## Magnetic Interfaces and Nanostructures
## Room: 206 - Session MI+NC-WeM

## Magnetic Thin Films, Nanoparticles and Nanostructures
**Moderator:** D.P. Pappas, National Institute of Standards and Technology

8:00am **MI+NC-WeM1 Reactive Biased Target Ion Beam Deposition of $AlO_x$ Barrier Magnetic Tunnel Junctions**, ***W. Chen****, *J. Lu, K. West,* University of Virginia, *W. Egelhoff,* National Institute of Standards and Technology, *S.A. Wolf*, University of Virginia

Magnetic tunnel junctions (MTJs) with $AlO_x$ barriers are deposited using a unique tool called Reactive Biased Target Ion Beam Deposition system (RBTIBD) utilizing low energy ion source (0~50eV) and target biasing (50eV~1200eV). The RBTIBD system applies bias voltage directly and only on the desired targets, providing sputtering energy and avoiding "overspill" contamination during film growth. The ability to control the low ion beam energy as well as the target bias, is suited for producing high quality atomic scale interface for the multi-layer structures, which is the key for high tunneling magnetoresistance (TMR) performance desired for application. A typical Exchange biased MTJs stack would be Si/SiO2/Ta/Ru/IrMn/CoFeB/$AlO_x$/CoFeB/Ta/Ru. The magnetic properties are measured by VSM and TMR ratio of unpatterned films is measured by CIPTech technology.

8:20am **MI+NC-WeM2 Anisotropic Competition in FM/AFM Bilayers: The Influence on Magnetic Easy Axis, FM/AFM Exchange Coupling, and Interfacial Coupled Spins**, ***B.Y. Wang****, National Taiwan University and TIGP, Academia Sinica, Taiwan, *W.C. Lin,* National Taiwan Normal University, *N.Y. Jih, C.-H. Chuang, C.W. Peng, S.S. Wong,* National Taiwan University, *Y.L. Chan, D.H. Wei,* National Synchrotron Radiation Center, Taiwan, *M.-T. Lin*, National Taiwan University

We present the studies of the magnetic easy axis, ferromagnetic/antiferromagnetic exchange coupling, and interfacial spins of Fe/fcc-Mn/$Cu_3Au$(001) ultrathin bilayers for probing both magnetic anisotropy of ferromagnetic Fe layer and antiferromagnetic Mn layer by using magneto-optical Kerr effect (MOKE) and photoemission electron microscopy with X-ray magnetic circular dichroism (XMCD-PEEM). Combining the experimental results with the analysis from phenomenological magnetic anisotropic model, we demonstrate that the Fe and Mn layer reveals intrinsic in-plane and out-of-plane magnetic anisotropy, respectively, in which the anisotropic competition between Fe and Mn layer significantly influences the orientations of magnetic easy axis, Fe/Mn exchange coupling, and interfacial coupled spins of Fe/Mn bilayers.

8:40am **MI+NC-WeM3 Time-of-Flight Secondary Ion Mass Spectrometry Study of Manganese Diffusion in Annealed MnAs/GaAs Layered Structures**, ***R.E. Goacher****, *H. Luo, J.A. Gardella, Jr.*, University at Buffalo

