## Magnetic Interfaces and Nanostructures
## Room 101C - Session MI+2D+AC-MoM

### Chiral Magnetism (8:20-10:20 am)/Magnetism and Spin Orbit Effects at Interfaces and Surfaces: Recent Experimental and Theoretical Advances (10:40 am - 12:00 pm)

**Moderators:** Markus Donath, Westfälische Wilhelms-Universität Münster, Germany, Hendrik Ohldag, SLAC National Accelerator Laboratory

8:20am **MI+2D+AC-MoM1 Manipulation of Magnetic Skyrmions with STM*, Kirsten von Bergmann,*** University of Hamburg, Germany **INVITED**

Magnetic skyrmions are topologically distinct from their ferromagnetic environment. They may form in an inversion asymmetric environment and are induced by a competition between magnetic exchange, Dzyaloshinsky-Moriya interaction, and typically the Zeeman energy. Scanning tunneling microscopy (STM) is a valuable tool to study the properties of nanometer-scale skyrmions [1]. In addition to measurements with spin-polarized STM tips skyrmions can also be detected with unpolarized electrodes due to spin-mixing effects in the non-collinear spin texture. We employ spatially resolved magnetic field dependent tunneling spectroscopy to identify this effect of non-collinear magnetoresistance and find that it scales with the angle between nearest neighbors [2]. With a non-magnetic STM tip it is also possible to locally switch the topology of a thin magnetic layer via the sign of the electric field between tip and sample [3]. The combination of these two phenomena –electrical detection and electric field switching of topologically distinct states– could lead to a robust non-magnetic read- and write-head for future skyrmion racetracktype devices.

[1] K. von Bergmann et al., *J. Phys.: Cond. Mat.* **26**, 394002 (2014).

[2] C. Hanneken et al., *Nature Nanotechn.* **10**, 1039 (2015).

[3] P.-J. Hsu et al., arXiv:1601.02935.

9:00am **MI+2D+AC-MoM3 Skyrmion Hall Effect***, W. Jiang,* Argonne National Laboratory*; X. Zhang,* The University of Hong Kong, Hong Kong Special Administrative Region of China*; G. Yu,* University of California Los Angeles*; M.B. Jungfleisch, J.E. Pearson, O. Heinonen,* Argonne National Laboratory*; K.L. Wang,* University of California Los Angeles*; Y. Zhou,* The University of Hong Kong, Hong Kong Special Administrative Region of China*; S.G.E. te Velthuis, **Axel Hoffmann**,* Argonne National Laboratory

Magnetic skyrmions are a perfect example for the ensuing complexity of mesoscale magnetism stemming from competitions between interactions crossing many lengthscales [1]. The interplay between applied magnetic fields, magnetic anisotropies, as well as symmetric and antisymmetric exchange interactions, can stabilize topologically distinct spin textures known as magnetic skyrmions. Due to their topology magnetic skyrmions can be stable with quasi-particle like behavior, and can be manipulated with very low electric currents. This makes them interesting for extreme low-power information technologies [2,3], where data is envisioned to be encoded in topological charges, instead of electronic charges as in conventional semiconducting devices. Recently, we demonstrated the ability of generating and stabilizing magnetic skyrmions at room temperature in Ta/CoFeB/TaOx trilayers, where the broken inversion symmetry gives rise to a net chiral exchange interaction [4,5]. Using spin Hall effects [6] from the Ta layer it is possible to efficiently move these skyrmions with electric currents. Theoretically it is expected that the motion of the skyrmions have a significant transverse component, the skyrmion Hall effect, which is directly related to the topological charge resulting in a net gyrotropic force. Here we demonstrate the direct observation of this transverse motion [7] using magneto-optic Kerr effect imaging. We observe that the skyrmion Hall angle varies continuously from zero just above the depinning threshold until 15º for current densities up to 107 A/cm2. This gradual variation of the skyrmion Hall angle indicates the changing competition between pinning and gyrotropic forces as the skyrmion motion transitions from the creep to the flow regime. The maximum observed Hall angle is in good agreement with theoretical expectations.

This work was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division. Lithographic patterning was carried out at the Center for Nanoscale Materials, which is supported by DOE, Office of Science, BES (#DE-AC02-06CH11357).

References

1. A. Hoffmann and H. Schultheiß, Curr. Opin. Solid State Mater. Sci. 19, 253 (2015)

2. A. Hoffmann and S. D. Bader, Phys. Rev. Appl. 4, 047001 (2015).

3. W. Jiang, et al., AIP Adv. 6, 055602 (2016).

4. W. Jiang, et al., Science 349, 283 (2015).

5. O. Heinonen, et al., Phys. Rev. B 93, 094407 (2016).

6. A. Hoffmann, IEEE Trans. Magn. 49, 5172 (2013).

7. W. Jiang, et al., arXiv:1603.07393.

9:20am **MI+2D+AC-MoM4 Microscopic Magnetic Structures in Dy/Y Superlattices Measured by Polarized Neutron Reflectometry with Off-specular Scattering***, **Gary Mankey**, J. Yu, P. LeClair,* University of Alabama*; R. Fishman, J.L. Robertson, H. Ambaye, V. Lauter, H. Lauter,* Oak Ridge National Laboratory

Epitaxial Dy/Y superlattices with vertically-oriented c-axes, nanometer-scale layer thicknesses and 8-80 repeats were fabricated by magnetron sputtering on a-sapphire substrates with Nb buffer layers. The samples are designed to study how helical magnetic structures in Dy are modified by coupling through non-magnetic Y layers. X-ray characterization was used to evaluate the crystallographic orientations and interface widths of the superlattices. The macroscopic magnetic properties were characterized by low-temperature magnetometery that shows cooling in a 1 T in-plane field results in significant ferromagnetically-aligned moments below magnetic transition temperatures of approximately 150 K. The microscopic magnetic structures were investigated by polarized neutron reflectometry with off-specular scattering (PNROS) with variable magnetic fields in a temperature range from 300K down to 5K. PNROS confirms the magnetic transition and shows how the microscopic magnetic structures of the multilayered samples change with temperature. The ordering of the helical modulation is sensitive to the interfacial roughness of the multilayers as well as the magnetic and temperature history of the samples. The turn angles of the helical magnetic moment can be extracted from fitting the data. When the samples are cooled from room temperature to 5 K in a 10 mT in-plane applied magnetic field, the helical magnetic structures appear to decompose into lateral domains of opposite chirality, as evidenced by strong off-specular Bragg sheets. The Bragg sheets originate from the magnetic peaks associated with the helical magnetic ordering. The strength of the scattering from these sheets varies from sample to sample, suggesting that some samples may have a preferred chirality, due to differences in the microscopic film structure.

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9:40am **MI+2D+AC-MoM5 Chirality Effects in Rare Earth based Thin Films and Multilayers***, **Dieter Lott**,* Helmholtz Zentrum Geesthacht, Germany*; K. Chen,* Universität Köln, Germany*; V. Tarnavich,* Petersburg Nuclear Physics Institute, Russian Federation **INVITED**

Films consisting of rare-earth elements became recently in the focus of attention due there rich variety of magnetic effects owed to the complex interplay between their spin and orbital magnetic moments. On the search of novel types of magnetic sensors and other spintronic devices they offer a path for creating complex magnetic spin structures that have the potential for being used in future applications in the field of information technology. In this presentation the focus is on the phenomena of magnetic chirality that was lately found in Rare-Earth multilayers. In the first part the chirality effects will be discussed for Dy/Y and Ho/Y multilayer where the symmetry of left- and right handed helical spirals formed by the RKKY interaction can be broken by the application of a magnetic field leading to a chiral state [1-3]. Here, different theoretical models are applied to explain the observed phenomena and will be discussed here. In the second part it will be shown how chirality in a thin film system consisting of alloys of rare-earth elements and 3d transition metals may be utilized for creating an exchange bias effect that differs fundamental from the one formed by conventional antiferromagnetic/ferromagnetic film systems. Furthermore, an outlook on the highly promising rare-earth elements / 3d transition metals alloys will be given [4]. For the exploration of the chirality effects in the here given examples, the application of polarized neutrons were essential enabling one to identify the magnetic states of the samples and the investigation of the intriguing phenomena of chirality.

