Magnetic Interfaces and Nanostructures
Room: C1 - Session MI-ThM

Magnetization Dynamics, Imaging and Spectroscopy
Moderator: A.T. Hanbicki, Naval Research Laboratory

8:00am **MI-ThM1 Correlated Magnetic Domain Structure and Magnetic Anisotropy Studies on Epitaxial Au / FePd(001) / MgO(001) Thin Films**, *J.R. Skuza**, *C. Clavero, K. Yang,* College of William & Mary, *B. Wincheski,* NASA Langley Research Center, *R.A. Lukaszew*, College of William & Mary

The FePd alloy system can exhibit the $L1_0$ chemically ordered phase when the Fe:Pd stoichiometry of the alloy is near 1:1.[1] The crystallographic structure of the $L1_0$ ordered alloy is characterized by alternating Fe and Pd atomic layers along a cubic stacking direction, which as a consequence suffers a tetragonal distortion. This tetragonal distortion induces a strong perpendicular magnetic anisotropy (PMA) when the layering is parallel to the film plane and the material is in thin film form. The origin of the strong PMA is the large spin-orbit coupling of the paramagnetic Pd atoms and a strong hybridization of their *4d* bands with the highly polarized Fe *3d* bands.[2] Although the mechanism of PMA is well known, controlling it in thin film form is non-trivial and warrants further study to be useful in applications such as magneto-recording media.

We will report on our correlated studies of the magnetic domain structure with the PMA in epitaxial Au / FePd(001) / MgO(001) thin films. Epitaxial FePd thin films were grown using magnetron sputtering in an ultra-high vacuum deposition system at elevated temperatures (400 – 600 °C) and on MgO(001) substrates to achieve highly ordered films with strong PMA. The films were subsequently capped with Au at room temperature (RT) to prevent oxidation, and alteration of the magnetic anisotropy.[3] Reflection high energy electron diffraction was used *in situ* to monitor the epitaxial growth and x-ray diffraction techniques were used *ex situ* to monitor the chemical ordering of the films. Magnetic anisotropy values were obtained from hysteresis loops measured at RT using a Superconducting Quantum Interference Device magnetometer and also by ferromagnetic resonance scans. The magnetic domain structure was investigated using a Nanotec scanning probe microscope with a magnetically coated tip in non-contact mode. These studies have improved our understanding of these strong PMA materials, enabling correlations between the observed domain structure and the magnetic anisotropy, along with comparison to models of domain structure.[4]

[1] T. B. Massalski *et al*. (eds.), Binary Alloy Phase Diagrams, (ASM International, 1990), p. 1751.

[2] A. Cebollada *et al.*, Magnetic Nanostructures, edited by H. S. Nalwa (American Scientific Publishers, 2002), pp. 94-100.

[3] C. Clavero *et al.*, Appl. Phys. Lett. **92**, 162502 (2008).

[4] A. Hubert and R. Schafer, Magnetic Domains The Analysis of Magnetic Microstructures (Springer, 2000), pp. 107-354.

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8:20am **MI-ThM2 Dependence of the Domain Wall Pinning Strengths to Lateral Constriction Size and Electrical Bias in GaMnAs**, ***S.U. Cho***, *H.K. Choi, Yang, Park,* Seoul National University, Korea, *F. DaSilva, T. Osminer, D.P. Pappas*, National Institute of Standards and Technology

Dynamics of domain wall (DW) motion and spin-polarized transport across DWs have received much attention due to their potential applications in large-scale memory storage and logic devices. Particularly for GaMnAs, spin-polarized current induced magnetization switching has been demonstrated [1]. Lateral nanoconstrictions (NC), from which DWs can form and be pinned, in GaMnAs have been utilized to demonstrate nonvolatile memory elements [2] as well as structures showing large magneto-resistances (MRs) [3]. Here, we investigate the size dependence of constrictions in GaMnAs epifilms, particularly the dependence of DW pinning strength as function of lateral constriction size, as well as electrical bias across the constriction. A method to realize nanoconstrictions without plasma-assisted methods and nonlinear IV transport across NC junctions have been reported previously [4]. For this study, we present magnetotransport measurements on identically sized constrictions in series (up to five NC in series) equally spaced apart (~ 2 microns). For large constrictions, the overall resistance (<25 kΩ at room temperature) as function of applied field shows a background negative MR response which can be attributed to anisotropic magnetoresistance with distinct jump-down behavior. The number of distinct jump-down behavior corresponds to number of NC plus one with little dependence of jump field to bias current. Thus, for large constrictions, the geometrical lateral constrictions act 'to seed' DWs. For smaller constrictions (overall resistance > 25 kΩ at room temperature), the MR response is more complex as DW are formed and pinned at the lateral constrictions. MR responses show jump-up behavior along with a complex dependence on jump field to bias current. Furthermore, we will discuss the complex switching behavior observed in small constrictions in series in terms of effects attributed to DW motion and spin-polarized transport across DWs.

[1] M. Yamanouchi *et al.*, Nature **428**, 539 (2004).

[2] K. Rappert *et al.*, Nat. Phys. **3**, 573 (2007).

[3] C. Rüster *et al*., Phys. Rev. Lett. **91**, 216602 (2003); A.D. Giddings *et al*., Phys. Rev. Lett. **94**, 127202 (2005).

[4] S.U. Cho *et al*. Appl. Phys. Lett. **91**, 122514 (2007).

8:40am **MI-ThM3 Racetrack Memory: A Current Controlled Domain Wall Shift Register**, ***S.S.P. Parkin***, IBM Almaden Research Center **INVITED**

Racetrack Memory[1] promises a novel storage-class memory with the low cost per bit of magnetic disk drives but the high performance and reliability of conventional solid state memories. Unlike conventional memories, the fundamental concept of Racetrack Memory is to store multiple data bits, perhaps as many as 10 to 100, per access point, rather than the typical single bit per transistor. In Racetrack Memory the data is stored in the form of a series of magnetic domain walls along magnetic nanowires which are oriented either parallel or perpendicular to the surface of a silicon wafer. These distinct structures form "horizontal" and "vertical" Racetrack Memories. Conventional CMOS devices and circuits are used to provide for the creation and manipulation of the domain walls in the magnetic nanowires or "racetracks". The domain walls are shifted back and forth along the nanowires using nano-second long current pulses via the transfer of spin angular momentum from the spin polarized current. Note that the shifting of neighboring domain walls in the same direction along a nanowire is not possible using conventional means of manipulating domain walls with localized magnetic fields.

In this talk we discuss progress towards building a Racetrack Memory and the fundamental physics underlying it. In particular, we discuss the current and field controlled dynamical motion of magnetic domain walls in magnetic nanowires formed from permalloy and related materials.

[1] S.S.P. Parkin, M. Hayashi and L. Thomas, Science **320**, 190 (2008); S.S.P. Parkin, Scientific American (June, 2009).

9:20am **MI-ThM5 Localized Magnetic and Electric Field Response in Mesoscopic InAs Quantum Well Hall Crosses**, ***M. Nishioka***, *L. Folks, J. Katine, E.E. Marinero, B.A. Gurney*, Hitachi GST

Transport properties of mesoscopic Hall crosses in localized magnetic and electric fields have received considerable attention because of their potential application to detection of localized magnetic fields with nanometer resolution. We recently made the first measurement of the response of the Hall voltage to the localized magnetic and electric fields in Hall crosses down to 50 nm x 50 nm cross-sections [1]. Hall crosses, based on InAs quantum well heterostructures, were scanned with a magnetically-coated probe which was also electrically gated to generate both localized electric and magnetic fields. We found that the Hall crosses were sensitive to magnetic fields at the center of the cross. Also, the sensitivity to the localized magnetic field was found to be much larger than that to the localized electric field.

In this work, we report the response to localized magnetic and electric fields of similar crosses configured electrically in "the bend resistance (BR) geometry", where current is passed between adjacent arms of the cross and a voltage is measured between the remaining arms. To our knowledge the response of such heterostructures in the BR configuration to localized magnetic and electric fields has not been previously reported. Figure 1 shows the BR response when the gate voltage applied to the probe and the current applied to the Hall cross are 1 V and -600 μA, respectively. The magnetic field created by the magnetic tip at the InAs quantum well is ~ 600 Oe. The prominent feature in this image is that the BR is sensitive to the localized fields both at the center and the two corners. This is quite different from the response of the Hall resistance [1] where magnetic

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sensitivity was predominant at the cross center. By using both non-magnetic and magnetic probes, we have found that the response to localized electric fields is comparable to localized magnetic fields. Thus, the mapping in Fig. 1 shows significant contributions from both fields. It may therefore be possible to combine the electric field sensitivity of BR measurements with conventional Hall measurements to obtain localized electric and magnetic field information on the nanometer size scale from the same device.

[1] L. Folks *et. al.*, "Near-surface nanoscale InAs Hall cross sensitivity to localized magnetic and electric fields", accepted by Journal of Physics: Condensed Matter.

9:40am **MI-ThM6 Isolation of Exchange- and Spin-orbit- Driven Effects via Manipulation of the Axis of Quantization**, *T. Komesu,* ***G.D. Waddill***, Missouri University of Science and Technology, *S.W. Yu, M.T. Butterfield, J.G. Tobin*, Lawrence Livermore National Laboratory

Double Polarization Photoelectron Spectroscopy (DPPS), using circularly polarized xrays and true spin detection, has been performed using the 2p core levels of ultra-thin films of Fe and Co. This includes both the separation into magnetization- and spin- specific spectra and an Instrumental Asymmetry analysis. By simply by choosing different axes of quantization it is possible to selectively manipulate the manifestation of exchange and spin-orbit effects. Furthermore, the underlying simplicity of the results can be confirmed by comparison to a simple yet powerful single-electron picture.

The interplay of spin-orbit and exchange effects is of crucial importance to the understanding of complex electronic structure. For example, in the highly relativistic 5f systems, this interplay may be the key to understanding electron correlation. [1] One way to address this crucial issue is via photon-helicity- specific and spin-polarized photoemission from core levels, which is strongly dependent upon each of the two effects. [2] In fact, it is possible to observe strongly spin polarized photoemission from completely "non-magnetic" systems. [3] Here, using circularly polarized x-rays and true spin detection, it will be demonstrated how each of the effects, exchange and spin-orbit, can be isolated and quantified, simply by choosing different axes of quantization within the same overall experimental geometry. Moreover, the underlying simplicity of the results will be illustrated by the utilization of separate magnetization- and spin-specific spectra, as well as a simple but powerful single-electron model.

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2. J.G. Tobin and F.O. Schumann, Surface Science 478, 211 (2001).
3. S.W. Yu et al, Phys. Rev. B 73, 075116 (2006); J.G. Tobin et al, EuroPhysics Lett. 77, 17004 (2007).

10:40am **MI-ThM9 Magnetic Soft X-ray Microscopy: Challenges and Opportunities to Image Fast Spin Dynamics on the Nanoscale**, ***P.J. Fischer***, Lawrence Berkeley National Laboratory **INVITED**

The manipulation of spins on the nanoscale is of both fundamental and technological interest. In spin based electronics the observation that spin currents can exert a torque onto local spin configurations which can e.g. push a domain wall has stimulated significant research activities to provide a fundamental understanding of the physical processes involved.

Magnetic soft X-ray microscopy is a powerful analytical technique since it combines X-ray magnetic circular dichroism (X-MCD) as element specific magnetic contrast mechanism with high spatial and temporal resolution. Fresnel zone plates used as X-ray optical elements provide a spatial resolution down to currently <15nm [1] thus approaching fundamental magnetic length scales such as the grain size [2] and magnetic exchange lengths. Images can be recorded in external magnetic fields giving access to study magnetization reversal phenomena on the nanoscale and its stochastic character [3] with elemental sensitivity [4]. Utilizing the inherent time structure of current synchrotron sources fast magnetization dynamics with 70ps time resolution, limited by the lengths of the electron bunches, can be performed with a stroboscopic pump-probe scheme.

I will review recent achievements with focus on current induced wall [5] and vortex dynamics in ferromagnetic elements [6].

Future magnetic microscopies are faced with the challenge to provide both spatial resolution in the nanometer regime, a time resolution on a ps to fs scale and elemental specificity to be able to study novel multicomponent and multifunctional magnetic nanostructures and their ultrafast spin dynamics. The unique features of soft X-ray microscopy and the current developments with regard to improved X-ray optics and high brilliant fsec X-ray sources seems to make this technique a strong candidate to meet this challenge.

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