Layered structures of MnAs/GaAs grown by MBE are characterized using ToF-SIMS before and after low-temperature annealing. MnAs is studied both as a model system for investigating Mn diffusion from (GaMn)As into GaAs and as a material that may have importance for Spintronics applications in its own right.[1,2] Two challenges that must be overcome to create practical Spintronics devices are to achieve high Curie temperatures and efficient spin injection.[3] It has been shown that the Curie temperature of (GaMn)As is improved by post-growth annealing at low temperatures.[4] However, one hypothesis regarding the failure of efficient spin injection is that the physical diffusion of spin dopant atoms (Mn) from a magnetic to a neighboring non-magnetic layer decreases the coherence of injected spin-polarized electrons. Therefore, this work investigates the extent of Mn diffusion over the relevant temperature range between the growth temperature (as low as 200 C) and approximately 400 C. The in-depth chemical profiles obtained by the ToF-SIMS analysis reveal the extent of manganese diffusion from MnAs into GaAs. Quantitative diffusion information is obtained by calibrating the Mn concentration to ion-implanted standards and the depth scale to profilometry measurements. Depth profiles obtained for samples of ~5 nm MnAs over GaAs as grown and annealed at 200, 300 and 400 C reveal the migration of Mn towards the sample surface for temperatures up to 300 C, and then significant diffusion into the bulk GaAs after annealing at 400 C. Significant Mn diffusion after annealing a thick (~150 nm) MnAs layer over GaAs at 400 C is also detected. Quantitative analysis reveals that the integrated Mn concentration decreases as the annealing temperature increases, indicating some evaporative loss of Mn during annealing. The instrumental broadening function is also measured from a delta-layer sample in order to de-convolute the broadened diffusion profiles. The application of the measured diffusion information to device design and post-growth treatment is also discussed.

[1] Ramsteiner, M. et al., Phys Rev B: Cond Matt Mat Phys, 2002, 66, (8), 081304/1-081304/4.
[2] Dvakonov, M. I., Los Alamos National Laboratory, Preprint Archives, Condensed Matter. 2004, 1-10.
[3] Ploog, K. H., J Cryst Growth, 2004, 268, (3-4), 329-335.
[4] Stanciu, V. et al., Phys Rev B: Cond Matt Mat Phys, 2005, 72, (12), 12534/1-12534/5.

9:00am **MI+NC-WeM4 Molecular Beam Epitaxy Integration of Barium Hexaferrite on Wide Bandgap 6H-SiC**, ***Z. Cai****, *T.L. Goodrich, Z. Chen, F. Yang, V.G. Harris, K.S. Ziemer*, Northeastern University

Integration of nonreciprocal ferrite microwave devices (e.g. circulators, isolators, phase shifters, etc.) with semiconductor platforms is a necessary to meet the increasing security, usage, and portability demands of civilian and military communication systems by increasing microwave power and by reducing device volume. Barium hexaferrite (BaM, $BaFe_{12}O_{19}$) is ideal for microwave device applications because of its high resistivity and particularly large uniaxial magnetocrystalline anisotropy (17 kOe) with the easy direction along the c-axis. BaM films with improved ferromagnetic resonance linewidths (< 100 Oe) have been deposited on 6H-SiC by pulsed laser deposition (PLD) through the use of a 10nm single crystalline MgO template grown by molecular beam epitaxy (MBE). Since the improvement in magnetic properties of BaM films is linked to the initial stages of BaM film growth, MBE deposition of high quality BaM has the potential to be an ideal seed layer for thick BaM film deposition by PLD or liquid phase epitaxy (LPE). BaM growth by MBE was carried out using an oxygen plasma source at pressure ($<1\times10^{-5}$ Torr) and solid source Ba and Fe effusion cells at substrate temperature ranging from 300~800ºC. High quality film with strong c-axis aligned normal to the substrate and low coercivity (200 Oe) was achieved at 750 ºC and $2\times10^{-6}$ Torr with 10nm MBE-grown MgO template. In-situ x-ray photoelectron spectroscopy and reflection high-energy electron diffraction showed stoichiometric chemistry and ordered crystal structure. Ex-situ atomic force microscopy revealed a smooth surface (1.2 nm root-mean-square roughness over a $2 \times 2\ \mu m^2$) and x-ray diffraction patterns showed strong epitaxial growth of c-axis perpendicular to the substrate. Magnetic hysteresis loops confirmed that the easy magnetic axis of the BaM film was aligned perpendicular to the film plane. This is believed to be the first demonstration of oriented, crystalline BaM on SiC by MBE, and has the potential to be a simple and successful method to realize effective integration of BaM with SiC for next-generation microwave device application.

