such sharp interfaces undoubtedly make MnGa/GaN a very attractive spintronic system. Growth under slightly Mn-rich conditions (Mn:Ga composition ratio ~1.09) causes Mn atoms to incorporate at different rates; surfaces become highly Mn-rich, while the bulk retains a 1:1 stoichiometry. In addition, their magnetic properties could potentially be tailored by altering elemental composition and/or film thickness. Motivated by these intriguing observations and possibilities, we explore what happens when crossing the Mn:Ga 1:1 stoichiometric limit into the less studied Ga-rich side. We combine various techniques to investigate in detail the growth, structure and magnetism of MnGa alloys with different thicknesses and compositions, when coupled with GaN substrates.

Samples are prepared using molecular beam epitaxy with GaN/Sapphire used as starting substrate. Subsequent depositions involve a fresh film of GaN followed by thin (~30-50 nm) or ultra-thin (~3.3 nm) MnGa films. Manganese and gallium are co-evaporated from Knudsen cells while keeping the substrate temperature at ~250 °C. The growth is monitored in real time using a 20 keV reflection high energy electron diffraction system. *In-situ* room temperature scanning tunneling microscopy investigations reveal highly epitaxial films with smooth surfaces that exhibit a rich variety of reconstructions. The Mn:Ga composition ratios range from ~1 (stoichiometric) to ~0.42 (very Ga-rich), as determined by Rutherford backscattering spectrometry. For stoichiometric films, x-ray diffraction characterizations show primarily MnGa peaks; upon transitioning into the Ga-rich regime, we find a co-existence of Mn_3Ga_5 and Mn_2Ga_5 phases, with Mn_2Ga_5 becoming predominant for the highly Ga-rich samples. Magnetic investigations reveal that all films exhibit ferromagnetism, including the very Ga-rich ones. Vibrating sample magnetometry measurements performed on the thin samples show stepped hysteresis loops, along with a decrease in coercivity and magnetic moment values as the Ga concentration increases. Additional superconducting quantum interference device measurements performed on the ultra-thin samples show that large magnetic anisotropies are induced by decreasing the thickness of our films. Most recently, similar investigations applied to FeGa magnetostrictive alloys reveal very interesting surfaces and magnetic properties.

*** Falicov Student Award Finalist**

5:20pm **MI+SA-TuA10 A Depth-Dependent Model for Atomic Valence in Magnetoelectric Systems**, ***Mikel Holcomb***, *R. Trappen*, *J. Zhou*, West Virginia University, *Y-H. Chu*, National Chiao Tung University, *S. Dong*, Southeast University

Interfacial magnetoelectricity across a multilayer system is known to sometimes result in much larger coupling between electric and magnetism than in single phase systems. The cause has been controversial, but the atomic valence of the magnetic element in these systems is known to change with an applied voltage. We wanted to understand how the interfacial atomic valence was effected as a function of film thickness in thin films of $La_{0.7}Sr_{0.3}MnO_3$ on $PbZr_{0.2}Ti_{0.8}O_3$. To separate the Mn valence at the interfacial layer with PZT from the bulk region of LSMO, we took advantage of the drastically different attenuation length of two techniques: x-ray absorption in *L*-edge total electron yield mode and *K*-edge fluorescence yield mode. By globally fitting both sets of experimental results, we were able to develop a depth-dependent model to estimate the layer by layer valences in our materials as a function of thickness. This empirical model was developed under the guidance of theoretical work from a two-orbital double exchange model, which also explored the effects of substrate termination and ferroelectric polarization direction. Estimates based on the data and models for surface, interface and bulk valence as well as surface and interface length scales will be discussed.

