Monday Morning, October 29, 2001

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+EL-MoM

Magnetic Devices

Moderator: B.A. Everitt, Seagate Technology

9:40am **MI+EL-MoM1 High Speed 256k Magnetoresistive RAM*, S. Tehrani,*** Motorola Corporate **INVITED**

Magnetoresistive Random Access Memory (MRAM) has the potential to be a high-speed, low-voltage, high-density, nonvolatile solid state memory. MRAM is based on magnetic memory elements integrated in a backend process with standard CMOS semiconductor circuitry. Key attributes of MRAM technology are nonvolatility and unlimited read/write endurance. Our bit architecture is based on a minimum-sized active transistor as the isolation device in conjunction with a magnetic tunnel junction element (MTJ) defining the MRAM bit. Our MTJ material stack is composed of two magnetic layers separated by a thin dielectric barrier with the polarization of one of the magnetic layers pinned in a fixed direction. The resistance of the memory bit is either low or high dependent on the relative polarization, parallel or anti-parallel, of the free layer with respect to the pinned layer. In this talk we will summarize our progress on MRAM based on MTJ integrated with CMOS circuitry. We have demonstrated MTJ material in the 10 kOhms-um^2 range with MR values up to 50 %. The MRAM module is inserted in the back-end-of-line (BEOL) interconnect using four additional lithography steps. The source and isolation are shared between neighboring cells to minimize cell area. In this particular architecture, the cell size is 7.2um^2, corresponding to 9f^2, where f is one-half the metal pitch. We have developed a 256kb (16k x 16) MRAM memory based on 0.6 um CMOS with a 1T1MTJ (one transistor and one MTJ) cell. Nonvolatile data storage and read cycle times of 35 ns have been demonstrated. Read power consumption at 3.0V and 20MHz is about 24mW. These results show that MRAM based on MTJ has the potential to be a competitive memory with the attributes of high-speed read and write, as well as nonvolatility. The progress, potential and challenges of MRAM technology will be discussed. @FootnoteText@ This work in funded in part by DARPA.

10:20am **MI+EL-MoM3 Dry Etching of MRAM Device Structures*, R.A. Ditizio*,** *G. Beique,* Tegal Corporation

Magnetic Random Access memory (MRAM) has experienced a rise in interest in recent years as an alternative to other non-volatile memory devices. As efforts continue to improve the electrical performance of these devices, parallel efforts are underway to meet the stringent requirements for the fabrication of MRAM device structures at high densities. In this report, recent efforts that have been undertaken to apply conventional etch practices to the unique requirements for the patterning of MRAM device structures in an inductively coupled plasma source are discussed. In particular, improvements in optical emission detection and the subsequent correlation of endpoint traces to films in the device structure will be presented. Correlation of the film structure to the optical emission trace is necessary, for example, as a means to identify the specific time in the etch process at which to stop on the thin insulating layer across which a magnetic tunneling junction might typically be formed. Post-etch corrosion control of the completed device structure using an integrated rinse module is also discussed.

10:40am **MI+EL-MoM4 Spin Dependent Tunneling Devices for Nonvolatile Latch Memory*, M. Tondra*,** *D. Wang, D.J. Brownell, Z. Qian, C. Nordman, J. Daughton,* NVE Corp. **INVITED**

Operation of integrated magnetoresistive nonvolatile latch cell memory using spin dependent tunneling (SDT) junctions has been demonstrated. These SDT devices were fabricated on top of commercially processed CMOS silicon circuit wafers. Fabrication of these devices presents many challenges to thin film deposition process developers. Process temperature compatibility and surface roughness are prime examples. In spite of these and other technical challenges, there is significant motivation to continue developing SDT fabrication processes. In particular, SDT devices provide resistance changes on the order of 50% (large signal), a wide range of resistance values (for low power applications), and magnetic switching speeds beyond 1 GHz. Furthermore, the SDT cell density is potentially competitive with commercial SRAM and DRAM. Recent success in SDT integrated device fabrication has been a result of using new approaches to surface preparation. Specifically, chemical mechanical polishing (CMP) has been employed to create a sufficiently smooth surface for SDT deposition. In-process atomic force microscopy (AFM) measurements suggest that a pre-deposition RMS substrate roughness of 0.2 nm is sufficient to allow successful SDT fabrication. This paper will discuss device-specific process details of SDT latch cells and their impact on the potential for near-term commercialization.

11:20am **MI+EL-MoM6 Effects of Interfacial Electronic States and Roughness on Tunnel Magnetoresistance*, J. Inoue*,** *H. Itoh,* Nagoya University, Japan

Recently, active researches on tunnel magnetoresistance (TMR) are under progress with the objects of its technical applications such as magnetic sensors and magnetic random access memories. In spite of these studies, the understanding of the electronic states at the interfaces of the ferromagnetic tunnel junctions and of the effects of roughness on the tunnel conductance and TMR is not still complete. Quite recently, numerical results on the TMR in the first principles band calculations have been reported for junctions with clean interfaces. The calculated results show that the contribution of the states with certain wave vectors parallel to the interface becomes dominant, which are known as hot spots. We calculate the dependence of the tunnel conductance and TMR on the barrier thickness including the interface roughness, and show that the contribution of the hot spots to the tunnel conductance is reduced by the roughness. We further argue the possibility of appearance of interfacial state due to amorphous-like barrier structure and its effects on the TMR.

11:40am **MI+EL-MoM7 Performance of the BARC Magnetoresistive Sensor*, *J.C. Rife*,** *R.J. Colton, M. Miller,* Naval Research Laboratory*; M.A. Piani,* Nova Research, Inc.*; C.R. Tamanaha,* Geo-Centers, Inc.*; P.E. Sheehan, L.J. Whitman,* Naval Research Laboratory

The Bead ARray Counter (BARC) is a microfabricated chip for quantitatively detecting and identifying biological molecules using giant magnetoresistive (GMR) sensors.@footnote 1@ The assay is based on highly selective biomolecular binding to the surfaces of numerous individually addressable GMR sensors, followed by labeling of captured molecules with magnetic beads. An externally applied AC magnetic field magnetizes the beads and a lock-in amplifier detects changes of 10@super -@@super 7@ in resistance of the GMR sensors, limited by Johnson and 1/f noise. Overall sensitivity is a convolution of chemical and magnetic/electronic sensitivities. Our current sensors can determine target concentrations from 10 fM to 1 nM with loading of one hundred to more than a thousand beads. In principle, each sensor could detect one bead/one captured molecule. Present electronic sensitivity is restricted, in part, by the properties of the commercial 2.8 µm diameter composite polymer/ferrimagnetic beads that result in signal levels a factor of ten below the electronic noise floor. We find 10 to 100x improved signal with solid, soft ferromagnetic beads of the same size that yield the theoretical susceptibility of solid magnetic spheres, but chemical functionalization of the surfaces is not yet resolved. We have measured bead signals versus magnetizing field to have an approximately square-law dependence determined by the magnetoresistance response curve. We have also measured the bead signal versus position across the 2 µm wide GMR sensor and generated a simple model of the local resistivity change. Finally, We have developed an overall model for the GMR sensor response that agrees in large part with the measurements. The model should enable sensor and magnetic physical design to be optimized for maximal chemical and electronic sensitivity. *Supported by the Defense Advanced Research Projects Agency. @FootnoteText@ @footnote 1@ Edelstein et al., Biosensors & Bioelectronics 14, 805 (2000).

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+NS-MoA

Nano Magnetics

Moderator: P.N. First, Georgia Institute of Technology

2:00pm **MI+NS-MoA1 Preparation and Magnetic Studies of Mass-Selcted Iron Clusters***, **V. Senz**, R.-P. Methling, A. Kleibert, J. Bansmann, K.E.H. Meiwes-Broer,* Universitaet Rostock, Germany

We have investigated the magnetic properties of mass-selected iron clusters using the magneto-optical Kerr effect (MOKE) in the visible and soft x-ray energy range. Using a continuously working cluster source (Arc Cluster Ion source - ACIS) we codeposited mass-selected iron clusters into a matrix of evaporated silver atoms on a silicon substrate. The source is based on cathodic arc erosion in inert gas environment and supersonic expansion. Its intensity and stability allows an enhanced mass-separation which is achieved by means of an electrostatic quadrupole deflector. Magnetization curves were measured for cluster sizes of 8.1nm and 11.7nm. The hysteresis curves reveal the transition from the ferromagnetic to the superparamagnetic state in dependence on the cluster size and temperature. Recently, element-specific reflectivity measurements have been carried out in the energy range of the Fe 2p core levels using linearly polarized light (X-MOKE). The observed MOKE effect at the 2p levels is much larger than the respective value at the Fe 3d valence band due to the enhanced spin-orbit interaction.

2:20pm **MI+NS-MoA2 Fabrication of Nanomagnet Arrays using Anodic Porous Alumina***, **J.H. Choi**, H.-Y. Kang, W.-G. Park,* Seoul National University, Korea*; Y. Kuk,* Seoul National University, Korea, South Korea

Anodic porous alumina has attracted increasing attention because of its naturally self-ordered porous structure and the capability for the fabrication of dots in nanometer scale. We present two fabrication processes of nanomagent arrays using anodic porous alumina. Electrochemically polished aluminum sheet is anodized in oxalic and sulfuric acid under constant voltage condition and porous alumina is used as a template. Co is electrodeposited in the pore of alumina and the deposition is stopped before Co fills the pore completely. Finally, ion milling is used to remove the upper side of alumina and get smooth surface. In the second process, we use anodic porous alumina as a mold for imprint lithography. Anodic porous alumina is placed on the PMMA/SiO@sub 2@/Co multilayer for the imprint. Hexagonal dot arrays are generated on PMMA and pattern-transferred to lower Co layer using reactive ion etching and ion milling. In both processes, nanomagnet arrays with the size of 40 ~ 100nm are successfully fabricated. The magnetic properties of the particles and their interactions have been investigated by spin polarized scanning tunneling microscopy, magnetic force microscopy and spin polarized scanning electron microscopy.

2:40pm **MI+NS-MoA3 Torques and Tunneling in Nanomagnets***, **D.C. Ralph**, E.B. Myers, M.M. Deshmukh, E. Bonet, F.J. Albert, R.A. Buhrman,* Cornell University **INVITED**

When the size scale of magnetic devices is shrunk to nanometer dimensions, qualitatively new properties can emerge. I will discuss two recent examples. First, I will review investigations of a new mechanism -- spin-transfer -- by which applied currents can be used to manipulate the orientation of ferromagnetic moments. Unlike traditional schemes which utilize a magnetic field to control magnetic reorientation, spin-transfer is based on the exchange interaction. It is a torque that results when a spin-polarized current scatters from a magnetic element, and in the process transfers spin-angular momentum to the magnet. Depending on device geometry and the magnitude of the applied magnetic field, this torque can cause either controlled magnetic reversal or the excitation of high-frequency precession driven by a dc current. Another property that emerges only in devices containing metal grains smaller than about 10 nm in diameter is that the electronic states involved in electron transport can be resolved individually. I will discuss spectroscopic measurements of the electronic states which contribute to electron tunneling in cobalt nanomagnets containing about 1000 atoms, and how these states are influenced by exchange interactions, anisotropy forces, and applied magnetic fields. We find that each electronic state in given magnetic nanoparticle is described by a slightly different anisotropy energy, with fluctuations of order 1 to 3 percent. Individual states are not purely spin-up or spin-down, but have a mixed character. Spin-waves and non-equilibrium excitations play a central role in shaping the tunneling spectrum, even at low energies.

3:20pm **MI+NS-MoA5 Self-assembled Magnetic Dots / Antidots and Dot Chains: Epitaxial Co/Ru(0001)@footnote *@***, **D. Li**, C. Yu, J. Pearson, S.D. Bader,* Argonne National Laboratory

We have grown ~ 0-420 nm thick epitaxial Co wedges on flat and grooved Ru(0001) with molecular beam epitaxy at 350 °C to investigate self-assembly in metals and their magnetic properties utilizing ex-situ atomic force microscopy and magnetic force microscope. Three-dimensional islands (dots) or a flat film network with deep holes (antidots) in well-defined truncated pyramidal shapes appear below or above ~ 20 nm, respectively.@footnote 1@ The lateral sizes of these dots/antidots, as well as their spatial distribution on the flat substrates, tend to be uniform at a lengthscale of ~ 10@super 2@ nm in diameter and ~ 10@super 0@ nm in height. This growth mode is mainly driven by strain as a result of an 8% lateral mismatch between the basil plane lattice constants of bulk Co and Ru. On grooved Ru substrates, these self-assembled Co dots align into linear chains along the top and bottom of the grooves. The average dot-to-dot distance within a chain changes from ~ 500 nm to connecting into uniform stripes as a function of coverage. Magnetically, the dots are single domain with in-plane anisotropy. The dot chains have uniaxial anisotropy along the grooves and exhibit dipolar ferromagnetic inter-dot interaction. @FootnoteText@ @footnote *@ Supported by DOE BES-MS #W-31-109-ENG-38. @footnote 1@ Chentao Yu, Dongqi Li, J. Pearson, and S.D. Bader, Appl. Phys. Lett. 78, 1228 (2001).

3:40pm **MI+NS-MoA6 Greatly Enhanced Magnetic Anisotropies in Pure and Bimetallic Co Nanostructures on Pt(111)***, **T. Cren**, S. Rusponi, N. Weiss, M. Epple, H. Brune,* Ecole Polytechnique Federale de Lausanne, Switzerland

We report on the enhancement of the magneto-crystalline anisotropy energy K in low dimensional Co islands induced by firm electronic coupling with the underlying Pt(111) substrate. The Co islands were created on Pt(111) using kinetically controlled MBE growth. The correlation between structure and magnetism has been studied by STM and in-situ Surface Magnetic Optical Kerr Effect (SMOKE). We generally observe that the magnetism of the islands is governed by the out-of-plane anisotropy and the M(H)-loops are well described by a two-state Ising model. For pure Co islands, of roughly 1000 atoms size, the shape has only little influence on magnetism (μ=2.2μ@sub B@/atom for ramified and μ=1.9μ@sub B@/atom for compact islands; bulk value 1,7μ@sub B@). From the blocking temperature we deduce an anisotropy energy of K=0.37meV/atom which is greatly enhanced as compared to the Co bulk value of K=0.7μmeV/atom. For double layers islands K is reduced by a factor of two (K=0.16meV/atom) which clearly demonstrates the role of the Co/Pt interface. Finally, we show that the anisotropy can further be enhanced by decoration with Pd or Pt and by bimetallic alloy islands.

4:00pm **MI+NS-MoA7 Invited Paper***, **A.D. Kent**,* New York University **INVITED**

5:00pm **MI+NS-MoA10 Collective Behavior in Patterned Nanomagnetic Dot Array - A Promising Route to Magnetic Data Processing at Room Temperature***, **A.J. Bennett**, J.M. Xu,* Brown University

It is well known that nanomagnetics could greatly improve data storage. In this work, through theory and experiment, we show that nanomagnetic patterned arrays are equally promising for data processing. Such arrays offer many potential advantages over CMOS circuits of the same scale: power dissipation drops through magnetostatic signal transport replacing resistive and radiative transmission lines; noise resistance is increased by low environmental coupling; interconnection problems are mitigated by signal transfer via "wireless" interactions. Magnetic interaction simulations using typical parameters suggest that room temperature operation is feasible. Experimental evidence and first-principles analysis will be presented to support this finding. We demonstrate specific nanomagnetic arrays which exhibit basic logic functions. We also show that the implementation of these arrays is within the reach of a hybrid strategy of e-beam lithography and a new non-lithographic nanofabrication technique our lab has developed (to be described in a separate report). Modeling collective behavior and designing nanomagnetic array logic represent new challenges which are met by a full-interaction-matrix Monte Carlo technique we developed. This approach enables simulation of nanodisk lattices as well as engineered branched arrays and gates for general logic. Unlike a nearest-neighbor model, our approach includes all interactions; thus, we may predict and compensate for problems arising from long-range interactions which arise in large circuits. In conclusion, magnetic nanostructures and nano-array gates show significant promise for nanoscale, room-temperature information processing.

Tuesday Morning, October 30, 2001

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+EL-TuM

Spintronics I: Magnetization Dynamics and New Materials
Moderator: S.E. Russek, National Institute of Standards and Technology

8:20am **MI+EL-TuM1 Noise-Derived Anisotropy Energy Distributions of Cobalt Nanoparticle Films*, S.I. Woods*,** *R.H. Koch, S. Sun, J. Kirtley,* IBM T.J. Watson Research Center **INVITED**

9:00am **MI+EL-TuM3 Spin Wave Dynamics of Interacting and Non-interacting Magnetic Elements on the Sub-micrometer Scale*, S.O. Demokritov*,** *J. Jorzick, B. Hillebrands,* University Kaiserslautern, Germany*; M. Bailleul, C. Fermon,* CEA Saclay, France*; K. Guslienko, A.N. Slavin,* Oakland University*; D. Berkov,* Innovent Jena, Germany

Confinement caused by the lateral edges of small magnetic elements qualitatively changes dynamic properties of such elements. Instead of well-known spin wave bands, characteristic for thin magnetic films that are infinite in plane, one observes quantized spin wave modes with wavevectors determined by the element lateral sizes.@footnote 1@ Here we report a new highly localized spin wave mode in small magnetic elements. This mode was observed using Brillouin light scattering from thermal spin fluctuation in arrays of micrometer-size, 35 nm thick permalloy elements: rectangular dots and stripes magnetized perpendicular to their axes. The in-plane field 0.3-0.6 kOe was high enough to remove the remanence domains in the investigated elements. However, due to the non-elliptical shape of the elements the total saturation cannot be reached at any applied field. Domains (near the edges of the element that are perpendicular to the field) exist. The observed new mode is localized near those edge domains and has a frequency of 4-6 GHz depending on the applied field. The width of the localization region is much smaller than the lateral size of the element (< 200 nm). Due to high magnetic susceptibility in the region of the mode localization the mode amplitude caused by thermal fluctuation is much higher than that of the quantized modes. The experimental observation of a new mode is confirmed by a theoretical analysis, based on the solution of a non-local dipole problem, as well as by numerical simulations. If the distance between the elements in an array approaches a value comparable with their thickness, the dipole-dipole interaction between the elements becomes measurable. Due to this interaction the phase locking of the spin waves of neighboring elements takes place: spin fluctuations in different elements are correlated. Thus, a collective spin wave mode propagating through the array of magnetic elements is created. @FootnoteText@@footnote 1@J. Jorzick et al. Phys. Rev. B, 60 (1999) 15194.

9:40am **MI+EL-TuM5 In-situ Characterization of Spin-dependent Scattering Mechanisms in GMR Spin Valves*, W.E. Bailey*,** *S.E. Russek,* NIST, Boulder **INVITED**

Although giant magnetoresistance (GMR) is widely used in magnetic recording, the relative importance of electronic scattering locations which contribute to--or limit--the effect is not generally agreed upon. The technologically important case of the Co/Cu/Co "spin-valve" trilayer is particularly rich since questions of surface scattering and possible channeling effects in the current-in-plane geometry (CIP-GMR) may be considered along with older questions of bulk vs. interface spin-dependent scattering. The role of surface scattering is crucial since it is widely believed that its reduction, through specularity enhancement, could provide a three- to tenfold enhancement of the spin-valve GMR. We have developed the in-situ magnetoresistance measurement as a method to locate scattering centers in the spin valve and to provide additional information on their nature. Film conductance and GMR are measured in-situ, in UHV, and in real time during magnetron sputtering, allowing the effects of interfaces and surfaces on scattering to be identified as they are created. Results from two sets of experiments will be presented. First, the onset of GMR has been investigated in NiO/Co(30)/Cu(30 Å)/Co(t) spin valves with ultrathin free layers. A main contribution to GMR is attributable to the interface alone, with a conductance response suggestive of the formation of a channeling state. Second, the response of GMR to surface treatment has been measured during coverage of NiO/Co(30)/Cu(30 Å)/Co(t) spin valves with noble metals and nano-oxide layers ("NOL"). The results in these cases do not match well with simple models of surface diffuse scattering or its reduction, and may be incompatible with them.

10:20am **MI+EL-TuM7 Highly Spin-Polarized Materials*, C.L. Chien*,** Johns Hopkins University **INVITED**

Magnetic heterostructures of highly spin polarized materials provide opportunities for the exploration of new physical phenomena and the development of spintronic devices where both charge and spin of electrons are exploited. Materials with spin polarizat ion (P) higher than those of traditional ferromagnets (P < 45% for Fe, Co, and Ni), and especially half-metallic ferromagnets with P = 100%, are highly desirable. We describe the measurements of the intrinsic spin polarization of half-metallic CrO2 with P = 96% and the unique magnetic and other electronic properties of these single-crystal CrO2 films, epitaxially grown on TiO2 substrates by chemical vapor deposition.

11:00am **MI+EL-TuM9 Characterization of a New Half-Metallic Ferromagnet: Yb@sub 14@MnSb@sub 11@*, A.P. Holm*,** *S.M. Kauzlarich,* University of California, Davis*; S.A. Morton, G.D. Waddill,* University of Missouri-Rolla*; W.E. Pickett,* University of California, Davis*; J.G. Tobin,* Lawrence Livermore National Laboratory

Utilizing a combination of bulk magnetization and magnetic X-ray circular dichroism measurements (MXCD), we demonstrate that Yb@sub 14@MnSb@sub 11@ is a half-metallic ferromagnet. The compound is isostructural to Ca@sub 14@AlSb@sub 11@, with the Mn occupying the Al site in the [AlSb@sub 4@]@sup 9-@ discrete tetrahedral, anionic unit. Bulk magnetization measurements exhibit an effective moment of 4.86 ± 0.02 µ@sub B@/ formula unit implying a Mn@sup 3+@, high spin d@sup 4@ state, but theoretical calculations suggest Mn is divalent with one hole in the Sb 5p states of the tetrahedron. MXCD measurements reveal that the Mn L@sub 23@ is strongly dichroic, and there is no evidence of any dichroism in either the Yb N@sub 45@ or Sb M@sub 45@ edges. Comparisons of the Mn spectra with the theoretical models for Mn@sup 2+@ show excellent agreement, and support the bulk magnetization measurements. The bulk magnetization measurements clearly show full spin alignment and the cancellation of one spin by the unpaired and antialigned spin in the Sb 5p band.

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+EL-TuA

Spintronics II: Spin Injection & Transport

Moderator: B.T. Jonker, Naval Research Laboratory

2:00pm **MI+EL-TuA1 III-V Based Epitaxial Magnetic Heterostructures: Large Tunneling Magneto-Resistance***, **M. Tanaka,*** University of Tokyo, Japan **INVITED**

Tunneling magnetoresistance (TMR) is one of the most important phenomena for future spin-electronics devices. Here, we present very large TMR (>70%) in all-semiconductor magnetic tunnel junctions (MTJs), having (GaMn)As ferromagnetic electrodes separated by an ultrathin AlAs tunnel barrier.@footnote 1@ Trilayer heterostructures, (Ga@sub 1-x@Mn@sub x@)As(x=0.04, 50nm)/AlAs(d nm)/(Ga@sub 1-x@Mn@sub x@)As (x=0.033, 50nm), were grown on p@super +@GaAs substrates by low-temperature MBE. Mesa etched MTJs with the barrier thickness d ranging from 1.3nm to 3.0nm were fabricated, and showed clear TMR due to the change from parallel to anti-parallel magnetization of the two ferromagnetic (GaMn)As layers. Very high TMR ratios up to 75 % were observed at 8K for the junction with d=1.5nm. For d@>=@1.6nm, the TMR ratio was found to decrease with the barrier thickness. This behavior can be explained by calculations assuming that the wavevector k// of carriers is conserved in tunneling. This means that conventional Julliere's model is not valid in such epitaxial MTJs. Also, we have found that the TMR behavior strongly depends on the applied magnetic field direction, which is well explained by the cubic magneto-crystalline anisotropy of GaMnAs.@footnote 2@ Unlike the conventional MTJs made of polycrystalline ferromagnetic metals and an amorphous tunnel barrier, the present MTJs are all-epitaxial monocrystalline semiconductor-based junctions, which have the following advantages: (1) MTJs made of all-semiconductor heterostructures can be integrated with semiconductor circuitry. (2) Many parameters, such as the barrier height, barrier thickness, and Fermi energy of the electrodes, are controllable. (3) Introduction of quantum heterostructures, such as resonant tunneling structures, will be easier than any other material system. @FootnoteText@ @footnote 1@ Y. Higo and M. Tanaka, Physica E (2001), in press. @footnote 2@ Y. Higo and M. Tanaka, J. Appl. Phys. (2001), in press.

2:40pm **MI+EL-TuA3 Spin Filtering and Tunneling Magnetoresistance in Double Barrier Magnetic Heterostructures***, **A.G. Petukhov,** D.O. Demchenko, A.N. Chantis,* South Dakota School of Mines and Technology

We report the results of our theoretical studies of spin-dependent resonant tunneling of holes in GaMnAs-based double-barrier magnetic heterostructures. Our approach is based on the k.p Hamiltonian with exchange-field parameters obtained from first-principle calculations and on multi-band transfer matrix technique. Zeeman splittings of the light hole (LH1) and heavy hole (HH2) resonant peaks are the most striking features of the calculated I-V characteristics of the structures with magnetic emitters. This finding is in good agreement with experimental data by H. Ohno et al.@footnote 1@ The splittings of other resonant channels are smeared due to various bandstructure effects. The resonant tunneling through magnetic quantum wells in GaAs/AlAs/GaMnAs/AlAs/GaAs resonant tunneling diodes displays even more pronounced Zeeman splittings of the resonant channels. These splittings strongly depend on the orientation of the magnetization. The spin polarization of the transmitted current is also quite significant and can be controlled by an external bias. This spin-filtering effect also leads to tremendous enhancement of tunneling magnetoresistance at small biases. @FootnoteText@ @footnote 1@H. Ohno et al., Appl. Phys. Lett. 73, 363 (1998).

3:00pm **MI+EL-TuA4 Magnetotransport in Digital Ferromagnetic Heterostructures***, **T.C. Kreutz,** G. Zanelatto, R. Kawakami, E. Johnston-Halperin, E.G. Gwinn, A.C. Gossard, D.D. Awschalom,* University of California, Santa Barbara

Recent studies of digital ferromagnetic heterostructures (DFH), in which fractional monolayers (ML) of MnAs alternate with interlayers of low temperature (LT) GaAs, have shown that the Curie temperature, Tc, is sensitive to the separation between MnAs sheets.@footnote 1@ We report studies of in-plane magnetotransport in these structures, for Be-doped and nominally undoped LT GaAs interlayers with thicknesses from 10 to 40 ML. For undoped DFH grown at 260 C, structures with 10 ML interlayers show an anom alous Hall effect, while structures with 20 and 40 ML interlayers show only the ordinary Hall effect. The decrease in Tc with increasing interlayer thickness is accompanied by a decrease in the Hall carrier density and mobility. The magnetoresistance of the 10 ML sample has a similar field dependence to bulk GaMnAs. The 20 and 40 ML magnetoresistances are qualitatively different. Effects of Be doping are also considered for DFH samples.. @FootnoteText@ @footnote 1@ R.K. Kawakami, et al APL 2379 (2000).

3:20pm **MI+EL-TuA5 Theoretical Band Offsets in Magnetic Semiconductor Heterostructures: CdCr@sub 2@Se@sub 4@ on Si and GaAs***, **J.M. Sullivan**, S.C. Erwin,* Naval Research Laboratory

Ferromagnetic semiconductors grown on semiconductor substrates are being widely investigated as spin injection sources for spintronics applications. Of the many issues critical to the injection efficiency, the band offset plays a central role. In particular, band offsets provide a direct link between microscopic parameters which can be determined theoretically, and macroscopic properties which can be measured experimentally. Moreover, magnetic band offsets can be tuned by methods well known from traditional band-offset engineering, and thus will be important for efforts to optimize injection efficiencies. Here we present first-principles results for the magnetic band offsets in heterostructures consisting of CdCr@sub 2@Se@sub 4@, an n-type ferromagnetic semiconductor with a Curie temperature of 130 K, grown on Si and GaAs substrates. We first use density-functional total-energy methods to explore and identify stable and metastable interface structures, taking into consideration different interface terminations, intermixing, and polar vs. non-polar interfaces. For the thermodynamically favorable interfaces we then apply standard first-principles methods@footnote 1@ for calculating the band offsets. Finally, we present detailed comparisons to recent experiments@footnote 2@ for these heterojunctions. @FootnoteText@ @footnote 1@ A. Franciosi and C. G. Van de Walle, Surf. Sci. Rep. 25, 1 (1996). @footnote 2@ D. Park et al., unpublished. .

3:40pm **MI+EL-TuA6 Effects of Interface Structure and Chemistry on Spin Injection Efficiency in Spin-LEDs***, **R.M. Stroud**, Y.D. Park, A.T. Hanbicki, B.R. Bennet, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, M. Furis, G. Kioseoglou, A. Petrou,* SUNY Buffalo

The efficiency of spin injection across a heterointerface can be strongly affected by the structure and chemistry of that interface. To quantify the relationship between interface quality and spin injection efficiency, spin-LEDs make an ideal test system. In a spin-LED, carriers with a net spin polarization are injected into a LED, where radiative recombination results in circularly polarized light emission. The optical circular polarization directly reflects the degree of the spin polarization of the injected current. By varying the growth conditions to vary the quality of the interface for ZnMnSe/AlGaAs/GaAs/AlGaAs spin-LEDs, injection efficiencies of 0 to 65% have been achieved. In this system, the primary structural defect, identified by cross sectional transmission electron microscopy, is a stacking fault that nucleates at the ZnMnSe/AlGaAs interface. Stacking fault densities ranged from 10@super 10@ cm@super -2@ for the lowest efficiency samples to < 10@super 8@ cm@super -2@ for the 65% efficiency sample., The optical polarization scales with the stacking fault density, which indicates that the spin injection efficiency is affected by the ZnMnSe/AlGaAs interface structure and chemistry. We compare results for growth on As- and Ga-terminated AlGaAs surfaces, and for structures grown with a Zn- and Se-initiated growth of the ZnMnSe polarized contact layer. These results demonstrate that although the spin injection efficiency is sensitive to interface quality, the spin injection effect is robust enough in all-semicondutor spin-LEDS to withstand moderately high defect densities, and can be produced using pre-grown LEDs. @FootnoteText@ @footnote 1@ This work supported by ONR and the DARPA SpinS program.

4:00pm **MI+EL-TuA7 Recent Developments in Spin Electronics***, **A. Fert,*** Université Paris-Sud, France **INVITED**

My talk reviews recent developments of the research in spin electronics at Unité Mixte de Physique in Orsay. I will focus on the three following topics: 1)Magnetization reversal by injection of a spin-polarized current: After an introduction on the effect predicted by Slonczewski (and also Berger), I will present experimental results obtained on pillar-shaped trilayers (collaboration with LPN-CNRS and University of Brest) and I will describe the pending problems in the understanding of the spin transfer mechanisms generating the reversal. Current-induced reversal could lead to general applications for the switching of spin electronic devices and I will present the perspective in this direction. 2)Magnetic tunnel junction (MTJ): Although applications of the magnetoresistance (TMR) of MTJ are already around the corner, physics of spin-polarized tunneling is still far from being clearly understood. I will present experimental results on epitaxial (single crystal) MTJ which shed light on the physical mechanisms of TMR. 3)Spin injection into semiconductors: the development of devices combining ferromagnets and semiconductors is an important challenge in spin electronics. I will present a model clearing up the conditions for efficient spin injection from a ferromagnetic metal into a semiconductor.

4:40pm **MI+EL-TuA9 Structural and Optical Characterization during Growth of Co on Ga@sub 1-x@In@sub x@As(001)**, ***K. L@um u@dge***[1], Technische Universität Berlin, Germany & University of Minnesota; *P. Vogt,* Technische Universität Berlin, Germany; *B.D. Schultz,* University of Minnesota; *C.J. Palmstrom,* University of Minnesota, United States; *W. Braun,* BESSY; *N. Esser, W. Richter,* Technische Universität Berlin, Germany

The growth of magnetic overlayers on semiconductors has received considerable interest due to their potential use in spintronic devices. The interface between the ferromagnet and semiconductor is critical to spin polarized transport across the interface. Thus, it is important to determine dependence of the interfacial structure and the crystalline quality of the ferromagnetic film on the substrate temperature and surface reconstruction. The initial growth of Co on GaAs(001) has been studied using STM, PES and reflectance anisotropy spectroscopy (RAS). The Co tends to be disordered when grown at room temperature. However, crystalline islands are observed at a substrate temperature of 430 K. STM-images taken during Co deposition show, that the substrate surface morphology does not change during deposition despite the change in surface reconstruction. The initial growth on the As-rich c(4x4) surface is different from the growth on the c(8x2) Ga-rich reconstruction. For growth on the c(8x2) surface two different growth modes can be distinguished. At first Co-atoms are adsorbed into rows to form one-dimensional chains. Further deposition results in epitaxial cubic islands. The PES data indicate two metallic components in the Ga3d core level. One is interpreted as resulting from CoxGay and the other from metallic Ga. The As3d core level contains two different components leading to the conclusion of As-Co bonds at the interface and access As on top. The influence of lattice mismatch on the structural and magnetic properties of the epitaxial Co-layer will be studied by Co growth on Ga@sub 1-x@In@sub x@As(001).

