Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI-TuA

Emerging Materials and Hybrid Structures

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

2:00pm **MI-TuA1 Spin Transport Effects in Ferromagnetic/Superconductor Heterostructures Grown using Molecular Beam Epitaxy**, ***A.M. Goldman****, V.A. Vas'ko, K.R. Nikolaev, V.A. Larkin, P.A. Kraus,* University of Minnesota **INVITED**

Heterostructures consisting of half-metallic ferromagnetic oxides in the lanthanum manganite family and high temperature superconductors in the YBCO family have been fabricated using the technique of ozone-assisted molecular beam epitaxy, and characterized using a number of techniques. These compounds have similar perovskite lattices, and therefore can easily be formed as epitaxial heterostructures. The fabrication and characterization of these heterostructures and the physics of the interplay between ferromagnetism and superconductivity at the interface between the ferromagnet and superconductor the will be discussed. High-resolution X-ray diffractometry, Rutherford back scattering and helium ion channeling were used to characterize the composition and crystal quality of samples. Simple patterning techniques were employed to prepare configurations in which the effects of carrier injection on superconductivity and the properties of the interfaces could be investigated. Injection of carriers from the magnetic oxides, which exhibit the phenomenon of "Colossal Magnetoresistance," into high temperature superconductors was shown to lead to the suppression of superconducting properties such as critical current and critical temperature. This suggests that spin-polarized transport can be used to investigate spin-dependent electronic properties of high temperature superconductors, and opens the possibility of a new class of superconducting devices utilizing spin injection. The differential conductances of superconductor-ferromagnet interfaces were also studied. The most striking feature of these investigations was the observation of a differential conductance dip at zero bias which was a decreasing function of temperature and/or magnetic field. This phenomenon has been interpreted using a picture of Andreev reflection as a consequence of the high spin polarization of the carriers in the half-metallic ferromagnet.

2:40pm **MI-TuA3 Enhanced Curie Temperature of GdN in GdN/Fe Multilayers**, ***W.J. Antel Jr.****, F. Perjeru,* Ohio University*; W.L. O'Brien,* University of Wisconsin, Madison*; G.R. Harp,* Ohio University

Both magnetic and semiconductor systems as distinct entities have found a wide variety of applications, however work on magnetic semiconductor systems is still in its infancy. The GdN/Fe multilayer system is investigated here as a function of GdN thickness. GdN alone is a ferromagnet with a Curie temperature of 60 K. In the multilayer structure, exchange coupling between the Fe and GdN is found to drastically raise the Curie temperature. The films are grown using reactive sputtering with a N and Ar atmosphere for the GdN, and a pure Ar atmosphere for the Fe. Magnetic moment measurements, using x-ray magnetic circular dichroism, are performed at the L@sub 2,3@ edge of Fe and M@sub 4,5@ of Gd. At room temperature, the Gd is found to maintain a significant moment up to a layer thickness of 3 Å. Measurements performed at 100 K indicate a constant Gd moment of approximately 6 µ@sub B@ out to at least a thickness of 10 Å.

3:00pm **MI-TuA4 Unusual Magnetic Ordering at Room Temperature in La-Ca-Mn-O Thin Films**, ***S.E. Lofland****, V.V. Srinivasu, S.M. Bhagat, R. Shreekala, M. Rajeswari, T. Venkatesan,* University of Maryland

Epitaxial thin films with a nominal composition of La@sub 0.8@Ca@sub 0.2@MnO@sub 3@ were grown by pulsed-laser deposition with thicknesses ranging between 300 and 2600 Å. The resistivity of the as-grown films had a peak near 210 K, similar to the value found in the bulk material. Electron spin resonance studies showed the films to be magnetically very inhomogeneous with no indication of ordering above 240 K. Subsequent heat treatment of the films at 900° C for an hour in flowing oxygen led to dramatic property changes. The resistvity peak temperature increased significantly, and in most cases was above 300 K while the magnitude of the resistivity was markedly less. Resonance experiments suggested that treated films less than 1000 Å thick were paramagnetic at room temperature; however, films thicker than 1000 Å showed multiline spectra at 300 K, with at least one line resulting from a ferromagnetic spin system. In the thickest film, resonance data suggested that 10% of the film was ferromagnetic at room temperature. This is in contradiction to the accepted phase diagram ordering temperature of around 220 K and the maximum ordering temperature of 270 K for the La@sub 1-x@Ca@sub x@MnO@sub 3@ system. We discuss how these observations may be reconciled. Supported in part by the National Science Foundation under Grant No. DMR-9632521.

3:20pm **MI-TuA5 Flux Pinning in Superconductors by Arrays of Submicron Structures***, ***I.K. Schuller****,* University of California, San Diego **INVITED**

We have used electron beam lithography to prepare triangular and square lattices, lines, etc. of submicrometer magnetic dots (Ni, Co, and Fe) and holes and studied their properties using a variety of techniques including magnetotransport, magnetization, Magnetic Force Microscopy and light scattering. We showed that the interaction between an ordered array of small magnetic particles and superconducting thin films leads to strong pinning effects due to the synchronized interaction with the vortex lattice. The resistivity vs. magnetic field curves present sharp minima close to the transition temperature, whereas the transport critical currents exhibit pronounced maxima. These minima and maxima appear at constant field intervals (@Delta@H), clearly related with the lattice parameter of the vortex lattice array. The angular dependence reveals that this interval @Delta@H increases with the angle between the field and the film normal (@theta@) as @Delta@H proportional to 1/cos@theta@, showing that only the perpendicular component of the magnetic field is relevant for this synchronized pinning effect. Comparisons with arrays of holes and normal submicrometric dots reveal the magnetic origin of these effects. Studies as a function of the various geometric parameters helps elucidating the pinning mechanisms involved. *Work done in collaboration with A. Hoffmann, Y. Jaccard, P. Prieto, M.-C. Cyrille, F. Sharifi, J. Martin, M. Velez, J. Nogues, J.-M. George, M. Grimsditch, M.J. Van Bael, K. Temst, C. Van Haesendonck, V.V. Moshchalkov and Y. Bruynseraede. Supported by the US-DOE and AFOSR.

4:00pm **MI-TuA7 Low-Field Magnetoresistive Properties of Manganite and Chromium Oxide Films**, ***A. Gupta****,* IBM T.J. Watson Research Center **INVITED**

The magnetotransport properties of the manganites has been the subject of intense research during the past few years. These oxides exhibit orders of magnitude change in resistance when subject to a magnetic field in the Tesla range. Reducing the field scale for magnetotransport has been a major goal of many research groups. We have followed two approaches in reducing the field scale in the manganites: (1) exploiting the spin-dependent scattering at grain boundaries by using polycrystalline and bi-epitaxial films for pinning the magnetic domains; and (2) fabrication of magnetic tunnel junctions, in the form of manganite/insulator/manganite structures, where the tunneling current between the ferromagnetic manganite layers depends sensitively on the relative orientation of their magnetization vectors. Both approaches benefit from the nearly half-metallic nature of the manganites and result in significant low field magnetoresistance (up to 100%) at low temperatures. Recent magnetoresistance results obtained using another half-metallic system, chromium oxide, will also be presented and the similarities and differences between the two systems will be discussed.

4:40pm **MI-TuA9 Epitaxial Growth of Co Layers on Sb-passivated GaAs(110) Substrates**, ***M. Martin****, C. Teodorescu,* LURE, Centre Universitaire Paris Sud and ICMM, France*; H. Ascolani,* Centro Atomico Bariloche, Argentina, Argentine*; J. Chrost, J. Avila, M.C. Asensio,* LURE, Centre Universitaire Paris Sud and ICMM, France

The growth of magnetic epitaxial layers on semiconductors has attracted considerably attention since it allows the integration of low dimensional magnetic materials with the silicon technology. The largest body of work has been focused to the magnetic 3d transition metals and the zinc blende semiconductors, which have similar lattice constants . In practice, however, the growth of transition metals on semiconductor substrates is difficult due to intrinsic surface states present at the gap of the semiconductors which dominate the electronic and reactivity of the interfaces. Pervious studies on Co/GaAs(110) have indicated that BCC Co can be grown epitaxially for thicknesses up to 300 Å. However, the metallic films are not flat and the As interdiffusion modifies the magnetic properties of the Co overlayer. In this work, we present new results of the growth of Co on a pervious Sb-GaAs(110) passivated surface, where the interdiffusion process is dramatically reduced and the quality of the metallic Co overlayer enhanced. The reactivity of the interface has been tested at different temperature and coverage conditions by high energy resolution synchrotron radiation photoemission and the morphology of the metallic overlayer determined by photoelectron diffraction.

Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI+EM-WeM

Spin-dependent Devices: Technology and Processing

Moderator: B.A. Everitt, Seagate Technology

8:20am **MI+EM-WeM1 Limiting Factors in Dense Pseudo Spin Valve and Spin Dependent Tunneling Memory Arrays*, A.V. Pohm*,** *M.C. Tondra, C.A. Nordman, J.M. Anderson,* Nonvolatile Electronics **INVITED**

For pseudo spin valve or spin dependent memory technology to persist for the coming decades, they must be able to exploit the evolving sub-micron semiconductor technology and adjust to the diminishing conductor widths. However, as pseudo spin valve and spin dependent memory arrays are scaled to 0.1 micron widths or less, a number of factors play a role in limiting ultimately the memory array densities which can be achieved. An analysis has been performed which shows that to achieve adequate stability against thermal agitation for half selected cells, the shape anisotropy in the 25 Angstrom storage layer must be at least 300 Oe for 0.1 x 0.3 micron cells. Half select fields of 100 to 150 Oe are required for the write operation. This necessitates current densities in the GMR sandwich in the 10@super 8@ A/cm@super 2@ range for the sense lines and 10@super 7@ A/cm@super 2@ in the word lines. Although GMR sandwiches can tolerate the high current densities, thin dielectrics and careful use of heat sinks are required to keep the temperature rise modest. Materials such as tungsten must be used for the word line in order to have adequate electro-migration limits. Because of the high resistance and capacitance in the spin dependent tunneling memory cells, semiconductor isolation is necessary for high performance. As a consequence, maximum array density is about ½ of that for pseudo spin valve cells.

9:00am **MI+EM-WeM3 New Aspects of GMR Spin Valves: Enhancing Specular Electron Scattering and Using Surfactants for Improved Growth*, W.F. Egelhoff, Jr.,*** National Institute of Standards and Technology

We have investigated the deposition and processing of a variety of giant magnetoresistance (GMR) spin valves with the aim of optimizing their properties. We have found that many of the magnetic and magnetoresisitive properties of spin valves are strongly influenced by surface and interface effects occurring during growth. These effects include the balance of surface and interface free energies, surface diffusion, interdiffusion at interfaces, low temperature deposition, the use of surfactants to modify growth, and specular electron scattering at surfaces. In some cases, it is possible to control these factors or to use them to manipulate the growth or improve post-growth processing of spin valves to improve their magnetic and magnetoresistive properties. For example, specular scattering is particularly important for achieving the largest possible GMR values in simple spin valves. For symmetric (or dual) spin valves GMR values as large as 24.8% have been achieved, and for simple spin valves (containing only one Cu layer) GMR values as large as 19.0% have been achieved. The best hope for someday achieving GMR values in simple spin valves as large as those reported for GMR superlattices appears to be increasing the degree of specular scattering and reducing the bulk defect scattering. The author would like to acknowledge his collaborators in this work, including P. J. Chen, C. J. Powell, M. D. Stiles, R. D. McMichael, J. H. Judy, K. Takano, A. E. Berkowitz, and J. M. Daughton.

9:20am **MI+EM-WeM4 High Temperature Pinning Properties of IrMn vs. FeMn in Spin Valves*, M.C. Tondra,*** *D. Wang,* Nonvolatile Electronics

The antiferromagnetic pinning properties of IrMn and FeMn have been observed by building spin valve samples with the structure NiFeCo / CoFe / Cu / CoFe / NiFeCo / (IrMn or FeMn) and measuring their magnetoresistive properties. The pinning strength was evaluated in terms of the break field, defined as the field applied in the direction opposite to the magnetization of the pinned layer at which the pinned layer switches. At room temperature, the break fields for both the IrMn and FeMn samples were about 250 Oe. But as the temperature increased, the break field for samples pinned with IrMn held up considerably better than for those pinned with FeMn. Specifically, the pinning of the FeMn spin valves was gone at 150°C while the pinning of the IrMn spin valves persisted to temperatures above 225°C. The IrMn spin valves performed as well as the FeMn spin valves in terms of magnetoresistance and lithographic process compatibility.

9:40am **MI+EM-WeM5 Magnetisation Reversal Studies by TEM of Continuous and Patterned GMR Films*, J.N. Chapman,*** University of Glasgow, United Kingdom **INVITED**

A highly modified transmission electron microscope has been used to study magnetisation processes in a range of GMR films suitable for application in devices. Films were deposited onto silicon nitride "window" substrates suitable for study in the TEM directly after growth or following patterning. Application of fields in-situ allowed the evolution of the magnetic domain structure to be followed in real time in both continuous films and elements. The latter frequently had dimensions in the sub-micron regime. Reversal of the free layer in spin-valve films is found to depend on the strength of coupling between free and pinned layers and the orientation of the applied field, the latter being readily under the control of the experimenter. Conditions under which quasi-coherent rotation of magnetisation takes place have been established. However, very significant changes take place as the dimensions of the films are reduced and magnetostatic energy contributions play an enhanced role. Domain nucleation at corners can lead to undesirable reversal modes and for elements with micron-sized dimensions the reversal depends critically on size, shape and the nature of the pinning layer. Examples will be given of how shape modification can change the characteristic of the reversal to suit sensing or storage application. In the case of Co/Cu multilayers reversal mechanisms quite different from those in spin-valves are observed and depend critically on the nature of the coupling between the layers. Thus films with strong biquadratic coupling tend to reverse in a relatively simple manner resembling processes in single layer films whilst films with weak antiferromagnetic coupling reverse through the formation and evolution of complex sub-micron "patch" domains. Irreversible processes are prevalent in the latter case but can be effectively suppressed in the former making films with biquadratic coupling suitable for applications where low hysteresis is essential.

10:20am **MI+EM-WeM7 Deposition and Processing of Novel GMR Structures @footnote 1@*, J.R. Childress,*** University of Florida, Gainesville **INVITED**

Optimized GMR devices may require the development of magnetic multilayer film structures combining binary and ternary alloys, composition gradients, composites, and metal/insulator interfaces. The structural and magnetic optimization of individual components within these multilayers often require specialized deposition and/or processing parameters which may be mutually incompatible, or incompatible with other necessary processing. Additionally, the interfacial structural and magnetic properties of alloys may be different from bulk, further complicating the interpretation of experimental data. Several current examples and experimental approaches will be discussed, such as the development of 100% spin-polarized magnetic films using NiMnSb and other compounds, metallic and insulating antiferromagnets for exchange biasing, and metal/insulator interfaces. @FootnoteText@ @footnote 1@ Author present address: IBM Almaden Research Center, 650 Harry Rd, San Jose, CA 95120

11:00am **MI+EM-WeM9 Direct-Measurement of Spin-Dependent Transport Across Ferromagnetic and Non-Magnetic Thin Films*, S.K. Upadhyay,*** *R.N. Louie,* Cornell University*; R.A. Buhrman,* Cornell University, US

We have used superconductor-ferromagnet nanocontacts to directly measure a>spin-polarization of the current in ferromagnets (Co and Ni) and b>spin dependent transmission rates of thin ferromagnetic (Co, Ni) and non-magnetic (Cu) films. Since the size of the contact (3-10nm) is smaller than other scattering lengths in the system, our measurements can selectively probe the scattering at interfaces of dissimilar metals. We will discuss our results in the context of giant magnetoresistance in thin film magnetic multilayers and their significance in understanding the role of interfacial versus bulk scattering.

11:20am **MI+EM-WeM10 Effect of Noble Gas Addition (He,Ar,Xe) on Cl@sub 2@-Based Etching of NiFe and NiFeCo*, K.B. Jung,*** *H. Cho, Y-.B. Hahn, E.S. Lambers, Y.D. Park, S.J. Pearton,* University of Florida, Gainesville*; J.R. Childress,* IBM Almaden Research Center*; M. Jenson, A.T. Hurst, Jr.,* Honeywell, Inc.

The mechanism for high rate dry etching of NiFe, NiFeCo and other components of multilayer magnetic thin film devices such as read/write heads and magnetic random access memories depends on formation of chlorinated etch products, and their efficient desorption by ion-assisted sputtering. A systematic study of the dependence of noble gas species (He, Ar, Xe) additive to high-density Inductively Coupled Plasma Cl@sub 2@

discharges has been performed. The etch rates of the NiFe and NiFeCo increase in direct proportion to the atomic weight of the noble gas species, which is the dominant factor controlling etch product desorption. Increasing the weight of the additive also leads to a decrease in residual chlorine on the etched surface, as determined by Auger Electron Spectroscopy. The effect of altering the noble gas species on etch selectivity over common mask materials (SiO_2, SiN_X and photoresist) has also been studied. