Magnetic Interfaces and Nanostructures
Room 204 - Session MI+NS-TuM

Magnetic Nanostructures, Surfaces, and Interfaces

Moderator: R.A. Lukaszew, University of Toledo

8:20am **MI+NS-TuM1 Size Effect and Chemical Ordering in [FePt]@sub 100-x@Cr@sub x@ Nanoparticles**, *C. Srivastava,* ***G.B. Thompson****, J.W. Harrell, D.E. Nikles,* University of Alabama

FePt nanoparticles have received considerable attention as candidate materials for achieving ultra-high areal storage densities. Recent experimental and modeling studies have suggested that FePt must achieve a critical size near 4 nm for the chemically ordered L1@sub 0@ phase to be stable. We report the use of Cr in controlling the size and ordering temperature in FePt nanoparticles. Two series of [FePt]@sub 100-x@Cr@sub x@ nanoparticles (x = 5, 10 and 16 at. %) were chemically synthesized by a high-temperature salt-decomposition process yielding as-prepared diameters of 2 nm and 4 nm. XRD and STEM-EDS confirmed that the Cr formed a solid solution within the A1 FePt phase. Upon annealing, the as-synthesized 4 nm [FePt]@sub 100-x@Cr@sub x@ particles ordered at 450°C while maintaining ~4 nm size. In contrast, the as-synthesized 2 nm [FePt]@sub 100-x@Cr@sub x@ particles ordered at 550°C. It was noted that the initial 2 nm particles had achieved an ~4 nm sintered particle size at 550°C. Thus, the initial particle size is critical before chemical ordering can commence. Once the critical size is achieved, Cr was able to reduce the ordering temperature. The initial 4 nm FePt nanoparticles ordered at ~500°C and experienced rapid particle sintering at the onset of its ordering temperature. In contrast, the Cr alloyed nanoparticles were shown to have reduced grain growth at elevated temperatures. Magnetrometry measurements of the nanoparticles indicated that the coercivity is reduced with Cr content.

8:40am **MI+NS-TuM2 Core Size Effects on Core-Shell Structured Fe/FeO@sub x@ Nanopaticles**, ***A. Ceylan***[1]*, S. Shah,* University of Delaware*; K. Hasanain,* Quaid-e-Azam University, Pakistan

In this study, we examined the particle size dependence of magnetic properties of Fe/Fe-oxide core/shell structured nanoparticles. Inert gas condensation has been used to synthesize the nanoparticles. Structural and magnetic properties of the samples have been investigated by various techniques. It has been observed that the effect of AFM shell can be relatively enhanced by decreasing the core size such that much higher exchange bias than larger particles is obtained. Furthermore, as an indication of pinned spins, which are attributed as one of the reasons of higher exchange bias field, at the AFM-FM interface, a vertical shift at the hysteresis loops has also been observed in small nanoparticles. Room temperature magnetic measurements have revealed that small particles show superparamagnetic behavior. However, the system does not reach to saturation even at 4T which indicates high anisotropy. These observations reveal that superparamagnetic behavior is related to the small size rather than a lack of anisotropy.

9:00am **MI+NS-TuM3 Magnetic Field Effects in Ferromagnetic/Organic Hybrid Structures**, ***J. Shi,*** University of Utah **INVITED**

Spin injection/detection and coherent spin transport are key ingredients in Spintronics, which were first demonstrated in the giant magnetoresistance or GMR effect in all-metal systems. In this talk, I will present our recent progress using organic semiconductors. In spin valves consisting of two ferromagnetic layers (La2/3Sr1/3MnO3 or LSMO and Co) and an organic semiconductor spacer (Alq3), we have successfully shown electrical spin injection/detection and coherent spin transport through the GMR effect. In addition, we have also found a high-field magnetoresistance effect in these structures. Our work shows that this high field effect originates from the magnetic field enhanced carrier injection due to the anomalous Fermi level shift in double exchange ferromagnets such as LSMO.

9:40am **MI+NS-TuM5 Magnetic Stripes at the Spin Reorientation Transition of a Magnetic Thin Film**, ***Z. Qiu,*** University of California at Berkeley **INVITED**

One fundamental issue in magnetic nanostructure research has concerned the presence of magnetic long-range order in a two-dimensional (2D) magnetic system. It has long been established that an isotropic 2D Heisenberg system does not carry long-range order at nonzero temperature. The magnetic order observed in ultrathin films is usually attributed to the existence of magnetic anisotropy. In an ultrathin film with perpendicular magnetocrystalline anisotropy, the spin direction could exhibit the so-called spin reorientation transition (SRT) from perpendicular to the in-plane direction of the film. At the SRT point, the perpendicular magnetocrystalline anisotropy is balanced out by the dipolar shape anisotropy and the system approaches to an isotropic Heisenberg system. Thus an investigation of the magnetic phase near the SRT point is expected to reveal the magnetic origin of 2D magnetic systems. In this talk, I will present an overview and our most recent experimental result on this subject. Using photoemission electron microscopy (PEEM) to do element-specific measurement, we studied the SRT in magnetically coupled sandwiches. We show that a crossover from the anisotropy length to the dipolar length governs the formation of the magnetic stripe phase.

10:20am **MI+NS-TuM7 Inhomogeneous Magnetic States in Gd/Fe and SmCo/Fe Nanolayers**, ***D. Haskel,*** Argonne National Laboratory **INVITED**

The reduced size and dimensionality of layered magnetic nanostructures enhances the role that surfaces and interfaces play in determining their magnetic structures. This can result in inhomogeneous magnetic states, wherein the local magnetization varies with distance away from surfaces or interfaces. Using hard x-ray magnetic circular dichroism and x-ray resonant magnetic scattering, we explore the nature of such inhomogeneous states in Gd/Fe metallic multilayers and SmCo/Fe spring magnets. In collaboration with Y. Choi, J. Lang, D. Lee, G. Srajer, C. Kmety, J. Pollmann, C. Nelson, R. Camley, J. Meersschaut, J.S. Jiang, S.D. Bader Work at Argonne is supported by the U.S. Department of Energy, Office of Science under contract No. W-31-109-ENG-38.

11:00am **MI+NS-TuM9 Magnetic Quantum Tunneling and Relaxation in Molecular Magnets**, ***L.J. de Jongh,*** *A. Morello, F. Luis, M. Evangelisti, F. Mettes,* Leiden University, The Netherlands **INVITED**

For strongly anisotropic magnetic clusters, like Fe@sub 8@ and Mn@sub 12@-ac, quantum tunneling of the cluster spins below their blocking temperatures T@sub B@ of a few K has been observed by several groups, and is expected to be triggered by the dynamic hyperfine interaction of the cluster spins with their surrounding nuclear spins, as recently predicted by Prokof'ev and Stamp.@footnote 1@ In that model, however, the ensuing relaxation of the electron spins is towards the nuclear spin system, leaving open the question if and at what stage, by which mechanism and at what rates the nuclear and electronic spin systems relax to the lattice phonons. That such phonon relaxation channels are indeed operative even deep in the quantum regime, could be proven unambiguously by our measurements of the specific heat contributions of both nuclear and electronic spin systems at temperatures T<<T@sub B@.@footnote 2-4@ Nuclear Magnetic Resonance is the technique of choice for studying the nuclear spin-dynamics involved in these processes. In addition, since the nuclear spins have to relax to the lattice via the electron spin system, also the dynamics of the latter is probed. In the talk such data (taken down to 20 mK), will be presented@footnote 5@ and analysed in the light of earlier developed theories for dynamic nuclear polarization and nuclear relaxation by paramagnetic impurities in insulating compounds, leading to new insights in the quantum relaxation mechanisms in molecular nano-magnets. @FootnoteText@ @footnote 1@ N.V. Prokof'ev and P.C. Stamp, Phys. Rev. Lett. 80, 5794 (1998). @footnote 2@ F.L. Mettes et al. Phys.Rev. B64, 174411 (2001);Phys. Rev. Lett. 85, 4377 (2000). @footnote 3@ M. Evangelisti et al. Phys. Rev. Lett. 93, 117202 (2004). @footnote 4@ A. Morello et al. Phys. Rev. Lett. 90, 017206 (2003). @footnote 5@ A. Morello et al. Phys. Rev. Lett. 93, 197202 (2004).

