Thursday Afternoon, November 12, 2009

Magnetic Interfaces and Nanostructures
Room: C1 - Session MI+TF-ThA

Magnetic Thin Films: Multilayers and Nanostructures
Moderator: D.P. Pappas, National Institute of Technology

2:00pm **MI+TF-ThA1 Magnetic Recording Sensor Materials and Technology Above 1 Tb/in^2**, ***J.R. Childress***, Hitachi Global Storage Technologies **INVITED**

Magnetic recording is constantly evolving to reach specific technology targets. Today's hard disk drives can store information at >300 Gbit/in^2, and represent a striking example of nano-technology integrated into everyday life: data bits < 100nm x 20nm, read sensors with dimensions < 80nm, and read/write heads flying < 10nm above the disk. The specific challenge for the read sensor is to maintain adequate signal-to-noise ratio as its dimensions are reduced. For example, the development of recording head sensors for 1 Tb/in^2 and above requires sensors dimensions < 30nm. In this regime, all-metal current-perpendicular-to-the-plane (CPP) giant magnetoresistive (GMR) sensors are an attractive alternative to CPP tunnel-magnetoresistance (TMR) sensors. With typical resistance-area products in the range 0.03-0.10 Ω-μm^2, CPP-GMR sensors have the potential to deliver low sensor impedance at the smallest conceivable dimensions, and therefore lower noise and higher bandwidth performance. Among the challenges that CPP-GMR sensors face are low signal levels due to their low resistance, typically low DR/R when using thin magnetic layers, as well as current-induced noise and instability due to the spin-torque effect. I will review several paths that we have recently explored to increase signal and reduce spin-torque effects in CPP-GMR sensors. For increased signal, a key may be the synthesis and integration of new ferromagnetic thin-films alloys with high spin-polarization at the Fermi level (and therefore resulting in high magnetoresistance spin-valves), such as the predicted half-metallic Heusler alloys. For lower spin-torque effects we have demonstrated the effectiveness of dual spin-valves sensors, rare-earth cap layers for increased Gilbert damping, and synthetic-ferrimagnet free layers. I will present some of the physical concepts behind these approaches, and discuss recent data in the context of the specific technological requirements for magnetic recording around 1 Tb/in^2.

2:40pm **MI+TF-ThA3 Synthesis of Highly Magnetostrictive Single Crystal $Fe_{1-x}Ga_x$ Thin Films**, ***A. McClure***, *H Li,* Montana State University, *J.X. Cao, R.Q. Wu,* University of California, Irvine, *E. Arenholz,* Advanced Light Source, *Y.U. Idzerda*, Montana State University

The $Fe_{1-x}Ga_x$ alloy system is a highly anisotropic magnetostrictive material at the appropriate alloy concentration (termed Galfenol at x ~ 0.2) [1]. In thin film form, the atomic pinning of such a material to a substrate can strongly modify the magnetic anisotropy and therefore the magnetization dynamics in a non-isotropic manner, as is demonstrated by a strong angular dependence of the ferromagnetic resonance (FMR) linewidth.

Single crystal $Fe_{1-x}Ga_x$ thin films of various Ga concentrations were prepared on GaAs(001) and MgO(001) substrates by molecular beam epitaxy (MBE), with and without ZnSe buffer layers, respectively. For both substrates, reflection high energy electron diffraction (RHEED) measurements, performed *in-situ* during the growth, show single crystal epitaxial growth of the bcc structure for alloy compositions up to x = 0.7, well beyond the bulk stability region. Vibrating sample magnetometry (VSM) measurements show a reduction in the saturation magnetization with the incorporation of Ga, as well as a migration of the magnetic easy and hard axes that varies slightly between the two substrates. This slight variation is most likely due to the additional uniaxial magnetic anisotropy present in the films grown on the GaAs substrate due to the directional bonding from the zinc-blende surface. X-ray magnetic circular dichroism (XMCD) performed at the Fe $L_{2,3}$-edges reveals a very gradual decrease (10%) in the elemental Fe moment as the Ga concentration approaches 20% followed by a precipitous drop in moment for higher concentrations, while X-ray absorption spectroscopy (XAS) and XMCD measurements performed on the Ga $L_{2,3}$-edges show an evolution in the local Ga electronic structure (a narrowing of 1.6 eV in the L_3 peak position) and establishes an induced moment in the gallium of 0.1 m_B anti-aligned to the Fe moment, in remarkably strong agreement with *ab-initio* density functional (GGA) calculations.

[1] A. E. Clark, J. B. Restorff, M. Wun-Fogle, T. A. Lograsso, and D. L. Schlagel, IEEE Trans. Magn. **36**, 3238 (2000).

3:00pm **MI+TF-ThA4 Anisotropic Transport in Manganite Films Driven by Selective Tailoring of Emergent Electronic Phase Separation**, ***T.Z. Ward***, *J.D. Budai, Z. Gai, J.Z. Tischler, L. Yin, J. Shen*, Oak Ridge National Laboratory

Complex oxides show a wide range of unique behaviors due to their often inseparable energy overlaps of spin-charge-lattice-orbital interactions. These interactions form the basis for emergent electronic phase separation in many complex materials which have been linked to exotic behaviors such as colossal magnetoresistance, the metal-insulator transition, and high T_C superconductivity. By selectively tuning the energetic landscape that shapes the emergent formation of electronic phase separation, we have uncovered never before seen anisotropic transport properties that promise new tunable device applications while answering fundamental questions on the role of electronic phase separation in manganites. Using $La_{5/8-x}Pr_xCa_{3/8}MnO_3$ (x = 0.3) (LPCMO) as a model system, we have found that we can selectively induce anisotropic electronic domain formation along one axis of a pseudocubic perovskite single crystal thin film manganite by epitaxially locking it to an orthorhombic substrate. Simultaneous temperature-dependent resistivity measurements along the two perpendicular in-plane axes show significant differences in the metal-insulator transition temperatures and extraordinarily high anisotropic resistivity on macroscales of up to 20000%. These findings show that emergent electronic phase domain formation can be selectively tuned over long distances which opens the door to new device engineering and a fuller understanding of the balanced energetics that drive emergent behaviors in complex materials.

3:40pm **MI+TF-ThA6 Spin-Torque Behavior of Perpendicular Anisotropy Nanopillar Devices**, ***E.E. Fullerton***, *I. Tudosa,* University of California, San Diego, *J. Cucchiara, S. Mangin,* U. Nancy, France, *Y. Henry,* IPCMS, France, *J. Katine,* Hitachi GST, *D. Ravelosona*, IEF, France **INVITED**

Spin torque reversal of nano-elements with perpendicular magnetic anisotropy have considerable interest for both the fundamental study of spin torque reversal and for possible spin-torque based devices. This ability to locally control magnetization opens the door to a range of applications such as high-density magnetic random access memories, tunable high frequency oscillators and possibly programmable logic devices. In perpendicular anisotropy systems the demagnetization field is commensurate with the anisotropy axis and can be described as an effective uniaxial anisotropy. Both the critical current for spin-torque reversal and the thermal stability are then proportional to the effective anisotropy [1-3] as shown experimentally for [Co/Pt]/[Co/Ni]/Cu/[Co/Ni] nano-pillar samples[2, 3]. In this presentation we describe recent experimental and theoretical studies of the influence of spin currents on the field and angular dependence of the free layer switching fields. The angular dependence of the switching field in the absence of current is well described by the Stoner-Wohlfarth asteroid for a uniaxial system. With the addition of current we find that spin-torque reversal is most efficient when the applied field is parallel to the anisotropy axis. Surprisingly, for fields applied at an angle to the anisotropy axis the switching fields are current independent for currents lower than a critical value and the critical current increases with increasing field angle. We will discuss the origin of this phenomena and results for coupled reversal of the free and reference layer.

[1]. J. A. Katine and E. E. Fullerton, J. Magn. Magn. Mater. **320**, 1217 (2008).

[2] S. Mangin et al., Nat. Mater. **5,** 210 (2006).