9:20am **MI+NC-WeM5 Exploring Complexity through Reduced Dimensionality: Novel Transport Properties of $La_{5/8-x}Pr_xCa_{3/8}MnO_3$ Wires**, ***T.Z. Ward****, *S. Liang,* Univ. of Tennessee & Oak Ridge National Lab., *K. Fuchigami,* Univ. of Tennessee & Oak Ridge National Lab. and IHI Corp., Japan, *L.F. Yin,* Oak Ridge National Lab., *E. Dagotto,* Univ. of Tennessee & Oak Ridge National Lab., *E.W. Plummer,* Univ. of Tennessee, *J. Shen*, Univ. of Tennessee & Oak Ridge National Lab.

Currently, the condensed matter physics community is devoting a great deal of attention to complexity and the nanoscale. By combining these two areas, even well studied complex systems such as the manganites might exhibit new and unexpected phenomena. Our work shows that this is indeed the case. We employ novel lithographic techniques to spatially confine single crystal $La_{5/8-x}Pr_xCa_{3/8}MnO_3$ (LPCMO) thin films to the scales of the inherent electronic phase separated domains. The results of this confinement are striking differences in the electronic transport properties which allow us new insights into the underlying balance of spin-charge-lattice interactions while increasing our knowledge of the formation of and interplay between domains. We expect this technique to offer similar rewards on other phase separated materials; and with the current trend toward reduced device sizes, this type of study will be critical for future applications.

9:40am **MI+NC-WeM6 Controlling Magnetic Anisotopy in Epitaxial FePt(100) Films**, ***Z. Lu****, *M.J. Walock, P. LeClair, W.H. Bulter, G.J. Mankey*, University of Alabama

L10 FePt is a good candidate for ultrahigh density magnetic recording media because it exhibits a perpendicular anisotropy which has a very high value of $K_u=7\times10^7$ erg/cm$^3$. The high anisotropy allows for a smaller thermally stable magnetic volume in the written bits. However, writing the magnetic information on a film with such a high anisotropy is a technical challenge. To solve this problem, some new multilayered media such as exchange spring, exchanged composite and anisotropy graded media have

* Falicov Student Award Finalist

been proposed. An important technical challenge for enabling these concepts is developing an ability to control the magnetic anisotropy of each magnetic layer. For FePt films, there are two methods to control the magnetic anisotropy, either by controlling the chemical order parameter S or by varying the composition to produce Fe-rich alloys. We will report our results obtained from epitaxial films fabricated by magnetron sputtering on MgO(100) substrates with Cr and Pt as buffer layers. By varying the growth temperature, epitaxial films of $Fe_{50}Pt_{50}$ were prepared with order parameters ranging from 0 to 0.95 as determined by x-ray diffraction. By carefully controlling the flux of the magnetron sources, epitaxial films of $Fe_{100-x}Pt_x$ with $25<x<50$ were also produced. Results of how the anisotropy changes with the order parameter and chemical composition will be presented.

10:40am **MI+NC-WeM9 Nanopatterning with Self-assembled Nanoparticle Arrays**, ***S.A. Majetich***, *C. Hogg, J.A. Bain*, Carnegie Mellon University **INVITED**