5:40pm **MI+SA-TuA11 Atomic-Scale Magnetism on a Complex Insulating Surface**, ***Barbara Jones***, IBM Research - Almaden, *O.R. Albertini*, Georgetown University, *S. Gangopadhyay*, IBM Research - Almaden, *A.Y. Liu*, Georgetown University

We will describe and analyze the unusual magnetic properties of transition metal atoms on complex, hybrid surfaces. In collaboration with IBM Almaden's Scanning Tunneling Microscopy team, we use DFT+U to calculate the properties of transition metal atoms on one or two atomic layers of insulator on top of a metal such as silver. We show the transition of the interface from bulk insulator or metal to a nanolayer that is nominally insulating, but that hybridizes strongly with the addition of a magnetic adatom to produce a long spin-polarized tail into the vacuum, akin to a metal. We report the results of detailed calculations of a range of magnetic atoms (Mn, Fe, Co, Ni) on MgO/Ag. MgO is a common spintronic insulator, but in a nanolayer on metallic Ag, its behavior is not that of the bulk. We find that each magnetic atom has its own surface signature, with very different local spin and charge interactions with this surface, and compare it to that of other related systems. Using an onsite Hubbard U parameter which we determine from first principles, we are able to study the variability of the magnetic moment and nature of bonding. The magnetic adatoms affect the surrounding interface layer in unexpected ways. We are able to obtain interesting insights which help us understand how magnetism propagates along surfaces as well as between interfaces. These systems have potential for future spintronics or quantum computing applications.

6:00pm **MI+SA-TuA12 Substrate Induced Spin-state Locking of $[Fe(H_2B(pz)_2)_2(bipy)]$ on Au(111)**, ***Sumit Beniwal****, *X. Zhang*, *S. Mu*, University of Nebraska - Lincoln, *A. Naim*, *P. Rosa*, *G. Chastanet*, CNRS Universite de Bordeaux, France, *J. Liu*, Northeastern University, *G. Sterbinsky*, *D. Arena*, Brookhaven National Laboratory, *P.A. Dowben*, *A. Enders*, University of Nebraska - Lincoln

Spin-crossover (SCO) complexes hold promise for spintronics applications as room-temperature single molecular magnets. Their signature functionality arises from a central transition metal atom, which is in a d^4-d^7 configuration in a (pseudo)octahedral N_6 environment and can be switched between a diamagnetic low-spin (S=0) and a paramagnetic high-spin (S=2) state by external stimuli such as temperature, pressure, light and electric field. The switching of the molecular spin-state is accompanied by change of other physical and electronic properties of these complexes, such as color, magnetic susceptibility and electrical conductivity. Application in devices requires that the molecules are in contact with metal electrodes, which can significantly alter their electronic and magnetic properties. This study makes use of a comprehensive suite of surface-sensitive spectroscopy and microscopy tools to investigate the electronic properties of SCO complex $[Fe(H_2B(pz)_2)_2(bipy)]$ on Au(111) to identify characteristic signatures of spin-state of the molecules across thermal spin transition temperature. Variable temperature scanning tunneling microscopy, performed as a function of film thickness, revealed that ordering in the molecular layers is established as the films are cooled well below their spin transition temperature, and this ordering is maintained when the films are brought back to room temperature. Temperature and thickness dependent studies of electronic structure using X-ray photoemission (XPS), X-ray absorption spectroscopy (XAS) and inverse photoemission (IPES) on surface supported networks, reveal substrate effects on the spin state. Satellite features in core level XPS Fe $2p_{3/2}$ peaks are characteristic of the spin transition, whereas angle-resolved XPS (ARXPS) helps to separately determine the electronic structure of interfacial molecules and of molecules away from the interface. Fe L-edge X-ray absorption XAS spectra taken on ultrathin films suggest that the substrate inhibits thermally induced transitions of the molecular spin state, so that both high-spin and low-spin states are preserved far beyond the spin transition temperature of free molecules. These results demonstrate that thin films of the spin crossover complexes studied have distinctively different phase transition behavior as compared to bulk-like samples, which is evidence that interface interactions can considerably affect the molecules' structural conformation, spin state as well as electronic properties. Understanding such interface effects can help establish conditions to control the spin state of molecules and to engineer spin state transitions.

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