[3] S. Mangin et al., Appl. Phys. Lett. **94,** 012502 (2009).

4:20pm **MI+TF-ThA8 Spin Transfer Switching in Magnetic Tunnel Junctions with Co-Based Perpendicular Magnetic Anisotropy Multilayers**, ***Z.R. Tadisina***, *A. Natarajarathinam, S. Gupta, T. Mewes, P. LeClair,* University of Alabama, *E. Chen, S. Wang,* Grandis, Inc., *W.F. Egelhoff*, NIST

Spin transfer switching (STS) has been studied for CoFeB/MgO/CoFeB magnetic tunnel junctions (MTJ) with perpendicular magnetic anisotropy (PMA) free and reference layers. The PMA multilayer material systems were studied as a function of bilayer thickness, bilayer ratio, and number of bilayers for Co/M multilayers, where M was Ni, Pd or Pt. After initial matrix experiments carried out to determine the experimental parameter space, a statistical Design of Experiments (DOE) was conducted to optimize the film structure that would maintain stable perpendicular anisotropy for a reasonable thickness of CoFeB, as well as minimize the damping parameter, α. For Co/Ni multilayers, the damping parameter varied from 0.016 to 0.023 as a function of the number of multilayers. As predicted and experimentally confirmed by others[1,2], we observed a critical thickness of Co above which

the PMA disappears and in-plane anisotropy is observed. The magnetic behavior of these PMA systems was studied by vector magnetometry and alternating gradient magnetometry. X-ray diffraction, transmission electron microscopy (TEM) and local electrode atom probe (LEAP) studies were carried out to investigate the structure of the multilayers, interface smoothness, and growth of (111) texture as a function of deposition conditions and post-deposition annealing. Stress and magnetic force microscopy (MFM) studies confirmed the presence of stripe domains in the PMA stacks. The resistance-area (RA) product and tunneling magnetoresistance (TMR) of the unpatterned MTJ stacks were tested by current-in-plane tunneling (CIPT) measurements to optimize the MgO barrier and PMA stacks prior to actual device fabrication. The transport properties of the patterned MTJ stacks were tested in a PPMS system for both field and current switching from 10K to 400 K to test the thermal stability of these devices.

References:

1. O. Hellwig, A. Berger, J. B. Kortright, and E. E. Fullerton, "Domain structure and magnetization reversal of antiferromagnetically coupled perpendicular anisotropy films," J. Magn. Magn. Mater., vol. 319, pp.13–55, May 2007.

2. M. Tekielak, P. Mazalski, A. Maziewski, R. Schäfer, J. McCord, B. Szyman´ski, M. Urbaniak, and F. Stobiecki, "Creation of Out-of-Plane Magnetization Ordering by Increasing theRepetitions Number N in (Co/Au)N Multilayers," IEEE Trans. Magn. vol. 44, pp. 2850-2853, November 2008.

4:40pm **MI+TF-ThA9 Experimental Evidence for an Angular Dependent Transition of Magnetization Modes in Magnetic Nanotubes**, ***O. Albrecht***, *R. Zierold*, University of Hamburg, Germany, *C. Patzig*, Leibniz-Institute of Surface Modification, Germany, *S. Allende*, FCFM Universidad de Chile, *D. Görlitz*, University of Hamburg, Germany, *B. Rauschenbach*, Leibniz-Institute of Surface Modification, Germany, *K. Nielsch*, University of Hamburg, Germany

Highly anisotropic magnetic nanostructures maybe used to overcome the superparamagnetic limit found in magnetic nanoparticles. A well known approach which yields highly anisotropic structures is the creation of magnetic nanotubes. An established route for the fabrication of tubular structures is the use of porous alumina membranes as templates for subsequent covering with a magnetic layer by atomic layer deposition (ALD).

By using glancing angle deposition (GLAD), we present an new approach for a template synthesis to realize magnetic nanostructures.

The combination of GLAD and ALD techniques has the ability to build more complex magnetic nanostructures such as zigzag structures consisting of segmented tubes with adjustable angle between them.

