Wednesday Morning, October 17, 2007

Magnetic Interfaces and Nanostructures

Room: 619 - Session MI-WeM

Magnetic Thin Films and Nanostructures

Moderator: S.H. Liou, University of Nebraska, Lincoln

8:00am **MI-WeM1 Surface Stability and Electronic Structure of Half-Metallic MnSb**, ***S.J. Jenkins***, University of Cambridge, UK **INVITED**

Half-metallic materials, which exhibit complete spin-polarisation at the Fermi level, hold great promise for device applications in the field of spintronics. Amongst a variety of potential drawbacks, however, one of the most pressing is a lack of knowledge concerning surface and interface properties. In particular, the relationship between the stability of different surface/interface phases and the presence of surface/interface-localised electronic states is of great importance.[1,2] We have performed first-principles density functional calculations aimed at elucidating this relationship for various surfaces of the half-metallic zincblende phase of MnSb, demonstrating that it is essential to account for the possibility of reconstruction in determining whether half-metallicity is retained at the surface.[3]

[1] S.J. Jenkins and D.A. King, Surf. Sci. Lett. 494, L793 (2001).
[2] S.J. Jenkins, Phys. Rev. B 70, 245401 (2005).
[3] S. Mollet and S.J. Jenkins, J. Phys.: Cond. Matter (invited, in press).

8:40am **MI-WeM3 Magnetic and Structural Properties of Epitaxial FeRh Thin Films Grown by MBE**, *Y. Ding*, ***D.A. Arena***, Brookhaven National Laboratory, *L.H. Lewis*, Northeastern University, *J. Dvorak*, Montana State University, *C. Kinane, M. Ali, C.H. Marrows, B.J. Hickey*, University of Leeds, UK

Thin films of FeRh alloys with near equiatomic composition and CsCl type ordering exhibit an intriguing antiferromagnetic (AFM) to ferromagnetic (FM) first-order phase transition near 100° C. This easily accessible phase transition has generated interest in using FeRh films as a temperature-tunable AFM pinning layer in exchange-biased magnetic structures.[1] The AFM to FM transition is associated with the dramatic increase of the saturation magnetization M_s, along with temperature hysteresis of M_s, and a variation in the lattice parameter. We have grown high quality, epitaxial FeRh films on MgO(100) via molecular beam epitaxy (MBE); film thickness ranged from ~200 Å to 1000 Å. The films are characterized with a combination of laboratory-based magnetometry and synchrotron-based x-ray diffraction (XRD) and x-ray magnetic circular dichroism (XMCD). Magneto-optic Kerr effect measurements and SQUID magnetometry confirm the AFM to FM transition in the films. Temperature dependent XRD indicates an expansion of the out-of-plane lattice parameter across the phase transition which mirrors the change in M_s. XMCD spectra were collected in conventional total electron yield (TEY) mode, which probes the near-surface region (probe depth ~50 Å - 100 Å) and in indirect transmission mode (ind-trans), where the oxygen K-edge fluorescence from the MgO substrate is monitored as the photon energy is swept through the Fe $L_{2,3}$ core levels. For the Au capped films, TEY scans reveal a FM near-surface region even at room temperature, while the ind-trans mode data are consistent with a bulk AFM state at ambient temperatures which transforms to a FM state above 100° C. The choice of capping layer also affects the room-temperature magnetism in the near-surface region as the MgO capped films do not exhibit an appreciable XMCD signal in TEY mode.

[1]Thiele. et al., Appl. Phys. Lett.,82, 2859 (2003).

9:00am **MI-WeM4 Properties of Epitaxial Co_2MnSi on Vanadium**, ***G.J. Mankey***, *M.J. Walock, C.A. Culbert, Z. Lu, M. Pathak, Z.T. Reddy, P. LeClair, S. Gupta, W.H. Butler*, University of Alabama

There is a consensus that read sensors for hard drives will transition from tunnel magnetoresistance based sensors to all metal current perpendicular to the plane giant magnetoresistive sensors. To achieve this goal, a new generation of high spin polarization materials are required. Half-metallic Heusler alloys, combined with carefully chosen spacer materials, are prime candidates for incorporation into these devices. However, robust half-metallic behavior must be established and confirmed. Recently, we have investigated the electronic structure of $L2_1$ full Heusler alloys in detail. We can, theoretically, devise an infinite number of periodic systems that are half-metallic, with the hope that at least a handful will be experimentally accessible. Our preliminary calculations of the electronic structure of these materials suggest that they have a robust half-metallic nature. These theoretical results are combined with an experimental study of the half-metallic compound, Co_2MnSi. Epitaxial films are deposited using magnetron sputtering on low-index, single-crystal vanadium substrates and their crystal structure, electronic structure and magnetic properties are determined. Films processed under different deposition conditions are compared to determine the optimum conditions for producing half-metallic single-crystal films. This work is funded by NSF-DMR 02-31985.