5:00pm **MI+EL-TuA10 Structural and Magnetic Characterization of the Fe@sub x@Co@sub 1-x@ / GaAs(100) Interface**, ***B.D. Schultz***[2], *L.C. Chen, A. Isakovic, J. Strand, P.A. Crowell,* University of Minnesota; *M.M.R. Evans,* University of Wisconsin-Eau Claire; *C.J. Palmstrom,* University of Minnesota

Two distinct surface contributions to the magnetic anisotropy can be used to control the magnetic properties of thin films of bcc Fe@sub x@Co@sub 1-x@ grown on GaAs (100). On bare GaAs (100), the sp@sup 3@ bonding in the zincblende structure results in a two-fold surface symmetry of the gallium and arsenic bonding and a (2x4)/c(2x8) surface reconstruction for an arsenic surface coverage ~0.75 monolayers. This two-fold surface symmetry reduces the expected cubic four-fold magnetic anisotropy for Fe@sub 1-x@Co@sub x@ films to a strong uniaxial magnetic anisotropy. However, four-fold symmetry is restored in films grown with an interlayer of Sc@sub 1-y@Er@sub y@As(100), in which the rock-salt structure provides an unreconstructed surface. Initial STM images of 0.10 monolayer deposited Fe@sub x@Co@sub 1-x@ on GaAs(100) (2x4)/c(2x8) surface grown by MBE at 95°C indicate isolated clusters of atomic dimensions with preferential attachment along the arsenic dimer rows. The images also indicate that the (2x4)/c(2x8) reconstruction remains relatively undisturbed by the initial nucleation and growth at this coverage. The deposition of bcc Fe@sub x@Co@sub 1-x@ on Sc@sub y@Er@sub 1-y@As(100) indicates there is no preferred nucleation site for the Fe@sub x@Co@sub 1-x@ atoms on the unreconstructed surface. Control of the interfacial properties of ferromagnetic metals and semiconductors is important for optimizing spin dependent transport across these interfaces. Spin dependent ejection of photo generated carriers from GaAs(100) into Fe@sub x@Co@sub 1-x@ ferromagnetic metal contacts has recently been observed. This paper will emphasize the correlation between the structure and chemistry of the Fe@sub x@Co@sub 1-x@/GaAs and Fe@sub x@Co@sub 1-x@/Sc@sub 1-x@Er@sub x@As/GaAs interfaces, determined by STM, RHEED, LEED, XPS, RBS, XRD and TEM, and the magnetic and transport properties. Supported by: ONR-N/N00014-1-0233, DARPA N/N00014-99-1-1005, and NSF-MRSEC NSF/DMR-9809364.

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[1] **Falicov Student Award Finalist**

[2] **Falicov Student Award Finalist**

Magnetic Interfaces and Nanostructures
Room 134/135 - Session MI-TuP
Emerging Materials & Nanostructures Poster Session

MI-TuP1 Structural, Electronic and Magnetic Properties of Chalcopyrite Magnetic Semiconductors: A First Principles Study*, **S. Picozzi,*** Univ. L'Aquila, Italy*; A. Continenza,* INFM - Univ. L'Aquila, Italy*; W.T. Geng, Y.J. Zhao, A.J. Freeman,* Northwestern University

Stimulated by recent experimental observations of room--temperature ferromagnetism of Mn@sub x@Cd@sub 1-x@GeP@sub 2@, we investigate the structural, electronic and magnetic properties of chalcopyrite systems as a function of Mn concentration by means of the first--principles density-functional-theory-based FLAPW (H.J.F.Jansen and A.J.Freeman, Phys. Rev. B 30, 561 (1984).) code. These new materials transcend the limitations (such as defect formation, and too low operating temperatures for spin injection and ferromagnetic properties) of the magnetic zinc-blende systems explored so far (e.g. Ga@sub x@Mn@sub 1-x@As) for spintronics applications. We investigate the effect of the anion (P vs As) and cation (Cd vs Zn) substitution in Mn-doped systems. Our calculations indicate that the antiferromagnetic alignment is the most stable ordering for the Mn-rich systems, at variance with that experimentally reported. Moreover, we focus on the dependence of the total magnetic moment per Mn atom and of the band gaps as a function of the Mn concentration in the different systems.

MI-TuP2 Component-resolved Electroluminescence from Spin-LED Structures: Implications for Quantifying Electrical Spin Injection in Semiconductors*, **B.T. Jonker**, A.T. Hanbicki, Y.D. Park, B.R. Bennett,* Naval Research Laboratory*; M. Furis, G. Kioseoglou, D. Coffey, A. Petrou,* State University of New York, Buffalo

The spin-polarized light emitting diode (spin-LED)@footnote 1@ has emerged as a very effective tool for accurately quantifying electrical spin injection in a model independent manner.@footnote 2@ The quantum selection rules which describe the radiative recombination process provide a direct and quantitative link between the circular polarization of the electroluminescence (EL) and the spin polarization of the electrically injected carriers. While these selection rules apply only to the free exciton and free carrier radiative recombination, the EL spectrum often consists of contributions from various recombination processes whose relative spectral weighting depends upon details of the LED heterostructure, such as doping, impurities and interface roughness. Common contributions include donor and acceptor-bound excitons, phonon replicas, and recombination mediated by various impurity levels or complexes. These components may completely dominate the spectrum in many instances. We resolve and identify such components in the EL spectra from several GaAs quantum well-based spin-LED structures by correlating reflectivity measurements with their dependence on doping, temperature and magnetic field, and examine the circular polarization of each. We show that these components exhibit markedly different polarizations which do not accurately reflect the electrical spin injection efficiency. Certain of these features derive from many-body effects, and may provide insight into related spin relaxation processes. We show that a reliable measure of spin injection efficiency can be obtained only if one takes care to spectroscopically resolve and accurately identify the origin of the components of the spin-LED EL spectrum. This work was supported by the DARPA SpinS program and ONR. . @FootnoteText@ @footnote 1@ B.T. Jonker, US patent # 5, 874,749 (filed 1993, issued 1999). @footnote 2@Fiederling, et al, Nature 402, 787 (1999), Jonker, et al. PRB 62, 8180 (2000), Park et al, APL 77, 3989 (2000).

MI-TuP3 Magnetic and Structural Properties of Fe- and Mn-Implanted SiC*, **N. Theodoropoulou**, A.F. Hebard,* University of Florida*; S.N.G. Chu,* Bell Laboratories, Lucent Technologies*; M.E. Overberg, C.R. Abernathy, S.J. Pearton,* University of Florida*; R.G. Wilson,* Consultant*; J.M. Zavada,* U. S. Army European Research Office, UK

P-type 6H-SiC substrates were implanted with Mn@super +@ or Fe@super +@ at doses of 3-5x10@super 16@ cm@super -2@ under conditions that avoided amorphization (substrate temperate ~350°C). After annealing at 700-1000°C, the magnetic properties of the samples were examined by SQUID magnetometry. The Mn-implanted SiC did not show any magnetization, remaining paramagnetic, but the Fe-implanted samples showed ferromagnetic properties below 200 K for the highest dose employed. The origin of the ferromagnetism is not the formation of secondary phases involving precipitation of the Fe. Results for Ni and Co implantation will also be presented, along with a comparison of data for implantation of the same elements into p-GaN epitaxial layers.

MI-TuP4 Magnetism and Transport in Manganite-based Trilayers A/B/A (A: La@sub 0.6@Sr@sub 0.4@MnO@sub 3@; B: La@sub 0.9@Sr@sub 0.1@MnO@sub 3@, La@sub 0.67@Ca@sub 0.33@MnO@sub 3@)*, **L.B. Steren**, M. Sirena, M. Granada, J. Guimpel,* Centro Atomico Bariloche and Instituto Balseiro, Argentina

We have studied the physical and structural properties of trilayers based on manganites compounds. Different ferromagnetic spacers, insulator (B1) and metallic (B2), have been used in order to compare the magnetotransport effect and interlayer coupling of both systems. Thin films and trilayers have been grown by dc sputtering. Films of La@sub 0.6@Sr@sub 0.4@MnO@sub 3@ ("A"}), La@sub 0.67@Ca@sub 0.33@MnO@sub 3@ ("B2") and La@sub 0.9@Sr@sub 0.1@MnO@sub 3@ (``B1"}) with thickness varying from 5nm to 50nm have been first prepared in order to study the intrinsic properties of these materials. "A" thin films are ferromagnetic with a Curie temperature around room temperature. These manganites present a metal-insulator transition below T@sub C@ and exhibit colossal magnetoresistance. A similar behaviour has been found in the "B2" films, with lower characteristic temperatures. "B1" are also ferromagnetic but present different transport properties : They are insulators between 4.2K and room temperature. All the compounds preserve its general properties, even for the smaller thicknesses. However, an important depression of the Curie point is observed as the films thickness is decreased. The trilayers have been prepared with different A and B thicknesses (10 nm <th@sub A@<50nm and 5 nm <th@sub B@< 15 nm). Strongly textured X-ray difraction patterns have been observed in the heterostructures. The magnetic coupling between A layers has been studied through temperature and field dependence of magnetization curves. Remanent magnetization curves show a single ferromagnetic transition around 200K. A metal-insulator transition is observed below the Curie point. Both results suggest a ferromagnetic coupling of the system. However, the role of the ferromagnetic spacer in the coupling cannot be explained by these measurements only. Complementary measurements of ferromagnetic resonance are under progress in order to better understand the interlayer coupling in these systems.

MI-TuP5 Observation of the Two-stage Magnetic Transition and the CMR Effect in Aged La@sub 0.5@Sr@sub 0.5@CoO@sub 3-@@delta@ Films Prepared by Laser Ablation*, **V.G. Prokhorov**,* Institut of Metal Physics, Ukraine*; J.S. Park, S.Y. Park, Y.P. Lee,* Hanyang University, Korea*; K.W. Kim,* Sunmoon University, Korea*; V.M. Ishchuk,* Insitute of Single Crystals, Ukraine*; I.N. Chukanova,* Institute of Single Crystals, Ukraine

The magnetic and transport investigations have been carried out for the as-deposited and the long-time aged La@sub 0.5@Sr@sub 0.5@CoO@sub 3-@@delta@ films prepared by pulsed laser deposition. It was shown that a decrease in the oxygen concenturation during aging of the film leads to the tetragonal distortion of the crystal lattice, to a shift of the metal-insulator transition temperature to a lower temperature(T@sub p@ = 250 K), and to the observation of a CMR effect (up to 3 % at magnetic field of 5 T). In addition to the usual ferromagnetic transition at T@sub c@ = 250 K, the second magnetic transition was observed at T@sub M@ = 50 K that is treated as the appearance of a cluster glass magnetic state. The non-monotonic behavior of the resistance observed in the low-temperature range, T < T@sub p@, is explained by the weak localization of the carriers.

MI-TuP8 Temperature Dependence of Line Width of Ferromagnetic Resonance in Nickel-Zinc Ferrites*, **S.C. Byeon**,* University of Alabama, US*; C. Alexander,* University of Alabama*; H.B. Hong, T.Y. Byun,* Seoul National University, Korea*; C.K. Kim,* Hanyang University, Korea*; K.S. Hong,* Seoul National University, Korea

The systematic temperature dependence in line width of ferromagnetic resonance with the Fe content was observed at X band (9.78GHz) in (Ni@sub 0.5@Zn@sub 0.5@)@sub 1-x@Fe@sub 2+x@O@sub 4@ (-0.2@<=@x@<=@0.2). The line width of the stoichiometric composition (x = 0) showed minimum value, 50 Oe. In contrast, the line width of the non-stoichiometric compositions sharply increased to 210 Oe with increasing non-stoichiometry (x). The mechanism for this line width broadening was investigated using thermoelectric power and electrical resistivity, since the contribution of anisotropy and porosity to the line width was negligible in this compositional region. In Fe excess region, Fe@super 2+@ ion concentration increased with increasing Fe content, resulting in line width broadening due to relaxation. But, it was suggested that Ni@super 3+@ and Fe@super 2+@ ions coexist in Fe deficient region. Therefore the increase of line width in nickel-zinc ferrites originated from the Fe@super 2+@/Fe@super 3+@ magnetic relaxation in Fe excess region, and the Fe@super 2+@/Fe@super 3+@, Ni@super 2+@/Ni@super 3+@ magnetic relaxation in Fe deficient region.

MI-TuP9 Magnetic Circuits for Atomic Matter Waves*, M. Vengalattore, W. Rooijakkers,* Harvard University*; S.A. Lee,* Colorado State University*; T. Deng, G.M. Whitesides, M. Prentiss,* Harvard University

Atom optics is an important branch of physics in which the quantum nature of atoms is exploited to realize systems equivalent to photonics. An example is the (single mode) atomic waveguide as compared to the (single mode) optical fiber. Another example is the atom laser, based on matter wave amplification, realized in 1997.@footnote 1@ The production of these matter waves, which are coherent over distances > 10 cm has facilitated applications such as interferometry. Since atoms have a much larger mass than electrons or photons, they offer the unique possibility of doing ultrasensitive gravitational field measurements. Furthermore, since the interactions can be controlled, neutral cold atoms provide a promising system for quantum computation. Following the integration in optics and electronics it makes sense to pursue miniaturization of atom-optical systems. This will allow for the realization of more complex functions on a relatively small surface. Arguably magnetic field gradients provide the most versatile means for non-dissipative manipulation of atoms. In this paper we describe a newly developed waveguide for coherent transport of atoms and possible future applications of this technology. Our waveguide consists of four parallel strips of ferromagnetic material, wound with kapton isolated wire. This configuration results in a magnetic field minimum above the surface. The position of this minimum can be controlled by varying the currents in the wires. Weak field seeking atoms can be trapped in this minimum by using laser cooling techniques, forming a magneto optical trap (MOT).@footnote 2@ Atoms from the background vapor are decelerated by laser beams and accumulate in the magnetic minimum. To provide damping in all directions the surface above the magnetic strips has been made reflective with a gold layer. In our experiment we use diode lasers with a wavelength of 852 nm to cool @super 133@Cesium atoms. The fluorescence of the atoms can be imaged onto a CCD camera. We have created very long (aspect ratio 1:500) and thin (20 mm) clouds. In our waveguide we obtain a gradient of 3 kG cm@super -1@ A@super -1@, and by further miniaturization we anticipate a further increase by a factor 10@super 3@. The next step is fabricating more complex structures. One example is the quantum point contact: a constriction through which the conductance of matter waves shows steps as a consequence of the quantum mechanics.@footnote 3@ Another example is a magnetic storage ring for atoms. Connecting up both ends of our waveguide seems a logical extension of our previous work. We are pursuing the propagation of matter waves in such a device, which may then be used as an interferometer for ultrasensitive inertial sensing. Presently we use mu-metal sheet to construct these devices. Alternatively we have also been using lithography@footnote 4@ and permalloy deposition. We continue our search for materials capable of generating large magnetic field gradients on a small substrate with the possibility of designing complex circuits for ultracold atoms. @FootnoteText@@footnote 1@M. Andrews, C. Townsend, H-J Miesner, D. Durfee, D. Kurn and W. Ketterle, Science 275, 637 (1997). @footnote 2@E. Raab, M. Prentiss, A. Cable, S. Chu and D.E. Pritchard, Phys. Rev. Lett. 48, 596 (1982). @footnote 3@J. H. Thywissen, R.M. Westervelt and M. Prentiss, Phys. Rev. Lett. 83, 3762 (1999). @footnote 4@N. H. Dekker, C. S. Lee, V. Lorent, J. H. Thywissen, S. P. Smith, M. Drndic, R. M. Westervelt and M. Prentiss, Phys. Rev. Lett. 84, 1124 (2000).

MI-TuP10 Investigation of MFM Tip Induced Magnetization Reversal of Magnetic Nanostructures*, X. Zhu, P. Grutter,* McGill University, Canada*; V. Metlushko,* University of Illinois at Chicago*; B. Ilic,* Cornell University

Magnetic Force Microscopy (MFM) has become a standard technique to study the magnetic reversal of nanoparticles. However, the magnetic tip stray field contribution to the reversal characteristics has not been systematically investigated. Here we compare data obtained in different operation modes of MFM such as tapping/lift mode or non-contact mode. We investigated e-beam patterned permalloy arrays with nominal thickness of 30nm, with aspect ratios of 1:1 up to 10:1, with widths of 100nm, 150nm and 200nm, and different spacing. Si cantilevers coated with 10nm to 90nm of CoPtCr, NiFe or NiCo are used as magnetic probes. Previously, we have found that the particle moment can easily be reversed when MFM measurements are performed in tapping and lift mode.@footnote 1@ This is associated with the fact that during tapping the tip stray field can be very substantial during part of the tip oscillation cycle. In the present study, we performed MFM measurements in the non-contact mode in our homebuilt vacuum MFM to further characterize how the magnetic tip influences the magnetic sample state. For large tip-sample separation (typically >100nm), and for large aspect ratio particles, we found that the magnetized tip very seldom reverses particle moments. These particles mainly form single domains due to their shape anisotropy. Within a few (

MI-TuP11 Magnetic Anisotropy in Epitaxial Fe(001) Micrometric Squares by Magneto Optical Torque*, D. Jaque,* Universidad Complutense de Madrid, Spain*; G. Armelles,* Instituto de Microelectrónica de Madrid, CNM-CSIC, Spain*; J.I. Martín,* Universidad de Oviedo, Spain*; P. García-Mochales,* ***J.L. Costa-Krämer****, F. Briones,* Instituto de Microelectrónica de Madrid, CNM-CSIC, Spain*; J.L. Vicent,* Universidad Complutense de Madrid, Spain

Magneto Optic (MO) studies are performed on regular arrays of 200 Å thick Fe (001) epitaxial tiles with different micrometric lateral sizes. MO studies are performed both on reflected and diffracted spots and analyzed in terms of the homogeneity of the magnetization within the tile. These are compared with predictions from micromagnetic simulations. The MO response to a rotating magnetic field (Magneto Optical Torque - MOT)is also measured in these structures, finding a clear evolution from the biaxial crystalline anisotropy towards an uniaxial one as the tile lateral size is reduced at constant thickness.