We investigate the angular dependent magnetization determined by SQUID magnetometry at room temperature for all three directions in space.

The main result is the experimental evidence for theoretically predicted transition between two magnetization reversal modes (Vortex to Transverse).

5:00pm **MI+TF-ThA10 Experimental Observation of Ligand Induced Paramagnetism in CdSe Nanocrystals**, ***J.R.I. Lee***, Lawrence Livermore National Laboratory, *R.W. Meulenberg*, University of Maine, *S.K. McCall*, Lawrence Livermore National Laboratory, *K.M. Hanif*, Naval Research Laboratory, *J.C. Lang*, *D. Haskel*, Argonne National Laboratory, *L.J. Terminello*, *T. van Buuren*, Lawrence Livermore National Laboratory

The observation of magnetism has recently been reported for numerous nanoscale materials that do not demonstrate comparable behavior in bulk form. This is intriguing because coupling the magnetic properties of the nanocrystalline materials with their size-dependent optical and electronic behavior presents the potential for application in a variety of technologies. Identifying the origin of the magnetic properties is, therefore, of paramount importance. To date, several conflicting mechanisms have been proposed in studies of a number of nanoscale systems and, significantly, the cause of the magnetism remains a matter of some controversy in the literature. For example, the ferromagnetic behavior observed for Au nanocrystals (NCs) has been attributed to interactions with the organic surface passivant in one study and an intrinsic property of the nanoscale metal in another. Comparable sources have been also been proposed for the magnetic properties of CdSe NCs, along with an alternative possibility that defect sites are responsible. We report a systematic investigation of the effects of the surface passivant on CdSe NCs using a combination of x-ray magnetic circular dichroism (XMCD) spectroscopy, superconducting quantum interference device (SQUID) magnetometry and x-ray absorption spectroscopy (XAS). The suite of experiments demonstrates that, contrary to the findings of prior studies, our NCs are not ferromagnetic and instead exhibit paramagnetic behavior. In addition, the magnetic susceptibility is dependent on interactions with the organic molecule used to passivate the surface of the CdSe NCs. More specifically, the paramagnetic properties depend upon electron transfer at the molecular level via π-back donation between surface Cd atoms and the organic ligands.

Project 07-LW-041 was funded by the LDRD Program at LLNL. This work was partially supported by the OBES, DMR, under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344. Use of the ALS and APS was supported by the U.S. DOE, Office of Science, OBES, under Contracts DE-AC02-05CH11231 and DE-AC02-06CH11357, respectively.

5:20pm **MI+TF-ThA11 Artificial Nanomagnets With Lateral Confinement**, *L. Yin*, ***Z. Gai***, *J. Shen*, *D. Xiao*, *Z.Y. Zhang*, Oak Ridge National Laboratory, *N. Widjaja*, The University of Tennessee, Knoxville, *E.W. Plummer*, Louisiana State University

We introduce a novel way—curved Cu(111) substrate—to smoothly modify the surface states by introducing a miscut angle and study the impact of modifying vicinal surface states on the ferromagnetic behavior of Fe nanodots. Fe nanodots are grown on a Cu(111)-curved substrate where the miscut angle changes from 0° (very large terrace width) to 8° (15-Å terrace width). With this curved substrate, the same growth parameter can be ensured in the whole miscut angle studied. When the Fe nanodot assemblies have an in-plane easy axis, two distinct regimes and a critical terrace width, separating these two regimes, can be identified. However, when the Fe nanodot assemblies have a perpendicular easy axis, we only observe one regime marked by a slight decrease in the critical temperature (T_c). There are three contributing factors: the vicinal surface state, the competition between the Fe nanodots diameter and the terrace width, and the in-plane uniaxial magnetic anisotropy. The couplings between these three factors lead to the interesting behavior observed in the Fe/vicinal Cu(111) nanodot assemblies. The vicinal surface strongly affects the coupling between Fe nanodots.

*Supported in part by Office of Basic Energy Sciences, U. S. DOE.

Authors Index

Bold page numbers indicate the presenter