9:20am **MI-WeM5 High Magnetization FeCo/Pd Multilayers**, ***M.J. Walock****, The University of Alabama, *H. Ambaye*, Oak Ridge National Laboratory, *M. Chshiev*, The University of Alabama, *F.R. Klose*, Oak Ridge National Laboratory, *W.H. Butler, G.J. Mankey*, The University of Alabama

A high saturation magnetization is advantageous in magnetic recording. For the 3d ferromagnets, the peak of the Slater-Pauling curve corresponds to BCC FeCo, with a saturation magnetization of 2.45 T. Recently, a magnetization of 2.57 T in the FeCo layers of a [40 nm $Fe_{70}Co_{30}$ /1.7 nm Pd]x25 superlattice has been reported.[1,2] This result may be attributed to an enhanced Fe moment due to interfacial strain and an accompanying induced moment in the Pd. We have fabricated multilayer samples with varying superlattice periodicity and interlayer thicknesses to determine the nature of the enhanced moment in this intriguing thin film system. Magnetic characterization experiments show an enhanced magnetic moment in the multilayers as compared to a film containing the same amount of FeCo. However, since the magnetization is defined as the magnetic moment divided by the sample volume, the sample exhibits an overall reduction in the magnetization when the volume of the Pd layers is also taken into account. Our experimental findings are also supported by theoretical calculations which identify the origin of the increased magnetic moment in the multilayer system. Polarized neutron reflectivity experiments will be used to determine the lateral distribution of the magnetization in a number of superlattice samples.[3].

[1] K. Noma, M. Matsuoka, H. Kanai, Y. Uehara, K. Nomura, and N. Awaji. IEEE Trans. Magn. 42, 140 (2006).
[2] ibid. 41, 2920 (2005).
[3] This project was funded by grants from the DOE, the INSIC EHDR Program, and NSF-DMR 0213985 .

9:40am **MI-WeM6 Induced Spin Polarization of Copper Spin 1/2 Molecular Layers**, ***D.S. Wisbey****, *D. Feng*, University of Nebraska-Lincoln, *A.N. Caruso*, North Dakota State University, *C.M. Silvernail*, University of Minnesota, *J. Belot*, University of Nebraska-Lincoln, *E. Vescovo*, National Synchrotron Light Source, *P.A. Dowben*, University of Nebraska-Lincoln

Substrate induced spin polarization was observed in molecular layers of $C_{24}H_{36}N_2O_4Cu$ ($Cu(CNdpm)_2$) deposited on cobalt (111). Extra molecular interactions between these Cu 1/2 molecules and the ferromagnetic substrate are implicated while the $Cu(CNdpm)_2$ molecular layers have an opposite spin polarization compared to the Co(111) substrate near the Fermi edge. The spin-polarized photoemission results are seen to be consistent with magnetometry and mean field (Ginzburg-Landau) models. The spin asymmetry favors select molecular orbitals, suggesting that the local spin 1/2 moment of copper is enhanced by contributions from select molecular orbitals.

10:40am **MI-WeM9 Controlling Magnetic Anisotropy and Probing Magnetic Structure in Magnetic Nanoparticles and Ferromagnetic/Antiferromagnetic Bilayers**, ***M.-T. Lin***, National Taiwan University **INVITED**

