Magnetic Interfaces and Nanostructures Division
Room 203A - Session MI+2D-ThM

Magnetism at the Nanoscale

Moderator: Hendrik Ohldag, SLAC National Accelerator Laboratory

8:20am **MI+2D-ThM2 Magnetic Competition in $La_{0.7}Sr_{0.3}MnO_3$ Thin Films**, ***Mikel B. Holcomb,*** West Virginia University

$La_{0.7}Sr_{0.3}MnO_3$ is a strongly correlated ferromagnetic system, commonly proposed for many magnetoresistance applications. Utilizing many techniques (bulk magnetometry, neutron reflectometry and resonant x-ray magnetic scattering), we observe magnetic competition between different magnetic phases in many samples under various growth conditions. This competition results in inverted hysteresis loops (common in superparamagnetic nanoparticles) and negative remanent magnetization. While transmission electron microscopy images show pristine epitaxial growth, the data supports that there are regions of different magnetic order. This results in interesting magnetic measurements, that share similarities with ferrimagnets with competing magnetic lattices. Sample growth and optimization were supported by NSF (DMR-1608656), national facility measurements and theory were supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0016176, and optical measurements by American Chemical Society (PRF #56642-ND10). **We acknowledge the support of the National Institute of Standards and Technology, U.S. Department of Commerce, in providing the neutron research facilities used in this work.**

8:40am **MI+2D-ThM3 Ferromagnetism in 2D Materials**, ***Jiabao Yi,*** The University of New South Wales, Australia **INVITED**

Discovery of graphene has attracted wide interest of research in the family of 2D layered materials including TMDC (transition metal dichalcogenide), silicene, metal oxide and boron nitride. 2D materials have shown many extraordinary properties, such as high carrier mobility, extra-large mechanical strength and high thermal conductivity and excellent performance in energy storages. Due to its two-dimension nature and high carrier mobility, 2D materials are also very promising for spintronics devices. Graphene has shown long spin diffusion length and high spin injection efficiency [1]. Therefore, introducing magnetism into 2D materials becomes one of the research interests in 2D materials. Doping magnetic element into 2D materials is one of the effective methods to achieve magnetism. Most of the research focuses on theoretical calculations. In this presentation, I will introduce both theoretical calculations and experimental results on magnetic element doped 2D materials. From first principles calculations, it shows defects or defect complexes play important role in the magnetism [2]. In addition, ferromagnetism can be tuned by strain [3]. Experimentally, we observe room temperature ferromagnetism in magnetic element doped 2D materials. Especially, giant coercivity and extremely high magnetization have been observed in magnetic element doped MoS_2. Defects and shape anisotropy play critical roles in the high magnetization and coercivity [4,5].

References:

[1] Bruno Dlubak et al. *Nature Physics* 8, 557 (2012).

[2] Yiren Wang, Sean Li, and Jiabao Yi, *Scientific Report*, 6, 24153 (2016).

[3] Shuan Li et al. *Journal of Physical Chemistry Letters*, 8, 1484(2017).

[4] Sohail Ahmed et al. *Chemistry of Materials*, 29, 9066 (2017)

[5] Sohail Ahmed et al. (to be submitted).

9:20am **MI+2D-ThM5 New Insights into Nanomagnetism by Low-temperature Spin-polarized Scanning Tunneling Microscopy**, ***Dirk Sander,*** Max Planck Institute of Microstructure Physics, Germany **INVITED**

Spin-polarized scanning tunneling microscopy at low temperature (8 K) and in high magnetic fields (6 T) is a powerful technique to investigate magnetic properties of individual nanoscale objects ranging in size form single atoms to several thousand atoms [1]. I focus on the magnetization reversal [2] and the spin-dependent electronic properties of bilayer Co [3], Fe-decorated Co and Fe islands on Cu(111). We find a novel noncollinear, helical magnetic order in the Fe islands, which is identified by a magnetic stripe contrast with a period of 1.28 nm [4,5] in bilayer islands. The periodicity increases to 2.2 nm in three-layer thick Fe islands [6]. The high spatial resolution of the spin-polarized scanning tunneling spectroscopy in combination with theory reveals the significance of structural and electronic relaxation [7] for the magnetic anisotropy, for subtle balances between ferromagnetic and antiferromagnetic exchange interaction, and for spin-dependent transport properties [8] of individual, single nanostructures.

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11:00am **MI+2D-ThM10 Materials Optimization to Form Skyrmion and Skyrmion Lattices**, ***Eric Fullerton,*** University of California at San Diego **INVITED**

There is increasing interest in materials systems where magnetic skyrmions can be observed. I will discuss two materials systems where we observe chiral spin structures at room temperature. The first system is ferrimagnetic Fe/Gd-based multilayers where we observe sub-100-nm skyrmions and skyrmion lattices. However, the chirality of the skyrmions are random indicating they are dipole stabilized (similar to of bubble memory in the 1970's) as opposed to by DMI that favors a fixed chirality. This further allows the formation of bi-skyrmions which result from the merging of two skyrmions of opposite chirality and anti-skyrmions. We find that there is a transition from stripe domains to a skyrmion lattice and then individual skyrmions with magnetic fields and this behavior is sensitive to alloy composition, film thickness, temperature, and field history and only emerges in a narrow range of parameters. Using micromagnetic modeling we are able to quantitatively reproduce our experimental observations. The modeling suggests that the domain wall is Bloch-like in the center of the films but broadens and transitions to more Néel-like towards the surface forming closure domains. The Bloch-like centers have an equal population of the two helicities while the Néel-like part of the walls will have the same helicity at the top of the film and the opposite helicity at the bottom of the film which allows coupling to spin-orbit-torque layers. The second system is Pt/Co(1.1 nm)/Os(0.2 nm)/Pt heterostructures. Using Kerr microscopy to observe skyrmions for a narrow temperature and field range. With relatively low currents, it is possible to generate and move these skyrmions both within patterned wires and full films and we further have observations of the skyrmion Hall effect. The research is done in collaboration with S. A. Montoya, R. Tolley, J. Brock, S. Couture, J. J. Chess, J. C. T Lee, N. Kent, D. Henze, M.-Y. Im, S.D. Kevan, P. Fischer, B. J. McMorran, V. Lomakin, and S. Roy and is supported by the DOE.