[1] **Falicov Student Award Finalist**

Electronic Materials and Processing
Room 310 - Session EM+MI-TuA

Spin Injection

Moderator: C.J. Palmstrom, University of Minnesota

2:40pm **EM+MI-TuA3 Characterization of Mn-based Contacts on GaAs**, ***J.L. Hilton***[1], *B.D. Schultz, S. McKernan, C. Adelmann, X. Lou, P.A. Crowell, C.J. Palmstrom,* University of Minnesota

Mn-based ferromagnetic materials, such as binary metals, Heusler alloys, diluted magnetic semiconductors, and digital alloys, are potentially useful as epitaxial spin injection contacts in GaAs-based spintronic devices. Defects and solid-state reactions at a ferromagnet/semiconductor interface have a significant influence on the spin injection efficiency of spintronic devices. Consequently, a detailed understanding of the interfacial interactions of Mn and Mn-based materials with GaAs is needed. In order to understand the thermodynamic phase behavior of the Mn-Ga-As ternary system, thin film Mn/GaAs structures were grown using molecular beam epitaxy. RHEED, LEED, STM, XPS, RBS, XRD, and cross-sectional TEM were used to characterize the Mn/GaAs interfacial reactions. These reactions initially resulted in the formation of a two-phase region of tetragonal Mn@sub 2@As and tetragonal @delta@-MnGa, with an average composition of Mn@sub 0.6@Ga@sub 0.2@As@sub 0.2@. The two phases formed an epitaxial lamellar layer on the GaAs substrate with Mn@sub 2@As(001) and @delta@-MnGa(001) // GaAs(001). Higher temperature anneals resulted in the dissociation of the Mn@sub 0.6@Ga@sub 0.2@As@sub 0.2@ region into a @delta@-MnGa layer near the sample surface and a Mn@sub 2@As layer near the GaAs substrate. Anneals of @delta@-MnGa films on GaAs suggest that @delta@-MnGa is thermodynamically stable in contact with GaAs over a narrow compositional range up to at least 400°C. For more Ga-rich Mn@sub 1-x@Ga@sub x@ films, no evidence of interfacial reactions with GaAs was observed, but there were significant structural changes within the film. Stable @delta@-MnGa films are especially desirable for use in spintronic devices due to their inherent perpendicular magnetization. Spin injection measurements utilizing @delta@-MnGa contacts on GaAs-based spin-LEDs will be presented. Supported by ARO, ONR, DARPA, NSF, and AFOSR.

3:00pm **EM+MI-TuA4 Interface Structure and Spin Injection Efficiency in a Ferromagnetic/Semiconductor Spin-LED**, ***A.T. Hanbicki***, *G. Kioseoglou, R. Goswami, T.J. Zega, O.M.J. van 't Erve, C.H. Li, R.M. Stroud, G. Spanos, B.T. Jonker,* Naval Research Laboratory

Considerable effort has been made to incorporate ferromagnetic metals into semiconductor spintronic devices. The nature of the interface between a magnetic contact and a semiconductor is expected to influence the spin-injection efficiency. Indeed, we have discovered interface effects play a role in the spin-injection efficiency for an all-semiconductor system.@footnote 1@ Recently we demonstrated robust spin injection from Fe into an AlGaAs/GaAs spin-LED. With this system, we have successfully injected spin polarized electrons with an electron spin polarization of 32% in the GaAs quantum well (QW).@footnote 2@ To correlate the interface structure with the observed QW polarization, we have characterized our Fe/AlGaAs contacts using high-resolution transmission electron microscopy (HRTEM), electron energy-loss spectroscopy, and high-angle annular-dark-field (HAADF) imaging. HRTEM together with HAADF imaging provides compositional information that can also be used to determine the interfacial character. We have studied several samples with different detector heterostructures. Optimized annealing can improve the measured spin polarization, therefore for each sample several pieces were annealed to generate a systematic dataset. Enhancement in polarization is seen with anneals as low as 175°C, and the maximum increase in polarization occurs for anneals above 200°C. Measured spin polarizations increase by 8 to 10%, independent of the starting value. Preliminary results reveal a correlation between the GaAs QW spin polarization and the thickness of the Fe/AlGaAs interface. As the interface thickness increases from 0.5 to 0.9 nm, the measured polarization decreases from 27% to 18%. There are also indications that the Fe film is affected by annealing and implications toward spin injection will be discussed. This work was supported by the DARPA SpinS program and ONR. @FootnoteText@ @footnote 1@R.M. Stroud, et al, PRL 89 (2002)@footnote 2@A.T. Hanbicki, et al, APL 82 (2003).

3:20pm **EM+MI-TuA5 Gate-Controlled Electron Spin Transport for Nonmagnetic Spintronics**, ***K.C. Hall***, Dalhousie University, Canada; *K. Gundogdu, J.L. Hicks, A.N. Kocbay, M.E. Flatte, T.F. Boggess,* University of Iowa; *K. Holabird, A. Hunter, D.H. Chow, J.J. Zinck,* HRL Laboratories, LLC **INVITED**

The prospect of novel high-performance spin-based semiconductor technologies has lead to new research in spintronics, in which the fields of electronics, photonics, and magnetics merge with the promise of applications in ultra-low-power logic architectures, non-volatile reprogrammable gate arrays, and optoelectronic technologies. Innovation in these areas requires the development of efficient methods for spin injection and manipulation in semiconductor materials. Spintronic device architectures that do not require external magnetic fields or magnetic contacts are especially attractive as they would provide seamless integration with the materials and processing techniques of existing semiconductor devices, while avoiding undesirable stray magnetic fields that may hinder device performance. We show that highly spin-polarized electron spin injection may be achieved in side-gated resonant interband tunnel diodes (RITDs) based on nonmagnetic (110) InAs/GaSb/AlSb heterostructures.@footnote 1@ Due to the strong spin-orbit effects in this system, electron spin splittings due to bulk inversion asymmetry approach 40 meV, permitting operation of the spin-RITD at practical temperatures. A nonmagnetic spin field effect transistor incorporating RITD contacts and gate-controlled spin relaxation will be described, along with our recent experiments demonstrating low-threshold spin lifetime switching in this device.@footnote 2@@FootnoteText@This research is supported by DARPA MDA972-01-C-0002, DARPA/ARO DAAD19-01-1-0490, NSF ECS 03-22021, and NSERC. @footnote 1@K.C. Hall et al., Appl. Phys. Lett. 83, 2937 (2003); @footnote 2@K.C. Hall et al., to be published in Appl. Phys. Lett. (2005).

Magnetic Interfaces and Nanostructures
Room 204 - Session MI-TuA

Magnetization Dynamics

Moderator: E. Nowak, University of Delaware

2:00pm **MI-TuA1 All Optical Pump/Probe Spectroscopy from Coherent Spin Waves in Exchange Bias Systems**, ***B. Beschoten***, *A. Tillmanns, S. Oertker, G. Guentherodt,* RWTH Aachen, Germany; *I.K. Schuller,* UC San Diego **INVITED**

Time-resolved Kerr rotation is used to generate and to probe coherent spin waves in exchange biased ferro-/antiferromagnetic bilayer films of Fe/MnF@sub 2@. In time-resolved Kerr rotation, an ultrafast laser pump pulse generates an unidirectional anisotropy field pulse which triggers coherent precession of the magnetization in the ferromagnetic layer. This coherent precession can be monitored by a time-delayed laser probe pulse yielding a quantitative method to study local magnetic anisotropies, ultrafast switching and damping phenomena. This time-resolved all-optical technique is combined with static vector MOKE measurements, which allow to link static magnetization reversal processes, such as coherent rotation of the magnetization vector or domain wall nucleation and propagation, with the precessional switching dynamics at all magnetic fields during magnetization reversal. Work supported by DFG/SPP 1133 and by European Community's Human Potential Program/NEXBIAS. Work at UCSD supported by US-DOE and by AFOSR.

2:40pm **MI-TuA3 Current-Driven Magnetization Dynamics: Domain Wall Motion and Thermal Effects**, ***S. Zhang***, *J. He, Z. Li,* University of Missouri-Columbia **INVITED**

The spin current induced spin torque has been written in several different forms, depending on materials as well as geometrical arrangements. We outline the key features of those various forms. Here we concentrate on two interesting issues: the effect of spin torques on the thermal assited magnetization reversal and the domain wall depinning by a spin torque. In the first case, we have demonstrated that a stochastic Fokker-Planck equation which explicitly includes the spin torque can be established and solved when the current is not too large, and thus we are able to predict finite temperature current-driven magnetization dynamics. In the second case, we investigate the effect of currents on geometrically confined domain walls. In particular, we construct domain wall pinning/depinning phase diagrams in terms of the applied magnetic field and the current. Our results agree with existing experimental data.

[1] **Falicov Student Award Finalist**

3:20pm **MI-TuA5 Propagation and Tunneling of Spin Waves through a Magnetic Field Inhomogeneity**, ***B. Hillebrands***, University of Kaiserslautern, Germany; *S.O. Demokritov,* University of Muenster, Germany; *A.A. Serga,* University of Kaiserslautern, Germany; *V.E. Demidov,* University of Muenster, Germany; *M.P. Kostylev,* University of Kaiserslautern, Germany; *A.N. Slavin,* Oakland University **INVITED**

We show experimentally and by numerical simulation, that spin waves propagating in a magnetic film can pass through a region of a magnetic field inhomogeneity, or, alternatively, can be reflected by the region depending on the sign of the inhomogeneous field contribution. If the reflecting region is narrow enough, spin wave tunneling may take place. We investigate the tunneling mechanism and demonstrate that it has a magnetic dipole origin. While travelling through a region of inhomogeneous field, spin waves undergo a phase shift. We show experimental evidence and we discuss that this can be used for designing phase shifters and spin-wave logic elements.

Magnetic Interfaces and Nanostructures
Room 204 - Session MI-WeM

Magnetic Imaging and Spectroscopies
Moderator: M.E. Hawley, Los Alamos National Laboratory

9:00am **MI-WeM3 Development of Spin Resolved Photoemission Facility at the LLNL for the Electronic Structure Study of Actinides**, ***J.G. Tobin***, *S.-W. Yu,* Lawrence Livermore National Laboratory

We have developed a spin-resolved photoemission facility at the Lawrence Livermore National Laboratory (LLNL) to study the electronic structures of Actinides. Although great progress in the determination of the electronic structures of low-Z materials has been achieved through the use of angle-resolved photoemission in combination with synchrotron radiation, the electronic structures of Actinides are less easily accessible with this technique because the electronic structures are modified strongly by spin-orbit interaction. In addition, the radioactivity of Actinides prevents them from easy access for experiments. In this talk, we will address how such problems can be removed in the new facility and present preliminary data.