MI-TuP12 Annealing Effect on Structure and Magnetism of CoNi Pattern Quantum Dots*, **H.L. Li**, C.W. Wang, D.H. Qin, M.K. Li,* Lanzhou University, P. R. China

NiCo alloy nanowires were prepared by AC electrodeposition into self-assembled porous anodic alumina template. Then the sample was annealed at 500 °C, 6 hours, with argon as protected gas. The composition, microstructure and magnetism of samples used in this work were characterized by atom absorbed spectrum, transmission electron microscopy (TEM), scanning electron microscopy (SEM), x-ray diffraction (XRD), and vibrating sample magnetometer (VSM). XRD results showed that there were preferred orientation in CoNi nanowire arrays with Ni content range from 0.2 to 0.8 during electrodeposition, while random orientation was observed after the sample was heat-treated. Though the shape anisotropy was very high in the sample, it is found that the squareness (Mr/Ms) of the hysteresis of the samples (Ni content is in the range of 0.2 to 0.8) was only about 0.6 before annealing, and increased to about 0.9 after annealing. As its high bit density, such media may be used as high-density quantum magnetic disks. A qualitative discussion was given and explanation of reversal mechanism was offered in term of localized magnetization model.

MI-TuP13 Magnetic Coupling in Epitaxial Fe/MgO/Fe Arrays of Micro Tunnel Junctions*, **J.L. Costa-Kramer**, J.V. Anguita,* Instituto de Microelectronica de Madrid, CNM, CSIC, Spain*; J.I. Martin,* Universidad de Oviedo, Asturias, Spain*; C. Martinez-Boubeta, A. Cebollada, F. Briones,* Instituto de Microelectronica de Madrid, CNM, CSIC, Spain

The magnetic properties of planar 100 Fe/ x MgO / 100 Fe epitaxial ferromagnetic micro tunnel junction arrays have been measured for different lateral sizes of the junctions (1-50 Âµm) and barrier thicknesses; (x=10,20,50,70). When the top and bottom electrodes magnetizations are uncoupled, they orient antiparallel in zero field due to the magnetostatic energy gain. On the other hand, the two electrodes magnetizations orient parallel when direct exchange couples them effectively through the barrier, most probably due to a critical density of pinholes. We find that both, lateral size and barrier thickness influence the ratio of junctions with their electrodes magnetization antiparallel to those in which they orient parallel. For a given barrier thickness, there is a threshold below which mostly all of the junction electrodes couple antiparallel. This happens at about 4 Âµm lateral size for electrodes separated by a barrier of 10 MgO (close to only two MgO unit cells). The field ranges where these phenomena occur agree reasonably well with the predictions from a simple analytical model, in which we solve the energetic balance between magnetostatic energy gain and orientational energy loss for our Fe/MgO/Fe sandwich geometry. In addition, and comparing with our previous results with single layer Fe microtile arrays, we confirm the intuitive picture that the micro sandwich structures can be placed closer than the single layer structures before they interact magnetically with their closest neighbors. This is due to a preferred closure of the magnetic flux between top and bottom electrodes in the sandwich structure, reducing considerably the magnetic field at the closest neighbors positions.

Electronics
Room 111 - Session EL+MI-WeM
Spintronics III: Ferromagnetic Semiconductors

Moderator: C.J. Palmstrom, University of Minnesota

8:20am **EL+MI-WeM1 Tailoring Spin Ordering in Magnetic Semiconductors***, **T. Dietl**,* Polish Academy of Sciences, Poland, Warszawa **INVITED**

Recent advances@footnote 1@ in the field of carrier-controlled ferromagnetism in tetrahedrally coordinated diluted magnetic semiconductors and their nanostructures will be reviewed with a focus on the phenomena important for prospective spintronic devices. Experimental results for III-V materials, where the Mn atoms introduce both spins and holes, will be compared to the case of II-VI compounds, in which the Curie temperatures T@sub C@ above 1 K have been observed for the uniformly and modulation-doped p-type structures but not in the case of n-type films. The experiments demonstrating the tunability of T@sub C@ by electrostatic gates as well as by light will be presented. The tailoring of domain structures and magnetic anisotropy by strain engineering and confinement will be discussed emphasizing the role of the spin-orbit coupling in the valence band. The question of designing modulated magnetic structures in low dimensional semiconductor systems will be addressed. Recent progress in search for semiconductors with T@sub C@ above room temperature and hopes associated with materials containing magnetic ions other than Mn will be presented. @FootnoteText@ @footnote 1@ T. Dietl, H. Ohno, F. Matsukura, J. Cibert, and D. Ferrand, Science 287, 1019 (2000); H. Ohno et al., Nature 408, 944 (2000); P. Kossaki et al., Physica E 6, 709 (2000); D. Ferrand et al., Phys. Rev. B 63, 085201 (2001); T. Dietl, H. Ohno, and F. Matsukura, Phys. Rev. B 63, 195205 (2001).

9:00am **EL+MI-WeM3 Dilute Magnetic Semiconductors Based Upon GaP***, **M.E. Overberg**, C.R. Abernathy, S.J. Pearton, N. Theodoropoulou, A.F. Hebard,* University of Florida*; S.N.G. Chu,* Agere Systems*; R.G. Wilson,* Consultant

Dilute magnetic semiconductors (DMS), where a semiconductor host material is heavily doped with magnetic ions, could potentially be used in a variety of interesting applications and devices where the spin degree of freedom of the electron is exploited, such as quantum-based computation, electro-optic switches and modulators, to name a few. Recent theoretical calculations based upon a 5% concentration of Mn have predicted a Curie temperature for (Ga,Mn)P of roughly 100 K.@footnote 1@ The challenge is to incorporate such a large amount of magnetic ions while still maintaining the integrity of the host semiconductor. In this paper, we will report on the growth of (Ga,Mn)P:C thin films by gas source molecular beam epitaxy (GSMBE) utilizing phosphine as the group V source, and co-doped with C via a CBr@sub 4@ source for enhanced p-type doping. Results of the epitaxially grown films will be compared to (Ga,Mn)P films produced via direct implantation of Mn into GaP:C, particularly in regard to the formation of alternate phases and how this correlates with the observed magnetic behavior. X-ray diffraction (XRD) of the epitaxial films indicates the presence of the orthorhombic MnP phase in layers grown at a temperature of 600°C, and in addition the hexagonal Mn@sub 5.64@P@sub 3@ phase in films grown at a temperature of 400°C. At lower temperatures, only the Mn@sub 5.64@P@sub 3@ phase exists. The use of superlattices appears to help suppress the second phase formation, particularly in the low temperature regime. Analysis of the GaMnP:C by SQUID magnetometry suggests the presence of a ferromagnetic phase with a T@sub C@ above 50 K. This behavior is most likely due to the presence of ferromagnetic MnP. In an effort to increase the T@sub C@ above that which is possible when using Mn, the properties of Ni implanted GaP:C will also be presented. @FootnoteText@ @footnote 1@ T. Dietl, H. Ohno, F. Matsukura, J. Cibert, and D. Ferrand, Science, 287, p. 1019 (2000).

9:20am **EL+MI-WeM4 Epitaxial Growth of a Group IV Ferromagnetic Semiconductor: Mn@sub x@Ge@sub 1-x@***, **A.T. Hanbicki**, Y.D. Park, A. Wilson, G. Spanos, B.T. Jonker,* Naval Research Laboratory

Ferromagnetic semiconductors promise to provide spin-dependent functionality to the well-established technology of semiconductor device heterostructures. While much effort has focused on the III-Mn-V materials such as GaMnAs, where hole density is believed to play a critical role, the origins of ferromagnetic (FM) order remain elusive. This is due in part to complications arising from use of compound semiconductor hosts. Mean field calculations predict that FM order should be stabilized in many other semiconductor materials, if certain Mn concentrations and hole densities can be realized.@footnote 1@ We have chosen one of the simplest semiconductor hosts, Ge, in which to investigate and better understand such effects. We report here the epitaxial growth of the first Group IV ferromagnetic semiconductor, Mn@sub x@Ge@sub 1-x@, and describe the structural, magnetic, and magneto-transport properties. Single crystal films were grown for x < 0.1 on GaAs(001) and Ge(001) substrates by MBE at low substrate temperatures from elemental sources. RHEED and x-ray diffraction confirm crystallinity and orientation. Samples exhibit hysteretic M vs H loops with significant remanence, and coercivities of several hundred Gauss. Curie temperatures range from 30 to 120 K with increasing Mn concentration, as determined from SQUID magnetometry. Films exhibit a non-metallic temperature dependent resistivity, as well as a pronounced extraordinary Hall effect. They are strongly p-type with hole densities of 10@super 19@ - 10@super 20@ cm@super -3@. Gated structures confirm that the hole density can be varied. Results will be presented on efforts to toggle ferromagnetism by application of a gate voltage at temperatures significantly higher than recently reported for InM nAs.@footnote 2@ This work was supported by the DARPA SpinS program and ONR. @FootnoteText@ @footnote 1@ T. Dietl, et al., Science 287, 1019 (2000). @footnote 2@ H. Ohno et al, Nature 408, 944 (2000).

9:40am **EL+MI-WeM5 Metalorganic Chemical Vapor Deposition of ZnO-based Diluted Magnetic Semiconductors***, **A.C. Tuan**[1],* University of Washington*; D. McCready, S. Thevuthasan, J.W. Rogers, Jr., S.A. Chambers,* Pacific Northwest National Laboratory

One of the most attractive means of adding the electron-spin degree of freedom to electronic and photonic devices is by spin injection and transport in semiconducting structures involving ferromagnetic metals or ferromagnetic dilute magnetic semiconductors (DMSs), as spin injectors. A great deal of work has been done in this area and thus far, DMSs have proven to be more efficient spin sources than ferromagnetic metals. This is because the conductivities of DMSs are better matched to those of the channel material. However, because of the very low ferromagnetic ordering temperature of current DMSs, efficient spin injection is only observed at cryogenic temperatures. A recent calculation predicts that heavily nitrogen-doped Mn@sub X@Zn@sub 1-X@O will exhibit a Curie temperature of ~320K,@footnote 1@ and serves as partial motivation for this work. We have grown Mn@sub X@Zn@sub 1-X@O films by metalorganic chemical vapor deposition (MOCVD), using a direct liquid injection system and @beta@-diketonate metal sources. Rutherford backscattering spectrometry (RBS) and X-ray photoelectron spectroscopy (XPS) show that compositions ranging from pure ZnO to ~Mn@sub 0.30@Zn@sub 0.70@O are achievable on Al@sub 2@O@sub 3@(0001) substrates, without carbon contamination. X-ray diffraction (XRD) was used to confirm that there was no phase segregation. XRD also indicated that all films grown below 500 °C had a preferred (0001) orientation, while epitaxy of ZnO was possible at 575 °C on both Al@sub 2@O@sub 3@ (0001) and ZnO(0001). Preliminary attempts at nitrogen incorporation show that NH@sub 3@ is a promising nitrogen source. @FootnoteText@ @footnote 1@T. Dietl, H. Ohno, F. Matsukura et al., "Zener model description of ferromagnetism in zinc-blende magnetic semiconductors," Science 287, 1019-22 (2000).

10:00am **EL+MI-WeM6 Heterostructures of Mn/GaN and MnGa/GaN Grown by ECR-Plasma Assisted MBE***, Y. Cui, **L. Li**,* University of Wisconsin

Ferromagnetic semiconductor GaMnN is very promising for developing spintronic devices.@footnote 1@ To investigate the mechanism of Mn incorporation in GaN, we have grown digital heterostructures by alternately depositing GaN (10 to 50 monolayers) and monolayer of either Mn or MnGa using ECR plasma assisted molecular beam epitaxy. The heterostructures are grown on 6H-SiC(0001) substrate with plasma power of 30 W at 550 °C. Adsorption and desorption of the Mn and MnGa on the non-growing surface, surface reactions and reconstruction are monitored by reflection high-energy electron diffraction (RHEED) and in situ scanning tunneling microscopy (STM). All the surfaces immediately following MBE are composed of spiral hillocks, with the edges of the spirals form bilayer steps. On the terraces, a gallium rich (1x1) structure is observed with a lattice spacing of 3.2 Å. At temperatures between 500 and 550 °C, deposition of approximately 1 ML of Mn on this surface results in a domain superstructure with a periodicity of ~ 32 Å. Within the domains the surface atoms are in (@sr@3x@sr@3) geometry. By closely monitoring the surface reconstruction present during MBE, heterostructures with high crystalline quality are grown, as confirmed by high-resolution x-ray diffraction. These

[1] **Falicov Student Award Finalist**

results and their implications for Mn doping of GaN will be presented at the meeting. This research is supported by NSF DMR-0094105. @FootnoteText@@footnote 1@T. Dietl et al., Science 287, 1019 (2000).

10:20am **EL+MI-WeM7 Epitaxial Growth of GaMnN**, ***G.T. Thaler***, *M.E. Overberg, C.R. Abernathy, S.J. Pearton, N. Theodoropoulou, A.F. Hebard,* University of Florida

Dilute magnetic semiconductors (DMS) offer the use of the spin degree of freedom of the electron in addition to its charge in device applications. Recent theoretical calculations have predicted a Curie temperature for GaMnN of roughly 400 K.@footnote 1@ In this talk we will discuss the feasibility of growing GaMnN via gas-source molecular beam epitaxy. Mn levels up to 47% as determined by Auger electron spectroscopy (AES) have been obtained in GaMnN. X-ray diffraction (XRD) shows no evidence of second phase formation in films with Mn concentrations less than 9%. Addition of Mn to the GaN changes the conductivity from highly conductive n-type to highly resistive, suggesting that at least some of the Mn behaves as a deep acceptor. Nominally semi-insulating GaMnN with a Mn concentration of ~5% shows paramagnetic behavior with a saturation moment per Mn of 3.9 Bohr magnetons, suggesting that much of the Mn is substitutional. Increasing the growth temperature increases the electron concentration due to enhanced incorporation of nitrogen vacancies. The increased carrier concentration produces what appears to be a ferromagnetic material, but with a low Curie temperature of ~100K. Similar studies on p-GaMnN will be discussed in this talk as will the effect of adding Al to the GaMnN. @FootnoteText@ @footnote 1@ T. Dietl, H. Ohno, F. Matsukura, J. Cibert, and D. Ferrand, Science, 287, p. 1019 (2000).

10:40am **EL+MI-WeM8 The Investigation of MnScN Grown by Molecular Beam Epitaxy**, ***H.A.H. Al-Brithen***, *H. Yang, A.R. Smith,* Ohio University

Nitride semiconductors are well known as important materials due to their unique electronic and optical properties. If it is possible to incorporate magnetic species (i.e. Mn or Fe) into nitrides, these may also be used as magnetic semiconductors for spintronics. Scandium nitride, shown to be a semiconductor, has been studied lately for its potential electronic applications.@footnote 1@ Since both MnN and ScN are known to exist with octohedral bonding,@footnote 2@ it seems likely that Mn may be soluble in ScN. Thus, we have undertaken a study of the growth of MnScN by molecular beam epitaxy. Mn@sub x@Sc@sub 1-x@N growth is initiated on a buffer of ScN grown on MgO(001). Growth has been performed for samples at substrate temperature between 350°C and 650°C with Mn/Sc intended flux ratios of 10 and 20%. For all samples, XRD reveals a clear alloy peak which is distinguishable from the ScN and MgO peaks. From the comparison of the alloy peak position with that of ScN and the expected peak position of MnN (based on separate studies of this binary compound@footnote 3@), the values of x are estimated and found to be in good agreement with the Mn/Sc flux ratios. RHEED patterns shows smooth growth on the ScN buffer at the initial stage. The evolution of the RHEED pattern depends on the substrate temperature and the Mn flux. For Mn/Sc ratio of 10%, the RHEED pattern show only a single phase with smooth growth; but for Mn/Sc ratio of 20%, some weak ring structures are observed after extended growth time, indicating a possible limit to the solubility of Mn in ScN. Studies of the magnetic properties of the MnScN alloy are underway. Work is supported by NSF. @FootnoteText@ @footnote 1@ H. A. Al-Brithen and A. R. Smith, Appl. Phys. Lett., 77, 2485 (2000); A.R. Smith et al., to be published. @footnote 2@ Suzuki et al., J. Alloys and Compounds 306, 66 (2000) @footnote 3@ H. Yang et al., Appl. Phys. Lett. 78, 3860 (2001).

11:00am **EL+MI-WeM9 MBE Growth and Properties of Co-doped TiO@sub 2@ Anatase**, ***S.A. Chambers***, *S. Thevuthasan, D. McCready,* Pacific Northwest National Laboratory; *R.F.C. Farrow, R.F. Marks, L. Folks,* IBM Almaden Research Center; *N. Ruzycki, D.L. Ederer, U. Diebold,* Tulane University

The realization of fully functional spintronics requires semiconductors that are magnetic at ambient temperature. In a recent publication@footnote 1@, Co-doped anatase TiO@sub 2@ (Co@sub x@Ti@sub 1-x@O@sub 2@) epitaxial films grown on SrTiO@sub 3@(001) and LaAlO@sub 3@(001) by laser ablation were shown to exhibit weak ferromagnetism at room temperature for x up to 0.08. We have grown Co@sub x@Ti@sub 1-x@O@sub 2@ by oxygen-plasma-assisted molecular beam epitaxy on SrTiO@sub 3@(001) and SrAlLaO@sub 4@(001) substrates, for which the lattice mismatches are -3.1% and -0.8%, respectively. Preliminary results have confirmed that this material can be ferromagnetic at room temperature. Kerr effect measurements on some samples show larger remanence (>40%) than that seen in fig. 3 of ref. 1. In all cases, reflection high-energy electron diffraction measured during growth reveals that the film surface becomes progressively more disordered with increasing thickness, with secondary phases and/or complete disordering occurring after several tens of nm. X-ray diffraction reveals the presence of rutile in some cases. X-ray photoemission and x-ray absorption spectroscopy carried out at the LBNL Advanced Light Source reveal that Co is extremely mobile in the anatase lattice, and in most cases has a tendency to concentrate in the near-surface region. In addition, these spectroscopies reveal that Co in the ferromagnetic films is nearly 100% Co(II), whereas a mix of Co(II) and Co(III) is found in nonmagnetic films. Hall effect and TEM measurements are being carried out at the time of abstract preparation, and will be discussed at the conference. These preliminary results reveal that the single largest obstacle to reproducibility is the extremely facile diffusion of Co in the anatase lattice. @FootnoteText@ @footnote 1@Y. Matsumoto, M. Murakami, T. Shono, T. Hasegawa, T. Fukumura, M. Kawasaki, P, Ahmet, T. Chikyow, S.-Y. Koshihara, and H. Koinuma, Science, 291, 854 (2001).

11:20am **EL+MI-WeM10 Epitaxial Growth of an n-Type Ferromagnetic Semiconductor: CdCr@sub 2@Se@sub 4@@footnote *@**, ***Y.D. Park***, *A.T. Hanbicki,* Naval Research Laboratory; *J.E. Mattson,* Naval Research Laboratory, US; *B.T. Jonker,* Naval Research Laboratory

Ferromagnetic semiconductors (FMSs) provide unprecedented opportunity to tune and optimize spin-dependent behavior in semiconductor device heterostructures. Most efforts have focused on III-Mn-V materials such as GaMnAs, which are p-type only.@footnote 1@ Since efficient spin injection and very long spin scattering lengths have been confirmed for electrons rather than holes in semiconductors such as GaAs,@footnote 2-4@ one would like to realize FMS materials which are both n-type and can be epitaxially grown on a readily available device-quality substrate. We report here the epitaxial growth of FMS CdCr@sub 2@Se@sub 4@(001) films on both GaAs and GaP(001) substrates, and describe the structural, magnetic and electronic properties. The samples were grown by molecular beam epitaxy from elemental K-cell sources, and exhibit a 1x1 RHEED pattern during growth. The film structure, orientation and composition were determined by post-growth x-ray diffraction and fluorescence measurements. SQUID magnetometry data confirm ferromagnetic order with a Curie temperature of 130 K, as in the bulk material, and hysteretic behavior with significant remanence. The easy axis is in-plane with a coercive field of ~125 Oe. Temperature dependent transport data show that the films are semiconducting in character, and lightly n-type as grown. We further describe efforts at controlled doping and electrical spin injection from CdCr@sub 2@Se@sub 4@ contacts into GaAs-based LED heterostructures. @FootnoteText@ @footnote *@ This work was supported by the DARPA SpinS program and ONR. @footnote 1@ Ohno, Science 281, 951 (1998). @footnote 2@ Fiederling et al, Nature 402, 787 (1999). @footnote 3@ Jonker et al, PRB 62, 8180 (2000); Park el al, APL 77, 3989 (2000). @footnote 4@ Oestreich et al, APL 74, 1251 (1999).

11:40am **EL+MI-WeM11 Characterization of High Dose Mn, Fe and Ni Implantation into p-GaN**, ***S.J. Pearton***, *N. Theodoropoulou, A.F. Hebard,* University of Florida; *S.N.G. Chu,* Bell Laboratories, Lucent Technologies; *M.E. Overberg, C.R. Abernathy,* University of Florida; *R.G. Wilson,* Consultant; *J.M. Zavada,* U. S. Army European Research Office, UK

High concentrations (3-5at.%) of Mn, Fe and Ni were incorporated into p-GaN by direct implantation at elevated substrate temperature (350°C). Subsequent annealing at 700°C produced apparent ferromagnetic behavior below ~175 K for the 3at.% Fe sample and ~100 K for the 5at.% Fe sample. Selected area diffraction patterns did not reveal the presence of any other phases in the Fe-implanted region. For Mn-implantation, ferromagnetic contributions to the magnetization were observed below 250K in 3at.% samples. In this material, platelets consistent with the formation of GaMnN were observed by TEM. The direct implantation process appears promising for examining the properties of magnetic semiconductors with application to magnetotransport and magneto-optical devices.

Magnetic Recording Topical Conference
Room 110 - Session MR+MI+AS+SE-WeM

Magnetic Recording: Tribology & Integration

Moderator: Y.T. Hsia, Seagate Technology

8:20am **MR+MI+AS+SE-WeM1 Nanotribology of Simple and Complex Fluids at Aqueous Interfaces@footnote 1@*, S. Granick,*** University of Illinois, Urbana **INVITED**

Oil and lubrication are so synonymous that it is easy to discount the importance of aqueous-based lubrication -- not least in our own bodies, wich are full of surfaces in sliding contact. This talk will present recent studies of (a) the hydrophobic effect when surfaces are in relative motion, (b) modifying the boundary conditions of fluid flow, from no-slip to slip, and (c) ongoing attempts to watch single molecules under confinement. These issues of water in intimate contact with solid surfaces point the way to possible new strategies for energy-saving during fluid transport and have relevance to filtration, colloidal dynamics, and microfluidic devices.@footnote 2@ @FootnoteText@ @footnote 1@Work performed with Yingxi Zhu, John Jiang Zhao, Ashish Mukhopadhyay, and Hyungjung Lee @footnote 2@Work supported by the National Science Foundation and by the U.S. Dept. of Energy, Division of Materials Sciences under Award Number DEFG9645439 through the Frederick Seitz Materials Research Laboratory at the University of Illinois at Urbana-Champaign.

9:00am **MR+MI+AS+SE-WeM3 The Ever Changing Disk Drive Environment: Can Filter Technology Keep Pace?*, A.J. Dallas,*** *J. Joriman, L. Ding, D. Arends, S.B. Miller, III,* Donaldson Co., Inc. **INVITED**

The cleanliness of the internal environment of a disk drive is critical to its reliability, performance, and longevity. As a result, we have seen particulate and chemical filters become commonplace in the design of disk drives of all types and sizes. The incorporation of chemical filters into the disk drive environment has proven to be an effective means of controlling the humidity and contamination level. Generally, silica gel is used to control the humidity level, whereas carbon and chemically-treated activated carbon are used to minimize organic and acid gas contamination levels. As disk drive technology moves into the future, chemical filtration is expected to play an ever-increasing role in the overall drive’s performance. How will filter technology change to meet these requirements? This presentation will provide an overview of chemical filtration, filter design, and the current technology. In addition, we intend to focus on: 1) test methods designed to evaluate and identify internal drive contamination; 2) test methods to evaluate materials used in chemical filters; 3) chemical filter performance; 4) extending test methods and chemical filters to low contaminant concentrations; 5) targeting specific chemical species with chemical filters; 6) humidity control; and 7) the future of chemical filtration.

9:40am **MR+MI+AS+SE-WeM5 Effect of Humidity on Lubricated Carbon Overcoats*, N. Shukla,*** Seagate Technology*; A.J. Gellman,* Carnegie Mellon University*; R. Veerdonk, X. Ma, J. Gui,* Seagate Technology

A quartz crystal microbalance has been used to measure contaminant adsorption on magnetic data storage media under controlled conditions. This apparatus has been developed to make measurements of contaminant adsorption at the level of 0.1 ng/cm2 with a time resolution on the order of seconds. Initially we have measured humidity uptake on amorphous carbon overcoats coated with lubricants. We have been able to estimate the amount of water adsorbed on lubricated carbon overcoats at room temperature and at moderate humidity levels (~ 25% RH). Adsorption and desorption is fast indicating that equilibrium with ambient humidity is reached on timescales of minutes, much faster than the timescales for fluctuations in ambient humidity. We have also studied water adsorption on different types of lubricants deposited at different thicknesses. Interestingly, the amount of water adsorbed on lubricated and unlubricated carbon overcoats is similar suggesting that water adsorption is primarily dependent on the properties of the carbon. We have studied the bonding of water on carbon overcoats and also studied bonding of lubricants on carbon overcoats.

10:00am **MR+MI+AS+SE-WeM6 Tribological Implications of the Confinement in PFPE Boundary Lubricant Films*, G.W. Tyndall,*** IBM Almaden Research Center **INVITED**

Perfluoropolyether (PFPE) films of nominally 1.0 - 2.5 nm are commonly utilized by the magnetic recording industry to lubricate the head/disk interface in hard-disk drives. In this film thickness regime, the surface of the magnetic recording disk will "energetically confine" the lubricant. This confinement is manifested in physical and mechanical properties of the PFPE lubricant that differ substantially from those of the bulk fluid. In the current talk, the experimental evidence for confinement in the PFPE/carbon system will be reviewed, and the implications to the tribology of the head-disk interface discussed.

10:40am **MR+MI+AS+SE-WeM8 Pushing Perfluoropolyether Molecules Across Surfaces Using Air Shear***, M.A. Scarpulla, **C.M. Mate,*** IBM Almaden Research Center

We have investigated the surface mobility of thin films (<5 nm thick)of linear chain perfluoropolyether polymers on silicon and CN@sub x@ surfaces while subjecting them to air shear stresses. These experiments are elucidating the nature of viscosity in molecularly thin films of lubricants important for magnetic recording. For polymer chains with neutral CF@sub 3@ end groups, we find that the effective viscosity is close to the bulk viscosity even at sub-monolayer coverage. The addition of alcohol end groups to the polymer chains acts to anchor the first layer of molecules to a surface, greatly increasing the effective viscosity relative to the bulk. For the second layer, the alcohol-terminated polymers exhibit effective viscosities near their bulk viscosity, while dewetting is observed in thicker films.

11:00am **MR+MI+AS+SE-WeM9 Kinetics and Energetics of the Desorption of Polyether Lubricants*, K.R. Paserba,*** *N. Prashanth, A.J. Gellman,* Carnegie Mellon University

Desorption or evaporation is one of the mechanisms for loss of perfluoropolyalkylether (PFPE) lubricants from the surfaces of data storage media. One approach to minimizing PFPE loss by desorption is the use of lubricants with increasing molecular weight or increasing average chain length. In order to understand the effects of chain length on the lubricant evaporation kinetics we have studied the desorption kinetics of monolayer films of oligomeric ethers with varying chain length adsorbed on the surface of graphite. This study has used monodispersed samples of oligomeric ethyleneglycol dimethylethers, CH3O(CH2CH2O)mCH3, and oligomeric ethyleneglycols, HO(CH2CH2O)mH, as models for the perfluoropolyalkylether lubricants Fomblin Z and Fomblin Zdol. Their adsorption and desorption from the surface of graphite has been measured as a function of chain length, M = 3m+3, or molecular weight by using thermally programmed desorption methods in ultra-high vacuum. The results of these measurements show the surprising result that the desorption energies, @DELTA@E@sub des@, are non-linear in the chain length. What is most interesting is that the desorption energies can be expressed by the power law expression @DELTA@E@sub des@ = a + b M@gamma@ with @gamma@ ~ 0.5. A model has been proposed for the desorption mechanism of such oligomeric lubricants from surfaces which can quantitatively reproduce the dependence of the desorption energies on chain length. The origin of the non-linearity is the conformational isomerism of the oligomers as they desorb from the surface. We will discuss the implications of these results on the desorption of oligomeric PFPE lubricants from the surfaces of magnetic data storage media.

11:20am **MR+MI+AS+SE-WeM10 Ramp Materials Challenges with Load/Unload Technology*, B. Hiller,*** Maxtor Corporation **INVITED**

Dynamic ramp load/unload technology (or short: ramp load) is replacing contact start/stop technology in hard disk drives. Key reasons are superior shock performance and improved reliability. Ramp load adds a new part to the drive (the ramp) and a new interface (between ramp and suspension lift tab). Proper selection of the ramp material and specification of the ramp/tab interface are key to drive reliability. This talk will address the important issues and will present state-of-the art solutions, as well as an outlook on future developments. As with all in-drive materials, minimal chemical outgassing is required. After that, the most important criteria for the ramp material are low friction and wear, and adequate mechanical stability. Out of a large number of candidate materials, only two materials are primarily used in today's products: Teflon-filled liquid crystal polymer (LCP) and acetal homopolymer (POM). These two materials optimize the materials issues in different ways and have their unique application range. LCP excels at mechanical stability, while POM exhibits superior tribology. Surface roughness affects friction and wear and needs to be controlled for both sliding partners, but control is more crucial for the much harder stainless steel suspension lift tab. Current products employ both spherical and cylindrical lift tab shapes. The relative merits of both approaches will be discussed. Tribological and mechanical properties are so multi-faceted that a large portion of this talk will be devoted to presenting measurement techniques and key results. Other important properties such as electrostatic charging and cost will also be addressed.

Magnetic Recording Topical Conference
Room 110 - Session MR+AS+SE-WeA

Magnetic Recording: Heads & Media

Moderator: D. Weller, Seagate Technology

2:00pm **MR+AS+SE-WeA1 Ultra-Thin Magnetic Media Overcoats through ECR Deposition***, **M.L. Wu**, J. Kiely, Y.T. Hsia, K.J. Howard,* Seagate Research

With increasing demands made on the performance of ultra-thin (<3 nm) overcoats in magnetic recording media, novel deposition approaches are needed to produce films that are mechanically robust and provide corrosion resistance to the underlying media. We have used the ECR (electron cyclotron resonance) approach to create a high-density plasma and have controlled the ion energy via the bias to increase the atomic mobility and density of deposited films. Using this approach, we have deposited a series of a-C:H (N) films with thicknesses as small as 0.8 nm and correlate their corrosion, wear, and nanometer-scale scratch resistance performance with film density measurements. We also present findings that the interaction with the cobalt underlayer changes with the ECR approach. The oxidation state of the cobalt underlayer was investigated by high resolution ESCA and preliminary results showed that the percentage of cobalt oxide was significantly decreased by the ECR approach while the C (1s) spectra showed the formation of cobalt carbide at the interface. We will contrast the behavior of films deposited with this approach with those conventional sputtered a-C:H (N) films, and comment on the extendibility of traditional overcoat designs.

2:40pm **MR+AS+SE-WeA3 Future Directions in Magnetic Storage Technology***, **M.H. Kryder**,* Seagate Research **INVITED**

Magnetic recording technology has advanced in areal density by over 10 million times, since it was first introduced in disk drives in 1957. Recently, the rate of progress in areal density has exceeded 100% per year, far outstripping the pace of Moore's Law for semiconductor technology. Throughout this history there have been a number of innovations that have been made to enable the sustained progress. Today, however, we are approaching areal densities where a change in the form of the recording technology may be required. Longitudinal recording, which has been practiced in disk drives since 1957, is approaching densities at which recordings may become thermally unstable. This is forcing the industry to change the way disk drives are scaled and to consider alternative means of data storage. Technologies such as perpendicular recording, patterned media recording, optically assisted magnetic recording and probe storage are being considered. This talk will describe the methods that are being considered to extend longitudinal recording, the alternative technologies and their prospects for success.

3:20pm **MR+AS+SE-WeA5 Antiferromagnetically-Coupled Magnetic Media Layers for Thermally-Stable High-Density Recording***, **E.E. Fullerton**, D.T. Margulies, M. Schabes,* IBM Almaden Research Center*; M.F. Doerner,* IBM Storage Technology Division **INVITED**

The combination of signal-to-noise requirements, write field limitations, and thermal activation of small particles is thought to limit the potential areal density of longitudinal recording media and is commonly referred to as the 'superparamagnetic limit'. Recording media composed of antiferromagnetically coupled (AFC) magnetic recording layers is a promising approach to extend areal densities of longitudinal media beyond these perceived limits [@footnote 1@,@footnote 2@]. The recording medium is made up of two ferromagnetic recording layer separated by a nonmagnetic layer whose thickness is tuned to couple the layers antiferromagnetically. For such a structure, the effective areal moment density (Mrt) of the composite structure is given by the difference between the ferromagnetic layers allowing the effective magnetic thickness to scale independently of the physical thickness of the media. This allows AFC media to maintain thermal stability even for low Mrt values. Experimental realization of this concept using CoPtCrB alloy layers that demonstrates thermally stable low-Mrt media suitable for high-density recording will be discussed. @FootnoteText@ @footnote 1@ E. E. Fullerton et al, Appl. Phys. Lett. 77, 3806 (2000). @footnote 2@ E. N. Abarra et al, Appl. Phys. Lett. 77, 2581 (2000).

4:00pm **MR+AS+SE-WeA7 Optimization of Media Properties in Magnetic Thin Films***, **E.B. Svedberg**[1], J.M. van de Veerdonk, K.J. Howard,* Seagate Research*; L.D. Madsen,* Carnegie Mellon University

Film depositions by ultra high vacuum magnetron sputtering with controlled gradients across the wafer in terms of composition and thickness have allowed (i) efficient exploration of a large number of variables, and (ii) the interdependencies between parameters to be studied. Output parameters such as coercivity and squareness of magnetic loops for magnetic media were measured and subsequently models were extracted that incorporated both the dependencies and co-dependencies of the input parameters. An added bonus to this approach is the tight control maintained on the "fixed" parameters (e.g. temperature and background pressure) through making many samples in a single deposition. To achieve the gradients, six tilted magnetrons were used to deposit the films. In one experimental setup the effect of underlayers was studied. The samples consisted of a set of layers as follows: Ta, RuxCo1-x, CoCr, CoCrPtB. In this setup, there seems to be an optimum Ru concentration in the range of 80-85% for achieving a maximum squareness, while the coercivity increases monotonically with the Ru concentration, hence, is not possible to maximize both the coercivity and the squareness in the same disc in terms of data. In a second set of samples the effort was focused on the hard magnetic layer and investigating the effect of the additives Ta, Nb, Pt and Ti to the CoCr to promote the desired magnetic properties. From the experiments it seems that the combination of Pt and Ta/Ti additives promotes a different growth mode than Pt or the additives alone. Further, to verify the possibility of structural characterization automation, two CoCr/Pt multilayers consisting of ten bi-layers each were mapped by x-ray diffraction. In the samples, the thickness of each Pt layer was kept constant over the surface of the wafer and the thickness of the CoCr layer was varied along with the total thickness.

4:20pm **MR+AS+SE-WeA8 Magnetic Nanoparticles and Nanoparticle Assemblies***, **S. Sun**,* IBM Research **INVITED**

We present our chemical synthetic approaches to monodisperse magnetic nanoparticles (Co and FePt) and nanoparticle superlattices. Advances of magnetic recording technology have driven the development of new magnetic nanoparticle-based media with uniformity in both particle size and particle magnetics. Self-assembly of magnetic nanoparticles may offer an easy way of fabricating such media. The key step for successful self-assembly approach is to use structurally stabilized magnetic nanoparticles as building blocks to form uniform nanoparticle arrays. We have found that steric repulsion from long chain hydrocarbon surfactants is effective in particle stabilization process. A combination of surfactants such as trialkylphosphine/oleic acid (for Co) and oleic acid/oleyl amine (for FePt) has been successfully employed to control particle growth, stabilize the particles, and protect them from oxidation. The particles can be prepared by metal salt reduction and metal carbonyl decomposition. By varying metal/surfactant or metal/metal ratio, both particle size (2-11nm) and alloy composition can be tuned. These monodisperse magnetic nanoparticles can self-organize into regularly arrayed magnetic superlattices. Microscopic studies of the assemblies have shown that the symmetry of these assemblies is dependent upon many factors including particle's size and shape. Thermal annealing is applied to adjust interparticle spacing of the superlattice assemblies and to control internal particle structure. Magnetic properties of these assemblies can be easily tuned from superparamagnetic to ferromagnetic. These well-controlled magnetic nanoparticle assemblies are of interest for future fabrication of nanoelectronic devices, and will have great potential for ultra-high density magnetic recording.

5:00pm **MR+AS+SE-WeA10 Thermal Stability of Granular Perpendicular Magnetic Islands Patterned using a Focused Ion Beam***, **S. Anders**, C.T. Rettner, M.E. Best, B.D. Terris,* IBM Almaden Research Center

We have studied the thermal stability of patterned magnetic media islands as a function of island size. A focused ion beam (30 keV, Ga+) was used to pattern granular CoCrPt media to produce square arrays of islands of different periods, ranging from 70-750 nm. Islands with periods smaller than 130 nm appear as single magnetic domains in MFM images, while larger islands show multi-domain behavior. The samples were magnetized perpendicularly in a field of 20 kOe (far in excess of the ~3 kOe coercivity) to produce fully magnetized films. This fully magnetized state should have the highest decay rate, since the demagnetization field is maximized. Magnetic force microscopy images taken at various times after the

[1] **IUVSTA Welch Scholar**

magnetization show that the patterned structures have a considerably slower thermal decay rate than the unpatterned film. Small single-domain islands were seen to have the smallest decay rate of less than 0.25% per decade compared to one order of magnitude higher decay rates for the unpatterned media. This enhanced stability is analyzed in terms of increased demagnetization fields and increased switching volumes introduced by patterning.

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+NS-ThM

Magnetic Imaging and Spectroscopy

Moderator: P.N. First, Georgia Institute of Technology

8:20am **MI+NS-ThM1 Measurement of Spin Polarization using Andreev Reflection***, **R.J. Soulen**, M.S. Osofsky, G. Trotter,* Naval Research Laboratory **INVITED**

Measurement of spin polarization using Andreev reflection A new class of electronics is emerging which relies on the ability of ferromagnetic materials to conduct spin polarized currents. The performance of devices based on this phenomenon is greatly enhanced as the spin polarization, P, of the ferromagnetic material approaches 100%. In the face of difficulties in measuring this important property, we have developed a very simple method to determine P in which a superconducting point is placed in contact with the candidate ferromagnetic material. The Andreev reflection process at the interface between the two metals is influenced by the spin polarization of the ferromagnet enabling the determination of P through measurement of the conductance of the contact. In a very short time we have been able to measure the spin polarization of several metals and conducting oxides: NixFe1-x; Ni. Co, Fe, NiMnSb, La0.7Sr0.3MnO3; CrO2, whose spin polarization ranges from 25% to over 90%. Our results compare well with other magnetic spectroscopy measurements of P where available. Our search continues for a material with 100% spin polarization.

9:00am **MI+NS-ThM3 Point Contact Spectroscopy in Magnetic Fields***, **M. Tsoi**,* IBM Almaden Research Center **INVITED**

9:40am **MI+NS-ThM5 Magnetocrystalline Anisotropy Probed using X-ray Magnetic Linear Dichroism***, **S.S. Dhesi**,* ESRF, France*; G. van der Laan,* Daresbury Laboratory, UK*; E. Dudzik,* Hahn-Meitner-Institut, Germany*; A.B. Shick,* University of Davis, California

The anisotropy of the spin-orbit interaction,@lambda@@sub 2@, in vicinal Co films has been measured using x-ray magnetic linear dichroism (XMLD). A linear increase in @lambda@@sub 2@ with Co step density is found using a new sum rule and represents the first experimental confirmation that XMLD probes the magnetocrystalline anisotropy energy (MAE). X-ray magnetic circular dichroism (XMCD) is used to confirm that the XMLD arises from changes in the local step-edge electronic structure. The XMLD sum rule gives a larger MAE compared to macroscopic values and is discussed with respect to other local probes of the MAE.

10:00am **MI+NS-ThM6 Soft X-ray Microscopy to Image Magnetic Domain Structures at High Resolution***, G. Schuetz,* Universitat Wurzburg, Germany*; **P. Fischer**,* MPI-MF, Germany **INVITED**

X-ray magnetic circular dichroism (X-MCD) serves as huge element-specific magnetic contrast mechanism in combination with soft X-ray microscopy to image magnetic domains with a current lateral resolution down to 25nm. The sensitivity of X-MCD on the projection of the magnetization of the ferro(i)magnetic species along the photon propagation direction allows to study both in-plane and out-of-plane magnetized systems. The capability of this photon based microscopy to record the images in varying external magnetic fields and the high sensitivity down to thicknesses of a few nm is outlined and proofs this novel technique to be a promising tool for the study of the switching behaviour of individual layers in thin film magnetic media that are currently discussed (magnetic sensors, spintronic devices, etc.). Recent results obtained on nanostructured and multilayered systems will be presented together with micromagnetic simulations to get insight into the micromagnetic properties of these systems.

10:40am **MI+NS-ThM8 Photoemission Electron Microscopy and X-Ray Magnetic Circular Dichroism of Ultrathin FeNi Alloy Films on Cu(111)***, **Y. Sato**, T.F. Johnson, S. Chiang,* University of California, Davis*; F. Nolting, A. Scholl,* Lawrence Berkeley National Laboratory*; X.D. Zhu, D.P. Land,* University of California, Davis

We are studying the system of NiFe/Cu(111) to understand and control the surface/interface magnetism relevant to the application of the giant magnetoresistive effect to magnetic recording heads. We used the Photoemission Electron Microscope (PEEM2) at the Advanced Light Source to observe the domain structures of the alloy films. PEEM has the unique capability of imaging the film's magnetic structure with high spatial resolution and elemental specificity. Element specific magnetic contrast images and X-ray Magnetic Circular Dichroism (XMCD) spectra were obtained for eight different samples of varying Fe compositions at two different thicknesses. Samples with higher Fe content (x = 0.66, 0.74) were non-magnetic at room temperature. This trend of reduction in Curie temperature at higher Fe concentration agrees both with our XMLD data on the same system@footnote 1@ and with previous work on FeNi/Cu(100).@footnote 2@ We speculate this is a structure-driven effect related to the "Invar effect" in the bulk alloy. The PEEM images clearly show that Fe and Ni form a good alloy and have the same domain structures with their magnetization aligned. Further, we find a strong thickness and concentration dependence of the magnetic domain structures. For 5ML films, the domain structures appear to be strongly influenced by surface topography of the substrate. For 10ML films, however, the effect of the substrate features is already insignificant. At this thickness, the Fe concentration is also found to affect the size of the domains and the presence of an easy magnetization axis. @FootnoteText@ @footnote 1@T.F.Johnson, S.Chiang, Y.Sato, et al., to be published @footnote 2@F.O.Schumann, S.Z.Wu, G.J.Mankey and R.F.Willis Phys.Rev.B 56, 2668 (1997).

11:00am **MI+NS-ThM9 Imaging Magnetization in MRAM Elements with Soft X-Ray Microscopy***, **J.B. Kortright**, G. Meigs, G.P. Denbeaux,* Lawrence Berkeley National Laboratory*; J.M. Slaughter, R. Whig, S.-I. Han,* Motorola

The magnetic elements used to store information in MRAM devices will have dimensions of less than 1 micron laterally and roughly 5 nm in thickness. Such small dimensions make it difficult to directly observe field-dependent magnetization structure in individual elements, and possible interactions between elements, by conventional magnetic microscopy techniques. We are using scanning and imaging soft x-ray microscopes based on zone-plate lenses (with resolution approaching 30 nm) and resonant magnetic circular dichroism contrast to image magnetization structure during reversal in arrays of lithographically patterned bits on SiNx membrane substrates. Remnant magnetization structure and its evolution through reversal are clearly resolved, as is the dependence of this structure on element size, shape and cyclic reversal. Following a brief review of techniques, microscopy results relevant to MRAM applications and comparisons with micromagnetic theory will be presented. Work at LBNL was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. Work at Motorola Labs was partially funded by DARPA.

11:20am **MI+NS-ThM10 Imaging Magnetic Nanostructures by Spin-Polarized Scanning Tunneling Microscopy***, **M. Bode**, A. Kubetzka, O. Pietzsch, M. Kleiber, R Ravli@aa c@, R. Wiesendanger,* University of Hamburg, Germany **INVITED**

Our recent progress in spin-polarized scanning tunneling microscopy (SP-STM) will be reviewed. By using magnetic thin film tips and spectroscopic techniques we could image the surface spin-structure of different surfaces and ultrathin films with a spatial resolution down to the atomic level. Namely, we will present results obtained on the topological antiferromagnet Cr(001),@footnote 1@ on self-organized Fe-nanowires@footnote 2@ and -islands,@footnote 3@ and on the antiferromagnetic monolayer of Mn/W(110).@footnote 4@ We will demonstrate that in-plane and out-of-plane spin-contrast can be achieved by choosing appropriate magnetic tip coatings and that the use of an antiferromagnetic tip material avoids any influence of the tip´s magnetic stray field on the sample´s domain structure. In contrast to most other electron-based microscopic techniques SP-STM as a near-field method can be applied even in large external magnetic fields up to several Tesla allowing the investigation of hysteresis effects in magnetically hard materials. @FootnoteText@ @footnote 1@ M. Kleiber et al., Phys. Rev. Lett. 85, 4606 (2000).@footnote 2@ O. Pietzsch et al., Phys. Rev. Lett. 84, 5212 (2000).@footnote 3@ A. Kubetzka et al., Phys. Rev. B 63, 140407 (2001). @footnote 4@ S. Heinze et al., Science 288, 1805 (2000).

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+TF-ThA

Magnetic Thin Films and Surfaces I
Moderator: E.E. Fullerton, IBM Almaden Research Center

2:00pm **MI+TF-ThA1 John Thornton Award Lecture - Magnetic Multilayers: Past, Present and Future @footnote 1@**, ***S.D. Bader***[1], Argonne National Laboratory **INVITED**

Highlights of magnetic multilayer research at Argonne are presented. The most recent past can be taken as the era of giant magnetoresistance multilayers. From there we move to the present where we are addressing issues associated with magnetic pinning across diverse interfaces. Illustrative examples include the coupling between ferromagnets and antiferromagnets, as well as between "hard" and "soft" ferromagnets. The former is of importance in understanding the design of spin valves and magnetic random access memory (MRAM). The later provides a possible nanotech route to the creation of a new generation of ultra-strong permanent magnets. In the future the expectation is that lateral patterning, self-assembly and spintronics will open new vistas. @FootnoteText@ @footnote 1@ This work was supported by the U. S. Department of Energy, Office of Science, under contract number W-31-109-ENG-38.

2:40pm **MI+TF-ThA3 Occupied and Unoccupied Metallic Quantum Well States in the Cu/fccM/Cu(100) [M=Ni, Fe] System**, ***A.G. Danese,*** *R.A. Bartynski,* Rutgers University*; D.A. Arena, M. Hochstrasser, J.G. Tobin,* Lawrence Livermore National Lab & Lawrence Berkeley Lab

Multilayers of alternating magnetic (FM) and non magnetic (NM) layers have attracted a great deal of attention due to their technological importance. We have studied the Metallic Quantum Well (MQW) electronic structure of the prototypical NM/FM/NM systems, Cu/fccM/Cu(100) [M=Ni,Fe], using both angle resolved photoemission (PE) and inverse photoemission (IPE) along the Gamma-bar X-bar direction. We have also used a phase accumulation model (PAM) to calculate the dispersions of MQW electronic states along this axis. The PAM predicts that MQW states will have a high effective mass when they lie in the energy and momentum region of the projected spin polarized band gap of the underlying FM material. PE of the Cu/fccNi/Cu(100) system shows one high effective mass state inside the Ni band gap and another near the gap edge while IPE shows one just above the Ni gap, in good qualitative agreement with the PAM. Numerous MQW states were seen using IPE on Cu/fccFe/Cu(100) but no pronounced high-effective-mass state was seen in the Fe band gap. We believe this can be explained if the Fe film is actually NM which will move the location of the high effective mass states from where they are expected. The PAM also predicts that MQW states will increase in energy as a function of increasing Cu thickness. Although we observed this in our IPE results for MQW states in Cu/fccFe/Cu(100) and PE of Cu/fccNi/Cu(100), our IPE data for Cu/fccNi/Cu(100) show MQW states decreasing in energy with increasing Cu thickness. This same result was observed for Cu films on a Ni(100) single crystal and attributed to lattice mismatch between Cu and Ni, but we have shown that strain cannot account for the behavior of these MQW states and are currently studying how the interface roughness between the Cu and Ni film may provide an explanation. We will discuss our results in the context of the PAM and address the origins of discrepancies between the PAM's predictions and our measurements.

3:00pm **MI+TF-ThA4 The Magnetic Properties of Fe@sub 50@Mn@sub 50@/Cu Multilayers**, ***G.J. Mankey***, *S. Maat, L. Shen,* University of Alabama*; S.C. Byeon,* University of Alabama, US*; E. Ada,* University of Alabama*; J.L. Robertson, M.L. Crow, T.C. Schulthess, W.H. Butler,* Oak Ridge National Laboratory

The temperature dependent magnetic properties of 50-period multilayers of Fe@sub 50@Mn@sub 50@/ Cu were investigated by squid magnetometry and neutron scattering. Squid magnetometry of a polycrystalline multilayer revealed that field cooling of the multilayer from above the Néel temperature aligns the uncompensated spins, resulting in ferromagnetic ordering of a small fraction of the sample. This ferromagnetic ordering may contribute to the exchange-bias effect observed in Fe@sub 50@Mn@sub 50@/ferromagnet layers. For neutron diffraction measurements, epitaxial multilayers with a fcc (111) surface orientation were produced by magnetron sputtering on H-terminated Si(110). The neutron diffraction measurements reveal a wider mosaic spread in the magnetic lattice relative to the chemical lattice and that only a portion of the Fe@sub 50@Mn@sub 50@ alloy was antiferromagnetically ordered. These observations suggest the domain walls occupy a significant fraction of the Fe@sub 50@Mn@sub 50@ volume. The critical behavior of the antiferromagnetic ordering was determined by measuring the temperature dependence of the magnetic diffraction peak with neutron diffraction. For the first heating cycle, a Néel temperature of 510K and critical exponent of 0.357 are found, consistent with bulk 3D Heisenberg behavior. However, measurements during subsequent heating cycles showed that annealing to 480 K irreversibly changes the microstructure of the multilayer, resulting in a reduction in the magnetization, a reduction of the critical exponent, and an increase of the Néel temperature. XPS depth profiling of the multilayer before and after annealing shows that the interface widths increase due to intermixing of the Fe@sub 50@Mn@sub 50@ and Cu layers. The intermixing is the cause of the changes in magnetic properties. Sponsored by ARO DAAH-04-96-1-0316, NSF MRSEC DMR-9809423, and DOE DMR DE-AC05-96OR22464.

3:20pm **MI+TF-ThA5 Magnetic Reversal of Exchange-coupled Co/Pt Multilayers Probed by Resonant Soft X-ray Scattering**, ***O. Hellwig,*** *S. Maat, E.E. Fullerton,* IBM Almaden Research Center*; J.B. Kortright,* Lawrence Berkeley National Laboratory **INVITED**

The balance between exchange, anisotropy and dipolar energies determines the domain structure in ferromagnetic films. For systems with perpendicular magnetic anisotropy such as Co/Pt multilayers, this often results in stripe domain patterns. In this study we modify the energy balance in Co/Pt multilayers by selectively replacing Pt layers in the structure by CoO or Ru layers. Adding antiferromagnetic CoO layers leads to a perpendicular exchange bias below the Neel temperature of the CoO. The addition of 0.9-nm Ru layers antiferromagnetically couples adjacent Co/Pt blocks and changes the characteristics of the magnetic reversal behavior dramatically. We use resonant soft X-ray small-angle scattering in addition to more conventional methods such as magnetometry and magnetic force microscopy to investigate the domain structure as well as the magnetic reversal process. By measuring both the angle and field dependence of the magnetic scattering we quantify the domain formation during reversal. For the CoO interlayers we find that the domain nucleation process in the biased samples is asymmetric to positive and negative field sweeps but once nucleated the domain patterns are symmetric to the field sweep directions. Zero field cooling in an aligned stripe domain pattern after in-plane demagnetization results in a periodic biasing of the system. At low temperature this leads to a memory effect in the domain pattern that forms during field reversal. The multilayers with Ru interlayers exhibit two distinct reversal modes that reflect the competition between the dipolar and the interlayer exchange energy. Such systems highlight the opportunity to tune the magnetic domain structure and reversal in perpendicular multilayers. Olav Hellwig was partially supported by the Deutsche Forschungsgemeinschaft via a Forschungsstipendium under the contract number HE 3286/2-1.

4:00pm **MI+TF-ThA7 Magnetic Phases of Fe Monolayers on Ni/Cu(001)**, ***M. Farle,*** Technische Universitaet Braunschweig, Germany*; H. Poppa,* Lawrence Berkeley National Laboratory

The spin reorientation transition (SRT) of Fe on 4 to 9 ML Ni on Cu(001) is studied by spin-polarized low-energy electron microscopy (SPLEEM) in situ at 295 K. The formation of magnetic domains is monitored during the growth of the Fe monolayers with video rates at a resolution of about 100 nm. The x,y and z components of the magnetization vector are determined. On 8.2 ML Ni/Cu(001) we find three different magnetic phases as a function of Fe thickness. a) 0.2 to 2.8 ML Fe : large out-of-plane magnetic domains, b) 2.8 to 6 ML Fe : large in-plane magnetic domains, c) > 6 ML Fe no magnetic contrast. At the transition from a) to b) which starts at 2.6 ML and ends at 3.0 ML narrow stripe domains appear with a tilted orientation with respect to the film plane. At the transition from b) to c) the size, shape and direction of the in-plane magnetic domains does not change, only the magnetic contrast is lost. This indicates a transition from a ferromagnetic to the paramagnetic state of 6 ML Fe on 8 ML Ni ! Our domain observations are disussed in terms of current concepts of spin-reorientation transitions.

[1] **John A. Thornton Award Winner**

4:20pm **MI+TF-ThA8 Spin-resolved Electronic Structure Studies of Ultrathin Films of Fe on GaAs***, **M. Spangenberg**, E.A. Seddon,* CLRC Daresbury Laboratory, UK*; E.M. McCash,* University of York, UK*; T. Shen,* University of Salford, UK*; S.A. Morton, G.D. Waddill,* University of Missouri-Rolla*; J.G. Tobin,* Lawrence Livermore National Laboratory

Fe thin films of up to 5.5nm were deposited on singular and vicinal GaAs substrates and their magnetic and structural properties investigated by spin polarized photoelectron spectroscopy, magnetic linear dichroism in photoemission, magnetization measurements and X-ray diffraction. On both types of substrate the Fe grows predominantly as delta Fe. In agreement with literature results, the magnetization measurements and the magnetic linear dichroism results indicate very similar magnetic properties for the Fe films grown on the two substrate types. However, comparison of the spin polarized valence bands of the Fe films on the singular and the vicinal substrates reveal very significant differences. The possible origins of these observations will be presented. Comparisons and rationalisations will also be made (were possible) between our observations on Fe on GaAs and literature reports for other Fe thin film systems. For example, we have found that the spin polarized valence bands of Fe deposited on the vicinal GaAs exhibit similar features to those reported in the literature for 10nm Fe(100) films on Cu3Au(100) . In contrast, the spin polarized valence bands of Fe films on the singular GaAs are very different to all Fe thin film literature reports, with the differences concentrated in the minority spin channel.

5:00pm **MI+TF-ThA10 Growth Mode Dependence of Magneto Optical Signal Evolution in an Ultrathin Film: Layer by Layer vs. 3D Growth***, **J.L. Menendez**, G. Armelles, A. Cebollada, J.L. Costa-Kramer,* Instituto de Microelectronica de Madrid (CNM-CSIC), Spain

In this work the magneto-optical properties of the first stadium of the initial growth of a ferromagnetic material deposited on top of a substrate will we analyzed. Two different growth modes will be discussed: layer by layer and three dimensional growth mode. A comparison of the magneto-optical signal for the two growth modes will be presented for three different configurations of the applied magnetic field: magnetic field applied perpendicular to the layer (polar) and in the plane of the layer (transverse and longitudinal). The main results are: In the layer by layer growth mode, the intensity of the magneto-optical Kerr signal is a linear function of the thickness of the deposit layer and the magnetic moment of the layer (i.e., the intensity is a linear function the amount of deposit material for the three configurations). Therefore, the intensity of the magneto optical signal can be used to analyze the evolution of the magnetic moment of the layer as we increase the thickness. In the case of three dimensional growth mode, the intensity of the magneto-optical Kerr signal does not only depend on the magnetic moment of the layer, but also on the shape and amount of islands present in the layer. Contrary to the layer by layer growth mode the intensity of the magneto-optical properties is not a linear function of the amount of the deposited material and therefore can not be directly correlated with the magnetic moment.

Magnetic Interfaces and Nanostructures
Room 134/135 - Session MI-ThP
Magnetic Thin Films & Surfaces Poster Session

MI-ThP1 Magnetic Spectroscopy at the Elliptically Polarizing Undulator Beamline 4.0.2 at the Advanced Light Source, ***E. Arenholz,*** *A.T. Young,* Advanced Light Source

Beamline 4.0.2 is the first undulator beamline at the Advanced Light Source equipped with a Sasaki-type elliptically polarizing undulator (EPU). The EPU allows full control of the polarization of the x rays. Variable linear polarization from linear horizontal to linear vertical as well as 100% circular polarization are possible. The undulator in combination with a plane-grating-variable-included-angle monochromator is designed to provide high flux photon beams from 50 eV to 2000 eV, fully covering the L@sub 3,2@ edges of important magnetic transition metals (Fe, Co, Ni, ...) and also the M@sub 5,4@ edges of magnetic rare earth elements of interest (Gd, Tb, ...). We will present first experimental results that illustrate the ability of the beamline to detect small dichroism effects in dilute systems and materials which show only weak magnetic effects (<0.3%), giving us confidence in the suitability of the set up to study novel magnetic systems with high precision.

MI-ThP2 X-ray Magnetic Linear Dichroism of Fe-Ni Alloys on Cu(111), ***T.F. Johnson,*** *S. Chiang, Y. Sato,* University of California, Davis; *D.A. Arena,* Lawrence Livermore National Laboratory; *S.A. Morton,* University of Missouri-Rolla; *M. Hochstrasser, J.G. Tobin,* Lawrence Livermore National Laboratory; *J.D. Shine, J.A. Giacomo, G.E. Thayer, D.P. Land, X.D. Zhu,* University of California, Davis; *G.D. Waddill,* University of Missouri-Rolla

We have prepared Fe@subx@Ni@sub1-x@ multilayers on Cu(111) in order to learn how to control the structure and magnetism of these thin alloy films, which are relevant to the giant magnetoresistance (GMR) effect used in magnetic disk drive heads. Using the Spectromicroscopy Facility (7.0.1.2) on Undulator Beamline 7.0 at the Advanced Light Source, we have measured X-ray magnetic linear dichroism (XMLD) signals from both Fe and Ni 3p lines for fourteen different thin Ni-Fe alloy films on Cu(111), with Fe concentration ranging from 9% to 84% and for a variety of film thicknesses. The Curie temperature for all of these samples was in the range 200K to 500K. For many of these films, the Curie temperature was considerably lower than was previously seen for similar films deposited on Cu(100). For a particular Fe concentration x, the Curie temperature increases with alloy film thickness. For a specific film thickness, the Curie temperature has a maximum near x=0.4. We have also measured the Fe and Ni asymmetries as a function of Fe concentration.

MI-ThP4 Growth of Mn on Fe(001): Surface Alloy Formation and Multilayer Growth, *T. Yamada, M.M.J. Bischoff, A.J. Quinn,* University of Nijmegen, The Netherlands; *T. Mizoguchi,* Gakushuin University, Japan; ***H. van Kempen,*** University of Nijmegen, The Netherlands

A complicated relationship is usually found between the magnetic configuration of a magnetic thin film, the crystallographic structure and the electronic structure. Mn films on Fe(001) are the ultimate example of a system where all these properties are interwoven. Conflicting results are, e.g., reported on the magnetic properties, which suggest a strong dependence on impurities, intermixing, and growth mode. Scanning tunneling microscopy (STM) is the ideal technique to tackle this problem, since it allows studying both the atomic structure in the conventional constant current mode and the electronic structure in the spectroscopic mode. In this contribution, it will be shown that for deposition of submonolayers at temperature s above 400K, Mn atoms are place exchanged with Fe substrate atoms. Locally a c(2x2) MnFe surface alloy is formed. Spectroscopy measurements will be presented for incorporated Mn atoms, pure Mn islands, and the local c(2x2) MnFe alloy structures which all show characteristic features in the dI/dV spectrum. For growth of thicker Mn films at 400K, intermixed Fe atoms can still be observed until the third layer. Analysis of the step heights gives evidence that the structure relaxes after the second layer. From the fourth layer upon, spectroscopy measurements reveal a feature in the dI/dV spectrum which strength oscillates with layer thickness and therefore seems to be related with the reported antiferromagnetic coupling of the Mn layers. The spin-polarized nature of these surface states can be used to study the surface magnetism on a local scale in spin-polarized tunneling experiments. Experiments with Fe covered tungsten tips will be discussed.

MI-ThP6 Epitaxial Growth of Ferromagnetic Ni@sub 2@MnIn Thin Films on InAs (001), ***J.Q. Xie,*** *J.W. Dong, J. Lu, S. McKernan, C.J. Palmstrom,* University of Minnesota

There has been growing interest in ferromagnetic/semiconductor hererostructures for the development of spintronic devices which utilize the carrier's spin as well as its charge. InAs is the semiconductor of choice because of its high electron mobility and the ease to form an ohmic contact to it. Although no elemental ferromagnet is lattice matched to InAs, the lattice mismatch between the Heusler alloy Ni@sub 2@MnIn and InAs is only 0.2%. In bulk, Ni@sub 2@MnIn is reported to have a cubic (L2@sub 1@) crystal structure with a lattice constant a@sub 0@ = 6.069 Å and a Curie temperature ~ 314 K. Recent theoretical studies showed that the minority spins are situated at the @GAMMA@ point in Ni@sub 2@MnIn and the majority spins are far away from the @GAMMA@ point. Therefore, the band structure alignment between Ni@sub 2@MnIn and InAs would enhance the injection of the minority spins, suggesting that Ni@sub 2@MnIn may be a good choice for spin injection as a ferromagnetic contact. In this talk, we report on the epitaxial growth of Ni@sub 2@MnIn thin films on InAs (001) by the molecular beam epitaxy technique. Both in situ reflection high energy electron diffraction and ex situ x-ray diffraction, Rutherford backscattering spectrometry, and transmission electron microscopy measurements indicate the high-quality epitaxial growth of Ni@sub 2@MnIn films on InAs (001). The films have a Curie temperature ~ 170 K and a saturation magnetization ~ 420 emu/cm@super 3@. The lower Curie temperature, compared to that of bulk Ni@sub 2@MnIn, is believed to result from the growth of Ni@sub 2@MnIn in the B2 structure. Composition has a dramatic effect on the Curie temperature. For Ni@sub 2@MnIn@sub 1.7@, a Curie temperature of ~ 290 K was observed. If ordered films can be grown, significantly higher Curie temperatures may be expected.

MI-ThP7 On the Origin of the Thickness-dependent Dimensional-crossover in Ultrathin Magnetic Films, ***N.A.R. Gilman,*** Penn State University; *M. Hochstrasser,* Lawrence Berkeley National Laboratory; *R. Zhang, R.F. Willis,* Penn State University

We report experimental results that show that the order parameter @beta@, which determines the long-range (spin) ordering in magnetic thin films (M=M@sub o@(1-T/Tc)@super beta@), changes abruptly due to a crossover in dimensionality at different thicknesses in Ni(100), Ni(110) and Ni(111) films. We argue that the different critical thicknesses arise from finite-size quantization energies of the (spin) excitations, which are dependent on the magnitude of associated wavevectors spanning different crystallographic directions of the fcc Fermi surface. Experimental data on nickel alloys support this view.

MI-ThP8 Fabrication of CoCrTa Magnetic Film by RF-sputtering, ***Y. Ohta,*** Fukui National College of Technology, Japan; *K. Ohashi, T. Tsumori,* Shin-Etu Chemical Co., Ltd., Japan

CoCrTa longitudinal media was prepared by sputtering onto Si substrates at substrate temperature of 523 K by RF magnetron sputtering system. The films were fabricated at the substrate temperature of 523K and Argon gas pressure of 3.5 mTorr during sputtering. The film was deposited on surface Si and glass substrates. CoCrTa thin films of several thicknesses were prepared by sputtering. The microstructures and particle size were investigated by transmission electron microscopy (TEM) and atomic force microscopy (AFM). The crystal structure was checked by X-ray diffractometry (XRD) and the magnetic properties were measured by a vibrating sample magnetorometer (VSM). The underlayer thickness dependence of magnetic properties of CoCrTa deposited on Si and glass substrates were investigated. It was known that thickness of underlayer has significant influence the crystallographic texture and magnetic properties of the magnetic layer. CoCrTa layer deposited on the Si substrate revealed small size grain and smooth surface than ones deposited on the glass substrate.

MI-ThP9 Ion-beam Modification of the Physical Properties and the Structure of Fe/Si Multilayered Films, ***Y.P. Lee,*** *J.S. Park,* Hanyang University, Korea; *Y.V. Kudryavtsev,* Institute of Metal Physics, Ukraine; *J. Dubowik, B. Szymanski,* Institute of Molecular Physics, Poland; *J.Y. Rhee,* Hoseo University, Korea; *G.S. Chang,* Yonsei University, Korea

The influence of ion-beam mixing (IBM) on the strucure, and the magnetic, magneto-optical and optical properties of Fe/Si multilayered films (MLF) was investigated. The IBM was performed with Ar@super +@ ions of an energy of 80 keV and a dose of 1.5 X 10@super 16@ Ar@super +@/cm@super 2@. It was shown that the IBM destroys the layered structure of the MLF down to a depth of about 110 - 150 nm and leads to the formation of a new phase which is characterized to possess a perfect crystalline structure, a low coercivity and a Curie temperature of about 550 K. It is suggested that the phase formed by the IBM is a metastable Fe_2Si silicide with a B2 type of structure. An annealing of the ion-beam mixed Fe/Si MLF at 720 K destroys further the undisturbed layered structure at the bottom and also leads to a decomposition of the Fe_2Si phase into a metastable magnetically-hard Fe_5Si_3 silicide and, presumably, Fe_3Si.

MI-ThP10 Suface Magnetic Phase Diagram for a Semi-infinite Ferromagnet*, **D.P. Pappas**,* National Institute of Standards and Technology, Boulder*; A.P. Popov,* Moscow State Engineering Physics Institute, Russia, Moscow, Russia

The phase diagram for the orientation of the surface region is calculated in the parameter space defined by the surface and bulk anisotropy for semi-infinite systems and thin films. A discrete layer-by-layer approach is developed and compared to the continuum approach. We also consider the 1.5 atomic layer Fe on Gd system, and find that it is a good physical realization of the model. We find that suface magnetic canting always occurs when the magnitude of the surface anistropy is comparable with the interlayer exchange interaction.

MI-ThP11 Low Field Magnetoresistance through Grain Boundaries in Double Exchange Compounds*, D. García, **B. Alascio,*** Instituto Balseiro, Argentina

To model transport through the grain boundary of a manganite bicrystal we study the conductance of a spin chain doped with itinerant electrons which are strongly Hund coupled to the spin at each site. We induce a domain wall in the chain and propose a single site pinning mechanism. At large pinning we find that the magnetoresistance corresponds to that of two uniformly magnetized domains. Assuming uniaxial anisotropy within each grain we use the above results to calculate the magnetoresistance through the grain boundary and obtain remarkable agreement with experiment. Further, our study solves an apparent contradiction between experiments by different authors.