Controlling the magnetic orientation and imaging magnetic structure are two of crucial issues in both aspects of fundamental science and application for magnetic nanomaterials. In particular, tuning perpendicular magnetic anisotropy by the more concise and efficient process draws a lot of attentions due to the possible application for perpendicular medium with high storage density. In this work, an enhanced perpendicular magnetic anisotropy of ferromagnetic thin films is demonstrated by introducing an antiferromagnetic (AF) underlayer. A new kind of spin-reorientation transition is also observed with varying thickness of the AF layer. This finding is shown to be related to the strength of the AF coupling of the AF layer. Controlling the magnetic anisotropy can be also important in the magnetic domain imaging with in-plane sensitivity by spin-polarized scanning tunneling microscopy (SP-STM). A simple method by using a ring-shaped magnetically coated wire as the tip of SP-STM is shown to be able to have the spin contrast easily in the in-plane direction of the film. A well-defined magnetization orientation of magnetic tip is achieved due to controlled anisotropy caused by geometrical asymmetry. Finally, magnetic

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coupling and magnetic structure in magnetic self-aligned Fe particles grown on the single crystalline oxide layer $Al_2O_3/NiAl(100)$[1,2] will be also discussed. With help of the technique of scanning electron microscopy with polarization analysis (SEMPA) the magnetic domain is imaged, revealing a vortex structure, which is suggested to be attributed to a dipole-dipole interaction. Furthermore, capping the magnetic particles with non-magnetic metallic layer (Cu) can enhance the magnetic coupling, and in turn the Curie temperature of the system.[3] This finding can also be confirmed in the enhanced spin contrast observed by SEMPA for magnetic particles with capping layer. The magnetic coupling under magnetic particles is shown to be able to propagate through the Cu layer.

[1] W.C. Lin, C. C. Kuo, M.F. Ro, K. J. Song, and Minn-Tsong Lin, Appl. Phys. Lett. 86, 043105 (2005).

[2] W. C. Lin, S. S. Wong, P. C. Huang, C. B. Wu, B. R. Xu, C. T. Chiang, H. Y. Yen, and Minn-Tsong Lin, Appl. Phys. Lett. 89, 153111 (2006).

[3] W. C. Lin, P. C. Huang, K. J. Song, and Minn-Tsong Lin, Appl. Phys. Lett. 88, 153117 (2006) .

11:20am **MI-WeM11 Fabrication and Real Time Characterization of Highly Anisotropic Magnetic Nanostructures**, ***J.R. Skuza****, *R.A. Lukaszew*, The University of Toledo, *C. Clavero*, Instituto de Microelectrónica de Madrid - IMM (CNM - CSIC), Spain, *D.A. Walko*, Argonne National Laboratory, *R. Clarke*, University of Michigan, Ann Arbor

The FePt binary alloy system exhibits several chemically ordered phases (i.e., $L1_0$ and $L1_2$) depending on the Fe:Pt stoichiometry. This chemical ordering affects the crystallographic structure of the alloy and hence the magnetic anisotropy. For example, in thin films of this alloy, the $L1_0$ phase exhibits strong perpendicular magnetic anisotropy when the ordering axis is in the growth direction (~10^7 erg/cc), while the $L1_2$ phase exhibits in-plane magnetic anisotropy. Thus, suitable combinations of these chemically ordered phases have been proposed for the next generation of magnetic recording media with tilted magnetization. A significant challenge for this latter application is to achieve chemically ordered nanostructures that can further push the present super-paramagnetic limit. Here, we report on our recent magnetic and real time thermal annealing studies of nanostructured FePt thin films. FePt nanocomposite thin films were obtained by implanting Fe^+ ions into epitaxial Pt thin films using the Toledo Heavy Ion Accelerator (THIA). The size and penetration depth of the resulting Fe nanoclusters were tailored by modifying the implantation conditions (i.e., ion beam energy and implantation dose). Upon annealing these nanocomposite samples at the Advanced Photon Source at Argonne National Laboratory, we observe within minutes the onset of the $L1_2$ phase at ~400° C with further re-ordering and formation of the $L1_0$ phase at ~500° C. Further data analysis shows that the activation energy of the $L1_0$ phase in these nanocomposite samples is ~1.0 eV. Our magnetic measurements show a strong out-of-plane component of the magnetic anisotropy after the annealing treatment consistent with the formation of the $L1_0$ phase.

This work was partially supported by the National Science Foundation (DMR Grant #0355171), the American Chemical Society (PRF Grant #41319-AC), and the Research Corporation Cottrell Scholar Award. Use of the Advanced Photon Source was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357. The authors would like to acknowledge M. S. Brown for his assistance during ion implantation.