9:20am **MI-WeM4 A Comparative Study of the Magnetic Domain Structure of Mn Doped ITO Thin Films by Magnetic Force Microscopy**, ***B.I. Kim***, Boise State University, United Sates; *J.O. Holmes, M.R. Kongara, A. Punnoose,* Boise State University

Semiconducting Mn doped ITO thin films have been studied with different Mn doping levels using high resolution magnetic force microscopy (MFM) to understand the magnetic microstructure and uniformity of this room temperature ferromagnet. The film was prepared by sol-gel mediated spin coat technique, and the Co-coated tip (radius < 10 nm) was magnetized vertically using strong external magnetic field before the experiment. We collected four different MFM images (topographic image, magnetic force image, amplitude image and phase image) at the same time to obtain complementary information using ac mode MFM technique. Stable imaging condition could be achieved at distance 50 -100 nm between tip and sample. The magnetic domain structures observed in the ambient condition show thin labyrinthine features with 1-2 µm width for all Mn : ITO thin films regardless of the Mn doping level. MFM images also show that magnetic structures are connected differently depending on the Mn concentration. We could observe a reproducible image with small fine magnetic features with 10nm size for the repeated images, indicating the fine features comes from 8 nm ferromagnetic nanoparticles confirmed from TEM. The sectional profiles across magnetic domains indicate that the variation between positive and negative orientation for the 6% Mn doped samples is twice bigger than those at 9% and 3% doped magnetic films, consistent with an independent magnetization measurement. Comparison of magnetic phase images with those of longitudinal medium suggests that the magnetic moments of Mn : ITO orient vertically on the plane of film surfaces. The study indicates the amount of Mn doping influences the individual magnetic fine features as well as the connectivity of magnetic domains. These observed domain features suggest that magnetic structures on nano- and- macro- scale of Mn : ITO films are closely related to the amount of Mn doping and preparation condition.

9:40am **MI-WeM5 Spin Polarized Scanning Tunneling Spectroscopy of Nano-Scale Co Islands on Cu(111)**, ***O. Pietzsch***, University of Hamburg, Germany **INVITED**

At room temperature, triangular Co islands can be grown on Cu(111), protruding two atomic layers high above the Cu surface. Two different orientations of the triangles are observed, indicating a stacking fault with respect to the fcc stacking of the Cu substrate in one case. We have studied the structural, electronic, and magnetic properties of these islands with spin-averaged and spin-resolved scanning tunneling spectroscopy at low temperatures. Using a non-magnetic tunneling tip, we found the electronic properties of the differently oriented islands to be clearly inequivalent. In differential conductance (dI/dV) maps this leads to strong contrasts at the appropriate energies with signal asymmetries as high as 50 percent. Applying a magnetic tip, another source of contrast with similar strength becomes accessible, originating from the perpendicular magnetization of the islands.@footnote 1@ We discuss the Co spin polarization which is strongly energy dependent and repeatedly changes sign. Quite similar to the Cu substrate surface, the Co islands exhibit a standing wave pattern in the local density of states. In the case of Co, however, the responsible dispersive state is spin-polarized. This spin imbalance modifies the oscillation amplitude. A comparison of the Cu and Co patterns as a function of energy reveals yet another difference: while the Cu patterns indicate two-dimensional free-electron gas behavior, the Co patterns are affected by lateral electron confinement. We compare our observations with models based on an exact solution of the particle-in-a-triangular-box problem@footnote 2@ and a multiple scattering approach.@footnote 3@ @FootnoteText@ @footnote 1@ O. Pietzsch, A. Kubetzka, M. Bode, and R. Wiesendanger, Phys. Rev. Lett. 92, 057202 (2004).@footnote 2@ H.R. Krishnamurthy, H.S. Mani, and H.C. Verma, J. Phys. A: Math. Gen. 15, 2131 (1982).@footnote 3@ E.J. Heller, M.F. Crommie, C.P. Lutz, and D.M. Eigler, Nature 369, 464 (1994).

10:20am **MI-WeM7 Evolution of (Surface) Magnetic Moment and Magnetic Ordering Behavior in Epitaxial Transition Metal Films**, ***K.R. Podolak***, The Pennsylvania State University; *N. Janke-Gilman,* Latrobe University, Australia; *R.F. Willis,* The Pennsylvania State University

We report dichroism in angle-resolved x-ray photoemission with linearly polarized synchrotron radiation of the 3p core levels of the ferromagnetic elements Fe, Ni, Co, and their binary alloys.@footnote 1@ A systematic study of the spectral width (W) and the dichroism asymmetry amplitude (A) distinguishes the magnitudes of the elemental moments from the overall saturization magnetization. The Slater-Pauling curve is shown to be a plot of the stoichiometric mean saturization magnetization per atom. The spectral width (W) increases with increasing ferromagnetism. The dichroism asymmetry amplitude (A) senses the onset of disorder, instabilities, and changes in the magnetic anisotropy. These new measurements provide a new insight into the magnetic order in these thin film alloys and surface moment enhancement. @FootnoteText@ @footnote 1@ R.F. Willis and N. Janke-Gilman. Europhys. Lett., 69, 411 (2005).

10:40am **MI-WeM8 Spin-Resolved Core Level Photoemission of the Ni/Co/Cu(001) System Using Circularly Polarized X-Rays**, ***T. Komesu***, *G.D. Waddill,* University of Missouri-Rolla; *M.T. Butterfield, S.-W. Yu, J.G. Tobin,* Lawrence Livermore National Laboratory

We present spin-resolved 2p core level photoemission results for Co/Cu(001) and for Ni/Co/Cu(001). For the former we have collected the core level spectra by reversing the magnetization of the Co film emphasizing exchange effects in the spin-polarization as well as by reversing the helicity of the incident x-rays on an unmagnetized sample which isolates spin-orbit effects in the observed spin-polarization. For the exchange effects we observe strong spin polarization in the main peaks and a weaker spin polarization effect in the controversial satellite peak at ~4 eV higher binding energy than the main peaks. The spin-orbit spectrum shows strong spin-polarization throughout the spectral region that changes sign between the 2p3/2 and 2p1/2 peak consistent with its sensitivity to the core-hole spin-orbit coupling. Finally, we have studied the effects of charge transfer for the Ni/Co/Cu(001) system using spin-resolved photoemission where we see changes in the spin polarization of the main peaks and satellite features of both Ni and Co 2p core levels that can be understood in terms of charge transfer from the Co to the Ni as a function of Ni film thickness. These results establish that spin-resolved core level photoemission is a sensitive probe of electron correlation effects in thin magnetic films and surfaces. This work was performed under the auspices of the U.S. DOE by University of California Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

11:00am **MI-WeM9 Medard Welch Award Lecture: Studies of Magnetic Materials and Nanostructures using Synchrotron Radiation Spectroscopy, Diffraction, and Holography**, ***C. Fadley***[1], University of California, Davis and LBNL, Berkeley **INVITED**

I will discuss several recent developments in studies of magnetic surfaces and magnetic nanostructures using synchrotron radiation, with special emphasis on work in the soft x-ray regime at the Berkeley Advanced Light Source. Instrumentation that has been developed to carry out multiple spectroscopies with varying degrees of surface sensitivity (photoemission, x-ray absorption, and x-ray emission) on a single sample will be introduced, together with future prospects in photoemission based on higher-speed detection.@footnote 1@ Then a new standing wave-plus-wedge method for non-destructively studying buried interfaces in multilayer nanostructures will be considered.@footnote 2@ This method has permitted determining concentration and magnetization profiles through an Fe/Cr giant magnetoresistive interface,@footnote 2a@ as well as layer-specific densities of states in a magnetic tunnel junction consisting of FeCoB/FeCo/Al@sub 2@O@sub 3@.@footnote 2c@ This approach should

[1] **Medard W. Welch Award Winner**

also be useful in a variety of other interface studies,@footnote 2b@ with the use of soft x-ray detection permitting the study of more deeply buried interfaces.@footnote 2d@ Application of the multi-spectroscopy experimental system to the colossal magnetoresistive oxide materials La@sub 1-x@Sr@sub x@MnO@sub 3@ (x = 0.3, 0.4) will also be discussed, including the direct observation of charge localization on Mn in polaron formation@footnote 3a@ and surface stoichiometry characterization.@footnote 3b@ Finally, the prospects for element-specific determinations of local atomic and magnetic structure using photoelectron holography will be considered.@footnote 4@ Work supported by the Dept. of Energy, Basic Energy Sciences, Materials Science and Engineering Division, under Contract DE-AC03-76SF00098. @FootnoteText@ @Footnote 1@J.-M. Bussat, C.S. Fadley, B.A. Ludewigt, G.J. Meddeler, A. Nambu, M. Press, H. Spieler, B. Turko, M. West, G.J. Zizka, IEEE Transactions on Nuclear Science 51, 2341 (2004), with further details at: http://www.physics.ucdavis.edu/fadleygroup. @footnote 2a@S.-H. Yang, B.S. Mun, N. Mannella, S.-K. Kim, J.B. Kortright, J. Underwood, F. Salmassi, E. Arenholz, A. Young, Z. Hussain, M.A. Van Hove, and C.S. Fadley, J. Phys. Cond. Matt. 14, L406 (2002) @footnote 2b@S.-H. Yang, B.S. Mun, and C.S. Fadley, Synchrotron Radiation News 17 (3), 24 (2004) @footnote 2c@S.-H. Yang, B.S. Mun, et al., to be published @footnote 2d@M. Watanabe, B.C. Sell, et al. to be published. @footnote 3a@N. Mannella, A. Rosenhahn, C. H. Booth, S. Marchesini, B. S. Mun, S.-H. Yang, K. Ibrahim, Y. Tomioka, and C.S. Fadley, Phys. Rev. Lett. 92, 166401 (2004) @footnote 3b@N. Mannella et al., to be published. @footnote 4@C.S. Fadley, M.A. Van Hove, A. Kaduwela, S. Omori, L. Zhao, and S. Marchesini, J. Phys. Cond. Mat. 13, 10517 (2001)

Magnetic Interfaces and Nanostructures
Room 204 - Session MI+EM-WeA

Magnetic Semiconductors
Moderator: A.T. Hanbicki, Naval Research Laboratory

2:00pm **MI+EM-WeA1 Effects Limiting the Formation of Ferromagnetic III@sub 1-x@Mn@sub x@V Alloys by Epitaxial Growth**, ***J.K. Furdyna***, University of Notre Dame **INVITED**

III@sub 1-x@Mn@sub x@V alloys (e.g., Ga@sub 1-x@Mn@sub x@As), comprised of Mn@super +2@ incorporating substitutionally for the group-III element in the III-V lattice are captivating the attention of the scientific community worldwide because of the promise they hold for spin-electronic applications. Incorporation of Mn into the III-V lattice in sufficient concentrations to render the III@sub 1-x@Mn@sub x@V alloy ferromagnetic must be carried out by non-equilibrium low-temperature epitaxy, whereby Mn concentrations x approaching 0.10 can be attained. The ferromagnetism of these alloys occurs because, in addition to providing magnetic moments, the Mn ions also act as acceptors, thus supplying large concentrations of holes that mediate the ferromagnetic interaction between magnetic moments of the Mn ions. A mean field theory projects that the Curie temperature T@sub C@ should scale as the product of the Mn concentration x and of the hole density p. Thus, in principle, one should expect above-room-temperature ferromagnetism for large values of the x·p product. Our research on Ga@sub 1-x@Mn@sub x@As and In@sub 1-x@Mn@sub x@Sb has shown, however, that the Fermi energies achievable in these materials cannot exceed a certain maximum E@sub Fmax@, corresponding to a maximum hole concentrations p@sub max@. This occurs because the relationship between the creation energies for negatively-charged defects (such as the desired substitutional Mn acceptors Mn@sub III@, e.g. Mn@sub Ga@ or Mn@sub In@) and positively-charged defects (such as the unwanted interstitial Mn double donors, Mn@sub I@) is controlled by the Fermi energy. When E@sub F@ in the III@sub 1-x@Mn@sub x@V reaches E@sub Fmax@ due to the increasing free hole density, further formation of Mn@sub III@ becomes energetically unfavorable, and a high concentration of compensating Mn@sub I@ defects begins to form. The creation of Mn@sub I@ is deleterious to the ferromagnetism for multiple reasons: (1) compensation by the double Mn@sub I@ donors reduces the hole concentration, (2) interstitial Mn is RKKY-inactive (due to negligible p-d exchange), and (3) Mn@sub I@ forms antiferromagnetic pairs with Mn@sub III@, reducing further the density of Mn ions that contribute to the ferromagnetism of the III@sub 1-x@Mn@sub x@V alloy. Thus any increase of the Mn@sub I@ concentration automatically leads to lowering the value of T@sub C@. Ion-channeling experiments directly reveal this type of interstitial Mn creation whenever p approaches p@sub max@ due to a high Mn concentration. In this talk we concentrate on showing that substitutional vs. interstitial incorporation of Mn in III@sub 1-x@Mn@sub x@V alloys is determined by the Fermi level during the growth process itself, no matter what is the source of holes that establish the value of E@sub F@, and independent on the spatial location of the acceptors with respect to the magnetic Mn ions. To demonstrate this, we discuss two types of growth experiments that allowed us to vary the Fermi level independently of the Mn concentration, namely, experiments on Be co-doping of III@sub 1-x@Mn@sub x@V alloys; and on modulation doping of Al@sub 1-y@Ga@sub y@As/Ga@sub 1-x@Mn@sub x@As/Al@sub 1-y@Ga@sub y@As heterostructures by Be. Having established causes for the limit which nature imposes on incorporating substitutional Mn ions at the Group-III sites in III-Mn-V alloys, I will then discuss possible strategies for circumventing this obstacle, with an eye on increasing the Curie temperature of these novel ferromagnetic semiconductors.

2:40pm **MI+EM-WeA3 Structural Properties, Lattice Dynamics, and Optical Properties of GaMnN**, *W.E. Fenwick, M.H. Kane, M. Strassburg, A. Asghar, S. Gupta, H. Kang,* Georgia Institute of Technology*; Z. Hu,* Georgia State University*; S. Graham,* Georgia Institute of Technology*; U. Perera,* ***N. Dietz***, Georgia State University*; I.T. Ferguson,* Georgia Institute of Technology

Dilute magnetic semiconductors (DMS) show promise as spintronic materials because of their electrical and magnetic properties. E.g., GaMnN exhibit ferromagnetism (FM) above room temperature (RT). Application of such materials for RT spintronic devices requires an understanding of the origin of this magnetism, which is still under debate in the literature. Knowledge of the structural properties is essential to determine the origin of the RT FM in GaMnN. Therefore this work provides structural and optical studies of GaMnN to reveal the crystalline quality, lattice dynamics, and some fundamental properties such as the optical constant. Increasing Mn concentration significantly affects long-range lattice ordering. The observation of a local vibrational Raman mode at 669 cm@super -1@ combined with the slight excess of metal components in the growth process and the incorporation of Mn acceptor states favors the formation of nitrogen vacancies. Such vacancies form shallow donor complexes and thus contribute to self-compensation, which may hamper carrier mediation. Raman spectroscopy also revealed a disorder-induced mode at 300 cm@super -1@. The intensity of both modes was found to be weaker by more than one order of magnitude compared to GaMnN grown by MBE or prepared by ion-implantation. This is a consequence of the improved MOCVD growth conditions. Crystalline integrity and the absence of major second phase contributions were confirmed by high resolution X-ray diffraction studies. Atomic force microscopy showed that optimized annealing conditions suppressed the formation of Mn-rich precipitates on the surface. Further investigations on the lattice dynamics and the determination of the optical constants were enabled by infrared reflectance spectroscopy. The GaN E1(TO) phonon frequency linearly increases with Mn composition, which is expressed by (558 + 2.7x) cm@super -1@. Meanwhile the peak values of the infrared dielectric functions of the GaMnN decrease with increasing Mn concentration.

3:00pm **MI+EM-WeA4 Epitaxial Growth of Ferromagnetic Mn@sub 3-delta@Ga Thin Films on Wurtzite GaN(0001) by Molecular Beam Epitaxy**, ***E.D. Lu***, *M.B. Haider, R. Yang, C. Constantin, G. Pokharel, D.C. Ingram, A.R. Smith,* Ohio University

Magnetic metal and/or alloy films on III-V semiconductor substrates have attracted considerable interest due to the potential applications for magnetic/spintronic materials and devices,especially as spin electron injection sources for spin-sensitive heterostructures as well. The binary MnGa alloy is one of several promising metallic ferromagnetic candidates with CuAu-I type ordering. It is a face-centered tetragonal (fct) structure with lattice constants a = 3.897 Å, c = 3.58-3.65 Å dependent on content of at.% Mn between 55-60%. The epitaxial ferromagnetic Mn@sub 3-Î´@Ga(111) thin films have been grown on wurtzite GaN(0001) substrates with Ga polar surface by molecular beam epitaxy through controlling the substrate temperature and flux ratio of manganese to gallium during the growth. Prior to growing Mn@sub 3-Î´@Ga thin films, the commercial MOCVD GaN substrates were directly heated for clean up and refreshed by growth of GaN layer by radio plasma MBE. The growth and structure of the Mn@sub 3-Î´@Ga thin films are monitored in situ by reflection high energy electron diffraction (RHEED). The RHEED pattern was spotty at the initial stage and gradually became streaky, indicating surface roughness at the beginning and finally a smoother surface at the end. Combined RHEED and ex situ XRD results have revealed the primarily structure of the CuAuâ?"I type fct Mn@sub 3-Î´@Ga thin films grown with (111) plane lying on GaN(0001) plane; due to double lattice constant of the Mn@sub 3-Î´@Ga(111) plane along [11-2] direction is a good match with that distance along [11-20] direction of GaN(0001) (less than 4% mismatch), the epitaxial relationship of the fct Mn@sub 3-Î´@Ga is (111)[01-1] MnGa // (0001)[1-100]GaN and (111)[11-2] MnGa // (0001)[11-20]GaN. Rutherford Backscattering Spectroscopy (RBS) has also confirmed composition of the Mn@sub 3-Î´@Ga thin films with the ratio of Mn to Ga about 1.5 to 1.

3:20pm **MI+EM-WeA5 Nanostructure of Ferromagnetic Mn-implanted Si**, ***C. Awo-Affouda***[1], *M. Bolduc, K.A. Dunn, M.B. Huang, F. Ramos, G. Agnello, B.L. Thiel, V.P. LaBella,* University at Albany-SUNY

Semiconductor devices which exploit the spin of the electron hold great potential to produce devices with increased functionalities. Making conventional semiconductors ferromagnetic via ion implantation of Mn will aid in fabricating future spintronic devices. We recently demonstrated that ferromagnetism can be achieved via Mn-ion implantation of n-type and p-type Si wafers. A Curie temperature greater than 400K was observed for the p-type samples. The structure of the implanted material was investigated in order to identify the source of the ferromagnetism. SIMS depth profiling of the as-implanted samples showed a typical Gaussian shape profile of Mn atoms in the silicon lattice, which peaks at 250 nm. Post-implant annealing was performed to heal the damage from the implantation process and resulted in a strong redistribution of the Mn atoms. Furthermore diffraction contrast TEM of the annealed samples revealed nanometer size precipitates distributed throughout the implanted region, along with a large band of dislocation and stacking faults. Selected

[1] **Falicov Student Award Finalist**

area diffraction patterns gave strong evidence that these phases are MnSi@sub1.7@ crystallites. We will discuss the role of these precipitates on the observed ferromagnetism.

3:40pm **MI+EM-WeA6 Ferromagnetic Properties of Mn-implanted Si**, ***M. Bolduc,*** *C. Awo-Affouda, M.B. Huang, F. Ramos, V.P. LaBella,* University at Albany - SUNY

Integrating spintronic device concepts with silicon may enable new possibilities for fabrication. In addition, theoretical calculations have predicted ferromagnetic ordering in Mn-doped group-IV semiconductors. This potential has motivated the search for a Si-based ferromagnetic semiconductor. We demonstrate that p-doped and n-doped Si crystals can be made ferromagnetic above room temperature through Mn-ion implantation. 300-keV Mn@super+@ ions were implanted at doses of (1-10)X10@super15@ cm@super-2@ reaching peak concentrations of (0.1-0.8) at.% as measured through SIMS profiling. Ferromagnetic hysteresis loops were obtained using a SQUID magnetometer at temperature of (10-300) K, yielding a saturation magnetization of 0.1-0.7 emu/g-sample. The Curie temperature is found >400 K with carrier concentration dependence. We will report on the dependence of the magnetic properties on the post-implant annealing temperature and Mn concentration. These results will be discussed in comparison with other ion implanted or MBE grown group-IV ferromagnetic semiconductors.

4:00pm **MI+EM-WeA7 Growth and Magnetic Properties of Doped ZnO Epitaxial Films and Nanocrystal**, ***S.A. Chambers,*** Pacific Northwest National Laboratory and Univ. of Washington*; A.C. Tuan,* Pacific Northwest National Laboratory*; K.R. Kittilstved, D.R. Gamelin,* University of Washington**INVITED**

Since 2001, researchers around the world have been involved in a vigorous search for new ferromagnetic oxide semiconductors with Curie temperatures above ambient. Such materials are vitally important for the practical realization of spintronics. Two wide bandgap oxide semiconductors have been of particular interest - TiO@sub 2@ anatase and ZnO. A number of claims of room temperature ferromagnetism (RTFM) in these host oxides with various dopants have been made. However, some of the results were based on poorly characterized material, often containing magnetic secondary phases, leading to illegitimate claims. Even for well characterized materials which are phase-pure magnetically doped oxides, the mechanism(s) of magnetism remain largely undetermined. We have used oxygen plasma assisted metal organic chemical vapor deposition along with direct wet chemical synthesis and spin coating to prepare Co@sub x@Zn@sub 1-x@O and Mn@sub x@Zn@sub 1-x@O epitaxial and nanoparticle films. Co(II) and Mn(II) substitute for Zn(II) in the wurtzite lattice in materials synthesized by both methods. Room temperature ferromagnetism in epitaxial Co:ZnO films can be reversibly activated by diffusing in Zn, which occupies interstitial sites and makes the material n-type. O-capped Co:ZnO nanoparticles, which are paramagnetic as grown, become ferromagnetic upon being spin coated in air at elevated temperature. Likewise, spin-coated N-capped Mn:ZnO nanoparticle films also exhibit room temperature ferromagnetism. However, the inverse systems, N-capped Co:ZnO and O-capped Mn:ZnO, are entirely paramagnetic when spin coated into films in the same way. Unfortunately, the nanoparticle films are not sufficiently conductive do perform magneto-transport measurements. Instead, we have carried out a detailed analysis of optical absorption, photovoltage, and magnetic circular dichroism spectra. This analysis reveals that the resonances Co(I) ↔ Co(II) + e@super -@@sub CB@ and Mn(III) ↔ Mn(II) + h@super +@@sub VB@ are energetically favorable, consistent with strong hybridization of Co (Mn) with the conduction (valence) band of ZnO. In contrast, the resonances Mn(I) ↔ Mn(II) + e@super -@@sub CB@ and Co(III) ↔ Co(II) + h@super +@@sub CB@ are not energetically favorable. These results indicate that Co(II)-derived states will strongly interact only with the conduction band, whereas Mn(II)-derived states interact strongly only with the valence band. These spectral results are consistent with the observed ferromagnetism in Co:ZnO (Mn:ZnO) being mediated by electrons (holes). @footnoteText@This work was performed in part in the Environmental Molecular Sciences Laboratory, a national scientific user facility sponsored by the Department of Energy's Office of Biological and Environmental Research and located at Pacific Northwest National Laboratory. This work was supported by the US Department of Energy, Office of Science, Office of Basic Energy Sciences, Division of Materials Science and Engineering Physics. Work at UW was funded by the NSF (DMR-0239325 and ECS-0224138) and the Research Corporation.

4:40pm **MI+EM-WeA9 Effects of Differing Mn@sub Ga@/Mn@sub I@ on the Anomalous Hall Effect in (Ga,Mn)As**, *Y.S. Kim, H.K. Choi, Z.G. Khim,* Seoul National University, Korea*; S.H. Chun,* Sejong University, Korea*;* ***Y.D. Park,*** Seoul National University, Korea

We report on the effect of differing ratios of substitutional and interstitial Manganese (Mn@sub Ga@/Mn@sub I@) on the Anomalous Hall Effect(AHE) in low temperature molecular beam epitaxy prepared (Ga,Mn)As diluted magnetic semiconductors. As-grown (Ga,Mn)As epifilms with Mn content from 2.4 % ~ 6.1 % exhibit ferromagnetic ordering below temperatures ranging from 60 to 110 K. Relatively differing Mn@sub Ga@/Mn@sub I@ ratios were achieved by careful annealing at moderate temperatures as evident in the differing resistivities (as low as 2.5 m@ohm@-cm)/ Hall carrier concentrations (as high as ~ 8 x 10@super 20@cm@super -3@) as well as T@sub C@ (as high as 150 K) with optimal annealing temperature found to be 250°C.@footnote 1@ AC-magnetotransport measurements conducted from 5 K to 300 K and with applied magnetic fields ranging to +/- 7 Tesla indicate similar field dependence of resistivity, AHE, and metal-insulator-like transition near T@sub C@ as reported by others.@footnote 2@ T@sub C@'s as found from Arrott plots from the resulting AHE measurements agree well with direct SQUID magnetometry measurements. Log-log plots of @rho@@sub xy@, d@rho@@sub xy@ /dH, and @rho@@sub xy@/M@sub S@ vs. @rho@@sub xx@, cumulated from AHE measurements at temperatures below T@sub C@ of differing as-grown Mn content and annealing conditions, indicate skew scattering to be the dominant mechanisms for AHE in (Ga,Mn)As regardless of as-grown Mn content or Mn@sub Ga@/Mn@sub I@ ratios and possibly regardless of presence of non-magnetic or magnetic Mn-rich nano-clusters. We will also discuss the results in light of theory@footnote 3@ of AHE in clean (Ga,Mn)As and experimental reports@footnote 4@ of AHE in DMS systems with ferromagnetic nano-clusters. @FootnoteText@ @footnote 1@T Hayashi et al. APL 78, 1691 (2001); KC Ku et al., APL 82, 2302 (2003).@footnote 2@M Tanaka, JVST B 16, 2267 (1998).@footnote 3@T Jungwirth et al., PRL 88, 207208 (2002).@footnote 4@SR Shinde et al., PRL 92, 166601 (2004).

Magnetic Interfaces and Nanostructures
Room 204 - Session MI+MS+NS-ThM

Advanced Magnetic Storage and Manufacturing Processes

Moderator: E.A. Dobisz, Hitachi Global Storage Technologies/San Jose Research Ctr.

8:20am **MI+MS+NS-ThM1 Interface Stability between Amorphous Ferromagnetic Layer and Oxide Barriers in Tunneling Magnetoresistive Films at Elevated Temperatures**, ***X. Peng***, *D. Kvitek, A. Morone, E. Granstrom, S. Xue,* Seagate Technology

Interface stability and microstructure between amorphous ferromagnetic (FM) layers Fe@sub 56@Co@sub 24@B@sub 20@ (atomic percent), and oxide barrier layers (AlO) as deposited by physical vapor deposition, in both as-deposited and annealed states, have been studied using magnetic measurement by looper, elemental depth profiling by X-ray Photoelectron Spectroscopy (XPS), and atomic level microstructure by Transmission Electron Microscopy (TEM) respectively. AlO is amorphous on both amorphous Fe@sub 56@Co@sub 24@B@sub 20@ and crystalline FM layers. Substantial Fe diffusion towards the AlO layer and Al towards FM layer are clearly observed for Fe@sub 56@Co@sub 24@B@sub 20@/AlO system for annealing beyond 360°C, and will likely cause the MTJ devices made from this system to not functioning.

9:00am **MI+MS+NS-ThM3 Nanoimprint Technologies for Magnetic Recording Media**, *T. Ando,* ***C. Haginoya***, *K. Kuwabara, M. Ogino, K. Ohashi, A. Miyauchi,* Hitachi Ltd., Japan **INVITED**

The discrete-track and patterned media have been developed as future magnetic recording media.@footnote 1,2,3@ Nano-scale patterns are formed on the disk surface of these media. The fine patterning technologies are required for producing the patterned disks. The nanoimprint technology is attractive for the fabrication of nano-scale structures in view of cost and mass production. There are two main types of the nanoimprint technologies. One is the thermal nanoimprint technology that fine structures are formed on thermoplastic polymer layer. Another is the photo nanoimprint technology that ultra-fine structures are formed on photo-curable polymer layer. There are several key points for media application such as pattern formation area, resolution, precise control of pattern transfer, lifetime of nano-mold, alignment and so on. The pattern formation area is important for producing patterned disks. We developed a thermal nanoimprint machine that has the auto-parallel system, two step pressure system and so on. The machine enabled us to imprint fine dots on a 300 mm diameter Si wafer using a 300 mm diameter mold. The pattern formation area is large enough to produce the 65 mm diameter patterned disks. The fine resolution is required for high recording density. Austin et al. formed 6 nm half-pitch structure using supperlattice stamper,@footnote 4@ and this resolution seems enough for Tbpsi storage era. D. Wachenschwanz et al.@footnote 1@ and Y. Soeno et al.@footnote 3@ evaluated write/read performance of the discrete-track media that the grooves and servo patterns were formed by using thermal nanoimprint and etching processes. Nanoimprint is promising way for discrete-track and patterned media. @FootnoteText@@footnote 1@ D. Wachenschwanz et al., INTERMAG 2005, no. BB02 @footnote 2@ B.D. Terris et al., INTERMAG 2005, no. BB03 @footnote 3@ Y. Soeno et al., INTERMAG 2005, no. FR04 @footnote 4@ M. D. Austin et al., 3rd Conf. on Nanoimprint Nanoprint Technology 2004, no. III.2

9:40am **MI+MS+NS-ThM5 Ultra Narrow Magnetic Recording Heads: Processing Challenges**, ***M.-C. Cyrille***, HITACHI Global Storage Technologies - San Jose Research Center **INVITED**

As the areal density of magnetic recording increases well beyond 100Gb/in2, the critical dimensions of recording heads continue to shrink at a rate of 30% per year.@footnote 1@ Today, thin film heads with 100nm or less critical dimensions are being routinely fabricated in manufacturing. By the end of 2006, the physical trackwidht of read head sensors is expected to be less than 60nm. The industry is turning to Direct write E-beam and DUV 193nm as the lithography tools of choice to meet those small dimensions. As the material set used to fabricate thin film magnetic heads is unique to this technology, specific challenges arise when trying to pattern such small devices without loss of performances. Damage due to standard patterning techniques can be now be observed on both the reader and the writer as their dimensions become smaller than 100nm and advances in tooling and processes tailored to each kind of magnetic sensor are required to overcome this issue. @FootnoteText@@footnote 1@ Fontana R.E., MacDonald S.A., Santini H, Tsang C., IEEE Trans. Mag 35, 806 (1999)

10:20am **MI+MS+NS-ThM7 Correlated AFM/MFM and Magneto-Optical Studies on Epitaxial L1o FePd Thin Films**, *R.A. Lukaszew, M. Mitra,* ***J. Skuza***, University of Toledo*; A. Cebollada-Navarro, J.M. Garcia-Martin, C. Clavero Perez,* Institute of Microelectronics in Madrid (IMM) - Spain

The latest trend in data storage exploits perpendicular recording. Magnetic binary alloys (e.g. Fe-Pd, Fe-Pt) are of significant interest in magneto-recording because highly ordered L1o structures of these alloys exhibit very large magnetic anisotropy that can withstand the super-paramagnetic limit when reduced in size to accommodate the projected demands for higher areal densities. They can be deposited as films with the anisotropy axis perpendicular to the film plane, making them suitable for perpendicular media. There are practical problems associated with this scheme because usually the experimentally achieved perpendicular anisotropy tends to be too large for writing on this media. Therefore it has been suggested that canted magnetization would be more appropriate. Here we show our correlated XRD, AFM/MFM and magneto-optical studies on two series of epitaxial L1o FePd thin films of varying thickness grown on MgO. We have observed that the choice of capping material has significant effect on the resulting magnetic and magneto-optical properties of the films. We will show correlated structural and magneto-optical data for films grown under identical conditions but capped with either MgO or Pd. Our studies demonstrate that in the first case the films exhibit strong perpendicular anisotropy while in the latter the films have a magnetization component along the plane of the films in addition to the perpendicular component, thus yielding a net canted magnetization. In addition the films capped with Pd exhibit smaller coercivities than the ones capped with MgO thus enhancing their prospect use in heat-assisted magneto-recording.

10:40am **MI+MS+NS-ThM8 Magnetic Properties of Epitaxial FeN Thin Films**, *R.A. Lukaszew,* University of Toledo*; R. Gonzalez-Arrabal,* University Autonoma of Madrid, Spain*;* ***C. Sanchez-Hanke***, Brookhaven National Laboratory*; R. Loloee,* Michigan State University*; D. Boerma,* University Autonoma of Madrid, Spain

Low anisotropy and low magnetostriction iron based FCC films are attractive candidate materials for inductive thin film write heads in magnetic recording. Currently these are made of permalloy and other Fe alloys with polarization ranging from 1.0-1.6 T. Higher polarization is needed to create sufficient stray field to write on the higher-coercivity media that is needed as head and bit dimensions decrease to allow higher areal densities. Fe-N has been proposed as a possible material for the sensing element in read-head. Fe-N exhibits a variety of phases, some of which have enhance magnetic moment. In particular the meta-stable @alpha@"- Fe16N2 is particularly interesting because has the largest saturation magnetization reported of all known materials. We will present a comparative experimental study on epitaxial Fe-N thin films with varying degrees of @alpha@", @alpha@' and @gamma@' phases. The films were obtained using either sputtering or MBE. In the latter case, the films were grown in the presence of a N flow and the growth conditions were optimised in order to obtain a high content of @alpha@"- Fe16N2. A variety of characterization techniques was used to establish the epitaxial character of the films as well as the amount and kind of phase present. The magnetic properties of the samples was characterized by element specific X-ray Magnetic Circular Dichroism (XMCD).

11:00am **MI+MS+NS-ThM9 Processing Technology for Magnetic Random Access Memory**, ***M.C. Gaidis***, *J.P. Hummel, S.L. Brown, S. Kanakasabapathy, E. O'Sullivan, S. Assefa, K. Milkove, D. Abraham, Y. Lu, J.N. Nowak, P. Trouilloud, D. Worledge, W.J. Gallagher,* IBM **INVITED**

Magnetic Random Access Memory (MRAM) offers the potential of a universal memory - it can be simultaneously fast, nonvolatile, dense, and high-endurance. Depending on application, these qualities can make MRAM more attractive than SRAM, DRAM, flash, and hard drive memories, with a market measured in the billions of dollars. Small-scale demonstrations have realized much of the potential of MRAM, but scaling the memory to production on economically-profitable 200 or 300 mm wafer sizes creates unique processing challenges heretofore unseen in a large-scale semiconductor fabrication facility. MRAM read operations rely on electron tunneling through a thin (1 nm) insulating barrier between magnetic films. The exponential dependence of tunnel current on barrier thickness imposes requirements for across-wafer film uniformity on the order of 0.01 nm, made possible only by recent developments in deposition technology. To maximize performance, typical magnetic film stack designs can incorporate more than 10 distinct film layers. Very few of these layers

can be etched by semiconductor-industry-standard RIE processes, and thus have required development of novel patterning techniques specifically tuned to minimize corrosion and to handle the nonvolatile nature of etch byproducts. The elements in these complex film layers tend to interdiffuse at temperatures below that of back-end-of-line (BEOL) semiconductor processing, thus necessitating the development of low-temperature processes for creating the BEOL wiring and packaging. Although daunting, each of the aforementioned challenges has largely been overcome. This presentation provides an overview of the basic MRAM structure and operation, followed by a discussion of the MRAM-specific processing techniques that have been developed to realize this technology in megabit arrays on 200 mm wafers.

Magnetic Interfaces and Nanostructures
Room 204 - Session MI-ThA

Magnetic Oxides
Moderator: A. Hoffmann, Argonne National Laboratory

2:00pm **MI-ThA1 Doped Cobaltites: Phase Separation, Intergranular GMR, and Glassy Transport Phenomena**, ***C. Leighton***, *J. Wu,* University of Minnesota*; J. Lynn, C. Glinka,* NIST*; H. Zheng, J. Mitchell,* Argonne National Laboratory*; W. Moulton, M. Hoch, P. Kuhns, A. Reyes,* National High Magnetic Field Lab*; C. Perrey, C.B. Carter,* University of Minnesota **INVITED**
Magneto-electronic phase separation, where a chemically homogeneous material displays spatial coexistence of multiple magnetic and electronic phases, is very common in perovskite oxides and is thought to play a key role in high temperature superconductivity and colossal magnetoresistance. We have used a battery of complementary experimental techniques to tackle the problem of magnetoelectronic phase separation in the perovskite cobaltite La1-xSrxCoO3. This is a material that offers many of the desirable attributes of a model system for investigating phase separation. Co and La NMR and small angle neutron scattering unequivocally demonstrate the existence of magnetoelectronic inhomogeneity in polycrystalline, single crystal and epitaxial thin film samples, which are chemically homogeneous on nm length scales. At low doping ferromagnetic metallic clusters form in an insulating matrix. These clusters coalesce with increasing doping, leading to a percolation transition and the onset of long-range ferromagnetic order. In single crystals, this formation of isolated clusters leads to a hysteretic negative MagnetoResistance (MR), which has field, temperature, and doping dependencies consistent with an intergranular Giant MagnetoResistance (GMR) effect. We argue that this system is a naturally forming analog to the artificial structures fabricated by depositing nanoscale ferromagnetic particles in a metallic or insulating matrix, i.e. this material displays an intergranular GMR effect without the deliberate introduction of chemical interfaces. The formation of nanoscopic F clusters also gives rise to glassy transport phenomena that are reminiscent of relaxor ferroelectrics. This is discussed in terms of the known phenomenology of the magnetic phase separation. Work supported by ACS PRF and NSF MRSEC.

2:40pm **MI-ThA3 MBE Growth of Epitaxial Co@sub2@MnGe on SrTiO@sub3@ (001) and MgO (001) Substrates**, ***S.K. Srivastava***[1], *C. Adelmann, X. Dong,* University of Minnesota*; D. Schlom,* Penn State University*; C. Ahn,* Yale University*; C.J. Palmstrom,* University of Minnesota
The combination of metallic ferromagnetic Heusler alloys with metal oxides can be used for the formation of multifunctional material heterostructures. The growth of Co@sub2@MnGe with a 45° in-plane rotation results in a lattice mismatch of -3.84% and +3.82% for SrTiO@sub3@ (001) and MgO (001), respectively. Etching of SrTiO@sub3@, followed by ex-situ annealing in O@sub2@ (~1 atm) at 1223K for 1 hour was used to form a TiO@sub2@ terminated surface@footnote 1@ with straight edged steps. AFM shows terraces with step heights on the order of one unit cell (~ 4Å) and LEED images show a (@sr@5x@sr@5)R26.6° superstructure. The growth of Co@sub2@MnGe was initiated by growing alternating atomic layers of MnGe and Co in an MBE system at 298K to promote wetting of the substrate and the desired (001) atomic stacking sequence. Following the growth of 20 atomic layers, the film was annealed in-situ at 673K for 1 hour. The remaining 250Å Co@sub2@MnGe film was grown by codeposition at 723K and annealed at 823K for 1 hour. RHEED and LEED images from the Co@sub2@MnGe films showed (2x2) reconstruction. For growth on MgO, the substrates were cleaned and annealed ex-situ in O@sub2@ (~1 atm) at 1273K for 2 hours giving a (1x1) RHEED pattern. A growth scheme similar to the one mentioned above was used for the growth of Co@sub2@MnGe on MgO and resulted in a (2x2) RHEED pattern. XRD is consistent with the single crystal epitaxial growth of Co@sub2@MnGe films on SrTiO@sub3@ and MgO, with out-of-plane lattice parameters of 5.745Å and 5.758Å, respectively. Both films are ferromagnetic with no significant in-plane magnetic anisotropy as measured by VSM. This presentation will emphasize the effect of pre-treatment and deposition sequence on the structural and magnetic properties of Heusler alloy films grown on oxide substrates. Supported by ONR-MURI. @FootnoteText@ @footnote 1@G.Koster, B.L.Kropman, G.J.H.M.Rjinders, D.H.A.Blank and H.Rogalla, Appl. Phy. Lett., 73, 2920 (1998).

[1] **Falicov Student Award Finalist**

3:00pm **MI-ThA4 Characterization of Transition Metal Doped MOCVD-Grown ZnO Epifilms and Nanostructures**, ***D. Hill,*** *R. Gateau,* Rutgers University*; J.F. Veyan,* Univ. Tech. Frederico Santa Maria*; L.S. Wielunski, S. Guha, R.A. Bartynski,* Rutgers University*; D.A. Arena,* Brookhaven National Lab*; J. Dvorak,* Montana State University*; P. Wu, Y. Lu, F. Cosandey, V. Poltavets, M. Greenblatt,* Rutgers University
ZnO is a wide bandgap (~3.3 eV) semiconductor that recently has been identified as a promising DMS candidate for room temperature spintronics. We have characterized the chemical, compositional, and magnetic properties of transition metal- (TM-) doped ZnO epitaxial thin films and nanostructures grown by MOCVD. The films and nanopillars were doped with Mn or Fe either by ion implantation or in-situ during MOCVD growth. RBS ion channeling shows a minimum yield < 2% for the ZnO epi films indicating excellent crystallinity. The minimum yield is much higher for the ion implanted samples, but improves dramatically upon annealing. Soft x-ray absorption spectroscopy (SXAS) indicates that the TM dopant may be in either the 2+ or 3+ oxidation state, depending upon annealing history. In-situ doped films exhibit oxidation states similar to ion implanted films that have been annealed. SQUID magnetometry measurements show that both the implanted and annealed films and nanostructures exhibit hysteretic M vs. H curves at temperatures as high as liquid nitrogen temperature. M(T) curves show a small paramagnetic component at 5 K, but the majority of the magnetization remains up to room temperature. TM-ion implanted MOCVD-grown ZnO nanotips show relatively uniform TM concentration (<~ 5%) throughout the tip, and TEM images show no indication of secondary phase formation or metal clustering upon annealing to temperatures as high as 700C. @FootnoteText@ @footnote 1@Supported by NSF grant # ECS-0224166 .

3:20pm **MI-ThA5 Detailed Investigation of Cr-doped Anatase TiO@sub 2@ as a Potential DMS**, ***T.C. Kaspar***, *T.C. Droubay, S.M. Heald, V. Shutthanandan, C.M. Wang, D.E. McCready, J.E. Jaffe, S.A. Chambers,* Pacific Northwest National Laboratory
Since the initial discovery of room temperature ferromagnetism in Co-doped anatase TiO@sub 2@ in 2001, there has been an explosion of interest in doped transition metal oxides as potential dilute magnetic semiconductors (DMSs), which may find application in future spintronic devices. The high electron mobility in n-type anatase TiO@sub 2@ (reduced to create oxygen vacancies) makes it an attractive candidate as a oxide semiconductor host material. Doping with Cr instead of Co is advantageous since Cr metal (antiferromagnetic) is more easily oxidized than Co metal (ferromagnetic). In this talk, we present results of a detailed study of Cr-doped anatase TiO@sub 2@ deposited by oxygen-plasma-assisted molecular beam epitaxy. Phase-pure, epitaxial films are obtained with particle-free surfaces and uniform distribution of Cr. Crystalline perfection is controlled by the deposition rate; nearly perfect films can be obtained at a sufficiently slow rate. For faster deposition rates, room temperature ferromagnetism is observed, with ~ 0.5 μ@sub B@/Cr and a Curie temperature of 690 K. Regardless of deposition rate, XANES and EXAFS indicate Cr incorporates into the anatase lattice as Cr(III), requiring one oxygen vacancy for every two dopants to maintain charge neutrality. The specific site occupancy, as well as the complex role of oxygen vacancies and crystalline defects in the ferromagnetic ordering, will be discussed. The electronic properties of Cr-doped anatase have been investigated in detail by XPS, XAS/XES, XMCD, and anomalous Hall measurements, as well as theoretical calculations of the band structure. These results and the implications for spintronic applications of Cr-doped anatase will be presented.