11:40am **MI+2D-ThM12 Giant Magnetostriction and Low Loss in FeGa/NiFe Nanolaminates for Strain-Mediated Multiferroic Micro-Antenna Applications**, ***Kevin Fitzell***[1], *C.R. Rementer,* University of California, Los Angeles; *N. Virushabadoss,* University of Texas at Dallas; *M.E. Jamer,* National Institute of Standards and Technology (NIST); *A. Barra,* University of California, Los Angeles; *J.A. Borchers, B.J. Kirby,* National Institute of Standards and Technology (NIST); *G.P. Carman,* University of California, Los Angeles; *R.M. Henderson,* University of Texas at Dallas; *J.P. Chang,* University of California, Los Angeles

The ability to reduce the size of antennae would enable a revolution in wearable and implantable electronic devices. Multiferroic antennae, composed of individual ferromagnetic and piezoelectric phases, could reduce antenna size by up to five orders of magnitude through the efficient coupling of magnetization and electric polarization via strain. This strategy

[1] **Falicov Student Award Finalist**

requires a low-loss magnetic material with strong magnetoelastic coupling at high frequency.

Galfenol ($Fe_{84}Ga_{16}$ or FeGa) is a promising candidate material due to its large magnetostriction (>200 ppm), large piezomagnetic coefficient (>3 ppm/Oe), and high stiffness (>50 GPa), but it is highly lossy in the GHz regime. On the other hand, Permalloy ($Ni_{81}Fe_{19}$ or NiFe) is a soft magnetic material that has very low loss in the GHz regime (ferromagnetic resonance linewidth <20 Oe) but almost no magnetostriction. In this work, nanoscale laminates containing alternating layers of FeGa and NiFe were fabricated via DC magnetron sputtering to combine the complementary properties of the two magnetic phases. Optimized magnetic laminates were shown to exhibit a small coercive field (<20 Oe), narrow ferromagnetic resonance linewidth (<40 Oe), and high relative permeability (>400) (Rementer et al., 2017). In addition, optical magnetoelastic measurements of these laminates confirmed the presence of strong magnetostriction; relative to single-phase FeGa, these laminates represent a threefold enhancement in magnetostriction at saturation and up to a tenfold enhancement at low magnetic fields.

Multiferroic composites incorporating these magnetic laminates were then studied via polarized neutron reflectometry, demonstrating coherent rotation of the individual layers' magnetization with an applied electric field across distances much larger than the exchange length of either material. Micromagnetic and finite element simulations support the experimental results, showing coherent rotation of the magnetization with only small deviations with thicker NiFe layers. Subsequent integration of these laminates into strain-mediated multiferroic antennae confirmed the absorption of electromagnetic and acoustic waves, showing great promise for the use of FeGa/NiFe laminates in micro-scale communications systems.

12:00pm **MI+2D-ThM13 Structural and Electronic Origin of Stable Perpendicular Magnetic Anisotropy in Pt/Co/Pt magnetic ultra-thin film with Ti Buffer Layer**, ***Baha Sakar,*** Gebze Technical University, Turkey; *Z. Balogh-Michels, A. Neels,* Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland; *O. Öztürk,* Gebze Technical University, Turkey

In this work, Pt and Co based multilayer samples with perpendicular magnetic anisotropy (PMA) are prepared. The aim of the work is the optimization and stabilization of the magnetic properties. Highly stable and repeatable PMA samples are demanded for standardization and calibration of magnetic measurements. For this purpose, Pt/Co/Pt (pcp) and Ti/Pt/Co/Pt (tpcp) samples are prepared on naturally oxidized Si(111) substrates by using magnetron sputtering. Electronic structures and elemental composition of the sample surfaces are investigated by X-Ray Photoelectron Spectroscopy. The same technique is also used for thickness calibrations of depositions. Magnetic properties of the samples are investigated by using Magneto-Optical Kerr Effect method. Orientations of the grains are important for defining the magnetic easy axis of a magnetic material. Typical symmetric XRD scans are not suitable for very thin films (<10 nm) since the signal to background ratio is low. For this reason, structural properties of the films are analyzed by using grazing angle XRD and in-plane XRD reciprocal space mapping.

Samples with the titanium buffer layer (tpcp) have perpendicular magnetic anisotropy where the pcp samples have in-plane magnetization. Structural differences in the presence of Ti layer are the strong preferred orientation for Pt, while the pcp film is random oriented. Multiple Co reflections are also visible for the pcp film. These confirmed a 111 fiber texture for the Pt in case of the tpcp sample. Contrary to that multiple Pt rings are observed for the pcp sample, which agrees with a random oriented nanocrystalline film. The lack of a texture explains the magnetic behavior.

Samples prepared in this work are used/using and studied within a joint research project, EMPIR SIB05 NanoMag funded by EURAMET.

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