Magnetic information storage density is quickly approaching limitations, due to the noise introduced by the grain size dispersion. The noise can be mitigated by shrinking the grain size, yielding more grains per bit, but if the grains are too small they will be superparamagnetic. This is overcome by increasing the magnetocrystalline anisotropy of the material, or by patterning the media. Self-assembled nanoparticle arrays could be useful for noise reduction in conventional media, even without perfect order. In the longer term, with ordered arrays, they could potentially be used as patterned media with very small bit size. Lithographic methods have been used to fabricate nanopatterns, but the features must be written serially, which would lead to high manufacturing costs. There is a great need for parallel nanopatterning approaches; many of the proposed techniques have taken advantage of self-assembly. Here we explore the limits of nanomasking on even smaller structures based on self-assembled nanoparticle arrays. Arrays of FePt nanoparticles have previously been proposed as magnetic recording media, but there have been difficulties in obtaining the desired high anisotropy phase together with regular order within the array. In addition, the particles in self-assembled nanoparticle arrays are not crystallographically oriented, and variations in the easy axis direction would be an additional source of noise. The nanomasking approach uses self-assembled nanoparticle arrays to create a template pattern that is then transferred into an underlying thin film. Ion milling is a well-known technique for patterning materials on the micron scale, but questions remain about its application to nanoscale patterning. In an ideal ion milling process, a high-energy ion strikes a surface and knocks out an atom, which is then removed by the vacuum system. One of the advantages of ion milling is its relative insensitivity to the type of atoms in the sample, in contrast to reactive ion etching, where the selective reactive chemistry of the ions provides the energy for the reaction. Reactive ion etching (RIE) is gentler, but requires that the etching products be gaseous. Here we compare the nanopatterning results using self-assembled nanoparticle array nanomasks with argon ion milling and RIE.

11:20am **MI+NC-WeM11 Functionalized $Gd_2O_3$ Nanoparticles to be used for MRI Contrast Enhancement**, *M. Ahren, L. Selegard, N. Abrikossova, A. Klasson, F. Soderlind, M. Engstrom, P.-O. Käll*, ***K. Uvdal***, Linköping University, Sweden

The properties of very small particles, i.e. particles with a small volume to surface relative ratio, have been shown to clearly differ from both the atom and bulk material. Such low dimensional materials will be of main importance during material design and optimization in the future. We are now designing functionalized rare earth nanocrystals and this material is very promising as positive contrast agent in Magnetic Resonance Imaging (MRI). The core of the nanomaterial is characterized using X-ray Photoelcetron Spectroscopy (XPS), Transmission Electron Microscopy (TEM) and Photo Emission Electron Microscopy (PEEM). The functionalization steps are investigated by means of XPS, Infrared (IR) Spectroscopy and Dynamic Light Scattering (DLS). The proton relaxation times were measured as a function of dialysis time and functionalization, with a MRI scanner. The relaxivity is compared to commercially available Gd based chelates (Gd-DTPA). We have shown that the core consists of pure Gd2O3, the particles are crystalline and in the size of about 3-5 nm. The functionalization process and dialysis procedure are shown to increase the stability of the material. A considerable relaxivity increase for functionalized and dialyzed particles compared to corresponding values for Gd-DTPA is obtained. The long term goal is to design a powerful, directed contrast agent for MRI examinations with specific targeting possibilities with strong MR- signal on the cell- and molecular level.

11:40am **MI+NC-WeM12 Interfacial Interactions of Magnetic and Nonmagnetic Spacer Layers in FeCo/Pd and FeCo/Ru Multilayer Stacks**, ***M.J. Walock***, The University of Alabama, *H. Ambaye*, Oak Ridge National Laboratory, *G.J. Mankey*, The University of Alabama

Residing at the peak position on the Slater-Pauling curve, FeCo alloys are heavily used in the magnetic recording industry. However, higher magnetizations are desirable. Prior results have shown that alloying FeCo with minute amounts of 4d elements have produced materials with higher magnetizations. Another approach is the deposition of 4d elements as thin spacer layers between FeCo layers. With this tactic, we investigate the interfacial interactions between the 3d alloy and 4d elements. Among the 4d elements, Pd and Ru offer intriguing possibilities. Ru layers permit both ferromagnetic and antiferromagnetic exchange interactions, but Pd layers show only ferromagnetic coupling between the magnetic layers. A series of multilayer samples with Pd and Ru spacer layers was studied to explore these interactions. Polarized neutron reflectivity enabled the determination of the layer-specific magnetization vector distributions. The neutron experiments show that there is a small but finite magnetization of the 4d spacer layers, dependent on the distance from the interface. To confirm this observation, x-ray magnetic circular dichroism was used to probe the element-specific average atomic magnetic moments in both the 3d and 4d layers.

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