MI-ThP12 Formation of Barriers for Magnetic Tunneling: Ion Embedding vs Diffusion*, **S.O. Demokritov**, B.F.P. Roos, P.A. Beck, B. Hillebrands,* University Kaiserslautern, Germany

A novel type of oxidation technique, the ionized atom beam oxidation, was used to prepare ultrathin insulating aluminum oxide barriers for magnetic tunnel junctions. Thanks to high chemical reactivity of atomic oxygen combined with very low energy (30-50 eV) of the ions the oxide grows fast, homogeneous, and amorphous. The limited oxidation depth reduces the possibility of an overoxidation of the underlaying magnetic electrode. By means of in-situ techniques for monitoring the oxide growth during the oxidation, it was possible to identify two mechanisms which dominate the oxidation at different stages of the process. During the initial stage an ion embedding mechanism controls the oxidation. This mechanism describes the penetration of kinetic O-ions into the target metal layer until they are stopped on their way through the film by elastic and inelastic processes. The ions form chemical bindings with the surrounding metal atoms at their stopping place. The oxidation depth defined by this mechanism depends on the energy of the ions and reaches 1-2 nm. As the oxide layer grows, the incoming O-ions find less and less leftover metal atoms near their stopping place and a diffusion process starts to effect the oxidation. The further oxidation growth is determined by an electrical field controlled diffusion of metal and oxygen atoms. Monte-Carlo-simulations based on the developed "ion embedding with diffusion" model completely describe the formation of thin oxide barriers for magnetic tunnel junctions.

MI-ThP13 Non-monotonic Magnetic Surface Anisotropy of Epitaxial Fe Films Grown on Vicinal Substrates*, S.O. Demokritov, **M. Rickart**, J. Jorzick, B. Hillebrands,* University Kaiserslautern, Germany

The presented work is devoted to the study of the influence of atomic steps at the interface between a magnetic film and a substrate on the magnetic surface anisotropy of the film. Step induced anisotropy contributions appear because of the broken translational invariance perpendicular to the steps. The Fe films were prepared on vicinal MgO(001) substrates with Ag(001) and Au(001) buffers using a molecular beam epitaxy UHV system. Substrates with two different miscut orientations (along [100] and [110]) were used. In-situ characterization was performed by LEED, RHEED and SPM, and chemical analysis by Auger electron spectroscopy. Magnetic anisotropy contributions have been determined from the hysteresis loops and from frequencies of spin waves measured by Brillouin light scattering. In addition to the four-fold anisotropy intrinsic for (001) Fe films the vicinal films demonstrate an uniaxial anisotropy. The strength of the uniaxial anisotropy depends on the miscut angle, the miscut orientation, and the buffer material. Fe films prepared on Au buffers with the miscut orientation along the [100]-direction show an additional uniaxial anisotropy with the easy axis perpendicular to the steps. For the Fe films prepared on Au buffers with the miscut orientation along the [110]-direction a non-monotonic dependence of the anisotropy strength as a function of the miscut angle is observed: the orientation of the magnetic easy axis switches from parallel to perpendicular to the steps, crossing zero value between 1.5 and 2 degrees of the miscut angle. Fe films prepared on Ag buffers with the miscut orientation along the [100] direction shows the same orientation of the uniaxial anisotropy easy axis, as those prepared on Au, however the anisotropy strength is much higher than that observed on Fe/Au system. The properties of the observed uniaxial anisotropies are analyzed on the basis of the Neel pair-bonding model.

Friday Morning, November 2, 2001

Magnetic Interfaces and Nanostructures
Room 110 - Session MI+SS-FrM
Magnetic Thin Films and Surfaces II

8:20am **MI+SS-FrM1 Novel Spin Structures in Fe@sub 3@O@sub 4@/CoO and Fe@sub 3@O@sub 4@/NiO Superlattices**, ***Y. Ijiri,*** Oberlin College; *J.A. Borchers, R.W. Erwin, S.H. Lee, K.V. O'Donovan,* National Institute of Standards and Technology; *P.J. van der Zaag, L.F. Feiner, R.M. Wolf,* Philips Research Laboratories; *D.M. Lind, P.G. Ivanov,* Florida State University **INVITED**

Using polarized neutron scattering methods, we have probed the magnetic ordering in MBE-grown Fe@sub 3@O@sub 4@/CoO and Fe@sub 3@O@sub 4@/NiO superlattices. Despite significant differences between the spinel ferrite and the rock salt monoxides, it is possible to grow high-quality epitaxial structures for these materials as a result of good oxygen sublattice matching. We have observed for these superlattices substantial changes in the spin structures for both the ferrimagnetic Fe@sub 3@O@sub 4@ and the antiferromagnetic monoxide (CoO or NiO). In particular, we have found new magnetic easy axes along with significant differences in the polarization characteristics for these thin films. The unusual structures are discussed in terms of the role of strain and exchange coupling between disparate magnetic materials.

9:00am **MI+SS-FrM3 Surface Structure and Phase/Orientation Control of Manganese Nitride Grown by Molecular Beam Epitaxy**, ***H. Yang***, *H.A.H. Al-Brithen, A.R. Smith,* Ohio University; *R.L. Cappelletti, J.A. Borchers, M.D. Vaudin,* National Institute of Standards and Technology

We have investigated the growth of manganese nitride on MgO(001) substrates using molecular beam epitaxy (MBE) and have studied the surfaces using scanning tunneling microscopy (STM). Manganese nitride has many bulk phases (labeled @theta@, @eta@, @zeta@, and @epsilon@). Using MBE, we can individually select these phases by controlling the growth parameters. For example, at low Mn flux, we obtain the N-rich @theta@ phase (MnN), which has fct structure;@footnote 1@ but at increased Mn flux, we obtain the less N-rich @eta@-phase (Mn3N2) which is also fct but includes ordered arrays of N vacancies, according to a model proposed by Kreiner and Jacobs.@footnote 2@ Neutron scattering confirms that the Mn moments are aligned in a layered antiferromagnetic arrangement. By adjusting the growth parameters, we are able to control not only the phase, but also the crystalline orientation. At low Mn flux, the @eta@-phase has its c-axis perpendicular to the growth surface (@eta@1). But at yet higher Mn flux, the c-axis is oriented parallel to the surface (@eta@2), a consequence being two equivalent domains, D1 and D2, at 90° to each other. These domains are evident during growth via RHEED, which shows two closely spaced 1st-order streaks due to the fct structure. Also, 1/3-order lines are observed due to the periodic vacancy planes which are normal to the surface. STM images following growth clearly reveal the two domains at the @eta@2 surface. Row structures corresponding to the vacancy planes are clearly observed. Atomic resolution images show enhancement for the Mn atoms at the intersections of the surface and vacancy planes. This is likely related to the fact that these Mn have fewer N neighbors compared to other surface Mn atoms. This work is supported by NSF. @FootnoteText@ @footnote 1@ Suzuki et al., J. Alloys and Compounds 306, 66 (2000), @footnote 2@ Kreiner and Jacobs, J. Alloys and Compounds 183, 345 (1992).

9:20am **MI+SS-FrM4 Mesoscopic Magnetic Structures Grown by Self-organization**, ***J. Kirschner,*** Max-Planck-Institut fuer Mikrostrukturphysik, Germany **INVITED**

Mesoscopic magnetic structures play an increasingly important role in magnetic storage technology, magnetic sensors, non-volatile random access memories, and "magneto-electronics" in general. Lithography-type processes for making such structures, though having been quite successful, will not be addressed in this talk. Rather, typical surface science approaches, involving adsorption, surface diffusion, epitaxial growth phenomena, and self-organisation will be exploited to produce and characterize mesoscopic magnetic structures. For example, magnetic wires may be made by step edge decoration on stepped single crystal surfaces by tuning surface diffusion. They form chains of long segments, connected by weak links. These structures resemble Ising chains, with magnetic properties determined by a gradual approach to thermodynamic equilibrium. Magnetic dots may be created by exploiting localized adsorption on reconstructed surfaces. It will be demonstrated, how magnetic pillars with a height-to-diameter ration of 2:1 can be grown on such a template and that such structures may perhaps overcome the "superparamagnetic barrier" in magnetic storage technology.

10:00am **MI+SS-FrM6 Direct Observation of Orbital Kondo Resonance on the Cr(001) Surface**, *O.Yu. Kolesnychenko, R. de Kort, M.I. Katsnelson, A.I. Lichtenstein,* ***H. van Kempen,*** University of Nijmegen, The Netherlands

Scanning Tunneling Microscopy (STM) is an excellent tool to explore many-body phenomena, such as the formation of the Kondo resonance@footnote 1@. In addition to``classical'' Kondo effect, many-electron resonances have been theoretically predicted for scattering centers with non-spin degrees of freedom. Here, we will present the first direct evidences for the existence of orbital Kondo resonance on a transition metal surface. Low-Temperature STM and STS investigations were performed on the atomically clean Cr(001). The Cr(001) surface was produced by cleavage of a 99.99% Cr single crystal in situ at 4K. As we found out, the cleavage of Cr single crystals produce atomically flat and clean (001) surfaces. The STS investigations of the Cr(001) surfaces showed a very narrow resonance at 26 meV above the Fermi level. We found that at bias voltages corresponding to the resonance energy a cross-like depressions centered around impurities appears. This cross-like feature is a fingerprint of the orbital symmetry of the resonance analogous, for example, to the visualization of a superconducting gap near a zinc atom@footnote 2@. Although the resonance in the Cr(001) surface density of states has been observed previously at room temperature@footnote 3@ and was interpreted as a one-electron surface state, we are going to present additional experimental data which strongly indicate that the observed state on the Cr(001) surface is a many-electron orbital Kondo resonance which is formed by two degenerate spin-split d@sub xz@, d@sub yz@ surface states. We also carried out calculations for the periodic degenerated Anderson model which confirm the existence of the orbital Kondo resonance on the Cr(001) surface. @FootnoteText@ @footnote 1@ H.C. Madhaven, et.al., Nature 403, 512 (2000). @footnote 2@ S.H. Pan. et.al., Nature 403, 746 (2000). @footnote 3@ J.A. Stroscio, et.al., Phys. Rev. Lett. 75, 2960 (1996).

10:20am **MI+SS-FrM7 High Dipolar Magnetic Moment Observed on Ni/Cu(111) Nanostructures by Magnetic Circular X-ray Dichroism**, ***C. Boeglin***, *S. Stanescu, S. Cherifi,* IPCMS-CNRS, France; *A. Barbier,* CEA/DRFMC, France; *N.B. Brookes,* ESRF, France; *P. Ohresser,* LURE-CNRS, France; *J.P. Deville,* IPCMS-CNRS, France

The correlation between ultrathin film growth, structure and morphology and the induced magnetic properties is of fundamental interest in order to improve the theoretical understanding of magnetic properties in ultra-thin films. We report here growth and morphology studies at the first stages of growth of Ni on a Cu(111) single crystal substrate. This work has been performed by in-situ Auger, RHEED and STM at room temperature. The morphology shows in the early stages of the growth that nickel induces 10-30 nm large triangular islands monolayer in height. In addition stripes are formed at the step edges via a step flow growth mode. The particular shape of the oriented triangular islands has been examined by STM and segregation of Cu atoms could be evidenced on top of the Ni islands after 0.5 ML deposition. It is shown that the Ni morphology and the Cu diffusion both have a strong influence on the magnetic properties. Correlations have be evidenced by performing in-situ Magnetic Circular X-ray Dichroism studies on Ni/Cu(111) ultra-thin films. The evolution of the island size during the growth can be correlated with the evolution of the orbital magnetic moment whereas strong dipolar magnetic moments are related to the formation of a second Cu/Ni interface. Moreover, the in-plane orbital magnetic moment anisotropy has been measured and related to magnetocrystalline effects in the film.

10:40am **MI+SS-FrM8 Relating Magnetic and Structural Changes of Thin FeNi Alloy Films on Cu(100)**, ***M. Hochstrasser***, *J.G. Tobin,* Lawrence Livermore National Laboratory; *S.A. Morton, G.D. Waddill,* University of Missouri-Rolla; *F.O. Schumann,* Freie Universität Berlin, Germany; *N.A.R. Gilmann, R.F. Willis,* The Pennsylvania State University

At a concentration of around 65% Fe, bulk FeNi alloys exhibit the "Invar effect", a sudden arresting of the Wigner-Seitz cell volume and a zero expansion coefficient. Simultaneously, the crystal structure changes from face-centered cubic to body-centered cubic while the Curie temperature goes to zero. This structural transformation can be arrested in ultrathin alloys films grown epitaxially on a Cu(001) substrate. Theoretical work predicts that the fcc phase can exist in two possible states: a ferromagnetic high volume state or a antiferromagnetic low volume state (2@gamma@ state model) and a volume change between the paramagnetic and the high spin state of ~7%, and 1% change between a non-collinear equilibrium state and the high spin state. Experimental work shows a lattice expansion increasing linearly up to 3% at 65% Fe content followed by a sudden relaxation of 2% with increasing Fe content. The initial volume increase is associated with increasing magnetization/magnetic moment & spin alignment in the Ni-rich alloys. As the alloy is cooled below T@sub C@ (or a strong external magnetic field is applied), an increasing alignment of the magnetic moments causes the nearest-neighbor spins to push apart producing an internal pressure which expands the lattice. With increasing Fe content, this effect increases due to the increasing number of Fe nearest neighbors with the larger atomic magnetic moments. Eventually, a critical limit is reached (~65% Fe), when a magnetic/lattice volume instability develops. W ith x-ray magnetic dichroism the changes in the elemental magnetic moments were tracked. Spin polarized photoemission studies record a sudden decrease in the "mean-field" exchange splitting of the d-states with increasing Fe content through the critical "Invar transition". Angle-resolved photoemission imaging of states at the Fermi level reveal a much smaller splitting of the sp-states, which also tracks the changing magnetization with changing composition.

11:00am **MI+SS-FrM9 The Structure of Ferromagnetic Ultrathin Fe Films on Cu(100) is not fcc***, A. Biedermann, R. Tscheliessnig, M. Schmid,* ***P. Varga,*** TU Vienna, Austria

Ultrathin Fe films on Cu(100) are an ideal model system to study martensitic fcc-bcc phase transitions in Fe.@footnote 1@ Ultrathin Fe films on Cu are also distinguished by the appearance of a novel ferromagnetic phase which showed distinct fcc-like features in p revious electron diffraction experiments. By means of scanning tunneling microscopy we were able to reveal this phase as a novel "nanomartensitic" phase with the Fe atoms forming localy a bcc like structure @footnote 2@. This shows that the assumption of a ferromagnetic fcc phase is not necessary to explain the ferromagnetism observed in these films. @FootnoteText@ @footnote 1@ A. Biedermann, M. Schmid, and P. Varga, Phys. Rev. Lett. 86 (2001) 464-67 @footnote 2@ A. Biedermann, Rupert TschelieÃŸnig,M. Schmid, and P. Varga, Phys. Rev. Lett., submitted

11:20am **MI+SS-FrM10 Angle Resolved Auger Spectra of Ultrathin Fe on Gd (0001)***,* ***J.P. Nibarger,*** *D.P. Pappas,* National Institute of Standards and Technology

The in-plane to out-of-plane spin-reorientation phase transition of ultrathin Fe on Gd (0001) has been measured recently.@footnote 1@ Theoretical work has indicated the need for six-fold symmetry of the ultrathin Fe film in order to fit existing data on the spin-reorientation phase transition.@footnote 2@ Fe films consisting of 1.5 atomic layers on bulk Gd do no exhibit any long range ordering as determined by low energy electron diffraction. Angle resolved Auger electron spectroscopy (ARAES) will be used because it is sensitive to local order on the atomic scale and will determine the local symmetry of the Fe atoms. ARAES spectra will be shown that demonstrate the extent of six-fold symmetry in these films. @FootnoteText@ @footnote 1@ C.S. Arnold et al., Phys. Rev. Lett. 83, 3305 (1999). @footnote 2@ A.P. Popov, private communication.

11:40am **MI+SS-FrM11 Transverse Magneto-optical Kerr-effect in the Soft X-ray Regime at Iron and Cobalt Films on W(110)***,* ***J. Bansmann,*** *V. Senz, A. Kleibert,* University of Rostock, Germany

Tunable soft X-ray radiation opens the possibility for investigating element-specifically the magnetic properties of thin films, islands, and nanoparticles on surfaces. Well-known techniques are magnetic dichroism in photoemission (MDAD) and X-ray magnetic circular dichroism in photoabsorption (XMCD). However, magnetic phenomena can also be studied using the transverse Magneto-optical Kerr effect (T-MOKE) at the core levels of ferromagnetic materials using linearly polarized radiation. We will present new data using T-MOKE at iron and cobalt films and self-organized islands on W(110). For recording hysteresis curves an external electromagnet has been applied to the setup. Close to the core levels of e.g., iron and cobalt, the reflectivity and the Kerr rotation is strongly enhanced by resonant forward scattering. We could observe huge intensities in reflexion and intensity asymmetries of 50% at Fe and Co films of less than 6ML. The experimental results will be compared to recent calculations. When annealing Fe(110) films on W(110) a well oriented Fe island structure can be created. Our experimental data clearly show a rotation of the easy axis with respect to thin films which depends on the original coverage before annealing and on the temperature during thermal treatment. In the case of cobalt on W(110) we have investigated the magnetic properties of fcc- and hcp-cobalt films on clean and modified W(110) surfaces. Although the direction of the easy magnetization axis does not change using different cobalt structures, the remanent magnetization and coercive forces have clearly changed.

Author Index

Bold page numbers indicate presenter

Author Index