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[2] S.V.Grigoriev, D. Lott,2 Yu. O. Chetverikov,1 A. T. D. Grünwald, R. C. C. Ward, and A. Schreyer, Phys. Rev. B 82, 195432 (2010)

[3] V. V. Tarnavich, D. Lott, S. Mattauch, A. Oleshkevych, V. Kapaklis, and S. V. Grigoriev, Phys. Rev. B 89, 054406 (2014)

[4] K. Chen, D. Lott, F. Radu, F. Choueikani, E. Otero, P. Ohresser, Scientific Reports 5, 18377 (2015)

10:40am **MI+2D+AC-MoM8 Is the High Tc Superconductivity in Cuprates an Interface Problem?***, Qi-Kun Xue,* Tsinghua University, China **INVITED**

We investigate the pairing mechanism of high Tc superconductivity in cuprates by using state-of-the-art molecular beam epitaxy (MBE)-scanning tunneling microscopy (STM) in ultra-high vacuum conditions. By two different approaches in sample preparation, namely $Ar^+$ ion bombardment and ozone-assisted MBE growth, we are able to study the gap structure of superconducting copper oxide planes in unprecedented way. We show that the Cooper pairing in cuprates is rather conventional and the unique interfacial structure plays a crucial role in the high temperature superconductivity.

11:20am **MI+2D+AC-MoM10 How to do Depth-Dependent Measurements on Magnetic or Magnetoelectric Thin Films***, **Mikel Holcomb**, R. Trappen, J. Zhou, C-Y. Huang, G. Cabrera,* West Virginia University*; S. Dong,* Southeast University*; Y-H. Chu,* National Chiao Tung University, Taiwan

Analysis of depth-dependent measurements can provide useful information on how material properties change near surfaces or interfaces with other materials. For example, this deviation commonly occurs in magnetic thin films and the variation of these properties can strongly influence how different materials couple with one another. We have recently utilized a combined approach of bulk and surface sensitive x-ray absorption techniques to nondestructively map out depth-dependent atomic valence and magnetization across magnetic $La_{0.7}Sr_{0.3}MnO_3$ and magnetoelectric $La_{0.7}Sr_{0.3}MnO_3/PbZr_{0.2}Ti_{0.8}O_3$ thin films. We have combined measurements on multiple sample thicknesses with theoretical approaches to map out the layer-by-layer atomic valences and how they vary with film thickness. Such efforts may play a critical role in understanding how to build future generations of devices that rely on enhanced surface and interface properties.

11:40am **MI+2D+AC-MoM11 Nano-Pico-Mikro - Dynamic Soft X-ray Microscopy of Magnetic Materials with High Sensitivity***, **Hendrik Ohldag**,* SLAC National Accelerator Laboratory

Understanding magnetic properties at ultrafast timescales is crucial for the development of new magnetic devices. Such devices will employ the spin torque or spin Hall effect, whose manifestation at the nanoscale is not yet sufficiently understood, The samples of interest are often thin film magnetic multilayers with thicknesses in the range of a 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 well 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). The pulsed or continuous sample excitation source is synchronized with the synchrotron source with a few picosecond drift over 24 hours.

In the first year of operation the excellent spatial resolution, temporal stability and sensitivity of the detection electronics of this microscope has enabled researchers to acquire time resolved images of standing as well as traveling spin waves in a spin torque oscillator in real space as well as detect the real time spin accumulation in a non-metal in contact with a ferromagnet.

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