11:40am **MI-WeM12 Effects of Preheat Treat on the Anisotropy and Particle Size of Sr(TiMn)2Fe8O19 Magnetic Powders**, ***H.Y. He***, Shaanxi University of Science & Technology, China

The excellent properties of Ti-Mn-substituted ferrite are largely dependent on the characters of multidomain ferrite powders except for Ti-Co-substitution rate. Preheat treatment can influences the formation process of Ba(TiMn)2Fe8O19 powders and further influences the anisotropy of the powders. However this effect has not be reported previously. Ultrafine substituted M-type Sr(TiMn)2Fe8O19 powders were synthesized successfully by sol-gel method. The hydroxide precursor particles were formed in gel solution containing ethanol and water at a ratio of 1:1 and NaOH as coprecipitation agent. The effects of preheat treatment on particle size and c/a value of Sr(TiMn)2Fe8O19 nano powders were studied using XRD and SEM. XRD analysis indicated single phase substituted M-type Sr-ferrite Sr(TiMn)2Fe8O19 were formed by either preheating precursors at 300oC and 400oC respectively for 1h or non-preheating followed by calcining at 900oC for 2h respectively. The particle sizes of powder were changed from 40.8nm to 39.8nm and 41.1nm when the samples were preheated at 300oC and 400oC respectively. Calculation of c/a value with XRD data indicated that the The c/a ratio changed from 3.9145 to 3.9183 and 3.9153 at the preheating temperatures of 300oC and 400oC respectively. A largest c/a value was achieved at preheating temperature of 300oC. SEM analyses revealed that particles were platelet and the decrease in aspect ratio in morphology was accordant to the increase in the c/a ratio with change from non-preheating to preheating at 400oC and to preheating at 300oC.

12:00pm **MI-WeM13 Surface Functionalization of Single Iron Oxide Magnetic Nanoparticles (SPIONs) for Targeted Magnetic Resonance Imaging (MRI)**, ***E. Amstad***, *E. Reimhult*, *S. Zurcher*, ETH Zurich, Switzerland, *J.A. Hamilton*, Boston University Medical Campus, *J.Y. Wong*, Boston University, *M. Textor*, ETH Zurich, Switzerland

Commercially available negative magnetic resonance (MR) contrast agents often consist of multiple iron oxide cores embedded in a macromolecular matrix such as dextran. An alternative to the reversibly binding dextran is PEG-gallol or PEG-dopamine. The latter two molecules have a considerably higher binding affinity towards iron oxide nanoparticles compared to dextran, leading to enhanced particle stability and smaller particle diameters. Because PEG-gallol and PEG-dopamine adsorb on iron oxide in a well defined way, particles can be stabilized individually. Moreover, surface modifications of such PEGylated particles can be achieved by using PEG-chains that bear functional groups. Superparamagnetic iron oxide nanoparticles have been synthesized by an aqueous precipitation reaction and were stabilized individually using PEG-gallol and PEG-dopamine. Particle size, thermal stability and magnetic properties of these individually stabilized PEGylated particles have been compared with Feridex, a commercially available negative MR-contrast agent. To functionalize the former particles, iron oxide cores were coated with a combination of biotinylated PEG-dopamine and PEG-gallol. Neutravidin, a biotin-binding protein, served as a linker between the PEGylated particles bearing biotin sites and biotinylated functional groups. Neutravidin is an attractive linker for research purposes because any biotinylated ligand can be attached to it. Moreover, the number of ligands bound to one particle can easily be varied if neutravidin is used as an intermediate layer. In a first approach, these neutravidin coated PEGylated nanoparticles were targeted against atherosclerotic sites by attaching a custom-synthesized biotinylated peptide sequence to them.[1] E-selectin is a transmembrane protein expressed on inflamed endothelial cells.[2] It thus is an early marker for atherosclerosis. The blood half-life time of these functionalized superparamagnetic iron oxide nanoparticles has been determined in vivo in rabbits using magnetic resonance imaging (MRI).

[1] Martens, C.L., et al., Peptides Which Bind to E-Selectin and Block Neutrophil Adhesion. Journal of Biological Chemistry, 1995. 270(36): p. 21129-21136.

[2] Choudhury, R.P., V. Fuster, and Z.A. Fayad, Molecular, cellular and functional imaging of atherothrombosis. Nature Reviews Drug Discovery, 2004. 3(11): p. 913-925.

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