3:40pm **MI-ThA6 Structural, Electronic and Magnetic Properties of MBE Grown Ti-doped @alpha@-Fe@sub 2@O@sub 3@**, ***S.A. Chambers***, *T.C. Droubay, S.M. Heald, C.M. Wang, K. Rosso,* Pacific Northwest National Laboratory
@alpha@-Fe@sub 2@O@sub 3@ is an antiferromagnetic wide bandgap semiconductor (E@sub g@ = 2.2 eV) which exhibits strong ferromagnetic coupling within cation layers perpendicular to the c axis, and antiferromagnetic coupling between adjacent cation layers. LSDA + U calculations predict that substituting Ti for Fe should lead to a ferrimagnetic state with a large moment per Ti because Ti is predicted to substitute for Fe preferentially in alternating cation layers perpendicular to the c axis.@footnote 1,2@ To test this prediction, we have used oxygen plasma assisted molecular beam epitaxy to grow @alpha@-Ti@sub x@Fe@sub 2-x@O@sub 3@, for which x varied between 0.01 and 0.04, on @alpha@-Al@sub 2@O@sub 3@(0001). Excellent heteroepitaxy was achieved by first growing a @alpha@-Cr@sub 2@O@sub 3@ buffer layer

to grade the lattice mismatch between @alpha@Fe@sub 2@O@sub 3@ and @alpha@-Al@sub 2@O@sub 3@. All Fe was found to be in the +3 charge state by Fe K-shell XAS and Fe 2p XPS. Ti was found to be in the +4 charge state and to uniformly substitute for Fe(III) in the lattice by Ti K-shell XAS and EXAFS, along with ion channeling. The conductivity increased monotonically with x, achieving a value of ~100 Ohm-cm at x = 0.04. All doped films were found to be weakly ferromagnetic at room temperature, as expected if Fe ions were replaced with Ti(IV) ions in a statistical fashion in all cation layers. The coercive field was found to be ~800 Oe, independent of x. The moment was found to be ~0.5 μ@sub B@ per Ti dopant, considerably lower than the 4 μ@sub B@ per Ti dopant predicted by LSDA + U theory.@footnote 1,2@. @FootnoteText@ @footnote 1@ W.H. Butler et al., J. Appl. Phys. 93, 7882 (2003).@footnote 2@ A. Bandyopadhyay et al., Phys. Rev. B 69, 174429 (2004).

4:00pm **MI-ThA7 Highly Spin Polarized Current from Tunnel Spin Injectors and in Magnetic Tunnel Junctions using MgO(100)**, ***S.S.P. Parkin***, IBM Almaden Research Center **INVITED**

Spin-based electronics, often referred to as "spintronics", is a research field of intense current interest, which aims to develop novel sensor, memory and logic devices by manipulating the spin states of electrons or holes in semiconducting materials. This talk will focus on electrical spin injection into semiconductors, which is a prerequisite for spintronics and, in particular, on tunnel based spin injectors operable above room temperature. Two types of spin injectors, formed from 3d transition metal ferromagnets and oxide tunnel barriers, are discussed: a three-terminal magnetic tunnel transistor (MTT) injector)@footnote 1,2@ and a two-terminal magnetic tunnel injector.@footnote 3@ A two terminal tunnel spin injector, comprised of CoFe/MgO(100), is shown to give more than 50% spin polarized current within GaAs (100) heterostructures at room temperature.@footnote 3@ The spin polarization of the injected current is inferred from the electroluminescence polarization (ELP) from GaAs/AlGaAs quantum well detectors. The high polarization values are consistent with giant values of tunneling spin polarization (TSP) measured in superconducting tunneling junctions in which the CoFe/MgO layers are highly textured (100). Recently, we have reported TSP values of up to 85% (at 0.25 K) and tunneling magnetoresistance values (TMR) of >220% in CoFe/MgO(100) magnetic tunnel junctions at room temperature.@footnote 4@ Such high values of TSP and TMR, previously only obtained at low temperatures using half-metallic ferromagnets, promise the development of new families of spintronic devices operating at room temperature based on conventional ferromagnets. * work carried out in collaboration with X. Jiang, R. Wang, C. Kaiser, R. Shelby, R. MacFarlane, G. Solomon and J. Harris. @FootnoteText@ @footnote 1@S. van Dijken et al., Appl. Phys. Lett. 83, 951 (2003). @footnote 2@ X. Jiang, et al., Phys. Rev. Lett. 90, 256603 (2003). @footnote 3@X. Jiang et al, Phys. Rev. Lett. 94, 056601 (2005). @footnote 4@S. S. P. Parkin, et al., Nature Mater. 3, 862 (2004).

Magnetic Interfaces and Nanostructures
Room 204 - Session MI+BI-FrM

Biosensors and Biomagnetism
Moderator: D.P. Pappas, NIST-Boulder

9:00am **MI+BI-FrM3 Engineered Magnetotactic Bioreporter Bacteria@footnote 1@*, L.J. Whitman,*** Naval Research Laboratory **INVITED**
There is an urgent need for compact, low power, broad spectrum sensors for sentinel point detection of toxins and pathogens. Although cell-based sensors have the potential to meet many of these requirements, it is a challenge to make such systems deployable because of the fragility of most cell cultures and the short lifetime of most bioreporter cells. We are addressing these issues by developing a robust, microbial sensor based on a strain of magnetotactic bacteria, Magnetospirillum magneticum AMB-1, that naturally produces an intracellular chain of magnetite nanoparticles (magnetosomes). We have produced a variety of genetically engineered AMB-1, including magnetic knockouts, with the goal of creating a reporter strain that only produces magnetosomes in the presence of specific toxic industrial chemicals. Wild-type and engineered strains have been extensively characterized by a variety of physical and chemical methods. We have determined that magnetosome production can be a rapid process, occurring in minutes, and that iron uptake correlates well with the measured magnetic moments. To rapidly determine when magnetosomes are present in the live cultures, a miniature optical system has been developed that detects differential light scattering from magnetically-aligned bacteria. Because stable populations of AMB-1 can be maintained for weeks under a range of environmental conditions, this organism appears to be a promising candidate for cell-based sentinel point detection. @FootnoteText@ @footnote 1@This work was done in close collaboration with M. B. Johnson, A. Krichevsky, J. C. Rife, M. J. Smith, C. R. Tamanaha, and R. J. Tonnuci at NRL, and B. M. Applegate, L. N. Csonka, L. K. O'Connor, and L. Perry at Purdue University. Supported by DARPA BioMagnetICs.

9:40am **MI+BI-FrM5 Synthesis and Surface Engineering of Superparamagnetic Nanoparticles*, R. De Palma,*** *S. Peeters, K. Bonroy, G. Reekmans, F. Frederix, W. Laureyn, G. Borghs, C. Van Hoof,* IMEC vzw, Belgium*; G. Maes,* KULeuven, Belgium
Superparamagnetic nanoparticles with appropriate surface chemistry have been widely used for numerous applications such as MRI, hyperthermia treatment, magnetic biosensing, etc. These applications require that the nanoparticles have high magnetization values, a well-defined and controllable morphology and an overall uniform size distribution. In addition, these applications need special (bio)chemical functionalisation of the magnetic nanoparticles, specifically tuned towards their demands. Most work has been done in improving the quality of magnetic nanoparticles, but only a few scientific investigations have been carried out in engineering and improving their (bio)chemical surface characteristics. Here we present several approaches, to engineer the surface characteristics of superparamagnetic nanoparticles, without altering their magnetic and morphological characteristics. Monodisperse superparamagnetic nanoparticles with controllable size, shape and magnetic properties were synthesized based on the thermal decomposition method. The chemical functionality of these nanoparticles could be tuned by the covalent attachment of thin silane SAMs on the particle surface. An optimized procedure allowed the controllable deposition of high quality silane SAMs with different endgroups. By these means, the nanoparticles could be made water-soluble and capable to covalently couple biological receptors. Several receptors were successfully immobilized onto magnetic nanoparticles, while retaining their biological activity. The degree of receptor immobilization was determined to be 2-10 times higher, compared to 2D substrates. The synthesized magnetic nanoparticles were also coated with a thin shell of inorganic material such as Au and SiO@sub 2@ based on a novel and straightforward coating procedure. The superparamagnetic nanoparticles were characterised using TEM, XRD, FTIR, XPS, UV/vis, SQUID and Bradford.

10:20am **MI+BI-FrM7 Shaken Not Stirred, A New Approach to Biomagnetic Sensing*, A. Hoffmann,*** *S.-H. Chung, K. Guslienko, S.D. Bader, C. Liu, B.D. Kay, L. Makowski, L. Chen,* Argonne National Laboratory **INVITED**
Micron and nanosized magnetic particles coated with biochemical surfactants have emerged recently as an important component for enabling many biological and medical applications. Among these biomagnetic sensors have received a lot of attention lately, due to their potential advantages of simplicity and rapidity. The most common approach to biomagnetic sensors utilizes magnetic beads, whose magnetic moment is detected by a magnetic field sensor, such as a giant magnetoresistive spin valve. In contrast we demonstrated a new substrate-free approach to biomagnetic sensing which uses the magnetic ac-susceptibility of ferromagnetic nanoparticles suspended in a liquid for the signal transduction.@footnote 1@ The magnetic relaxation of these nanoparticles is due to their Brownian rotational diffusion, which is easily modified by binding the target of interest to the particles. This scheme has several distinct advantages; (i) it requires only one binding event for successful sensing; (ii) since there is a useful signal both in the absence and presence of the target it has an inherent check for integrity; and (iii) the signal contains information about the size of the target besides the biochemical affinity, which may be used to further distinguish between several different potential targets. We are developing novel magnetic viruses for application in our sensing scheme. They provide a well-defined, mono-dispersed size distribution of the ferromagnetic particles and offer the possibility to readily engineer the desired biological recognition functionality. This work was supported by DOE, BES under contract W-31-109-ENG-38 and DARPA under contract 8C67400. @FootnoteText@ @footnote 1@ S.-H. Chung, et al., Appl. Phys. Lett. vol. 85, 2971 (2004).

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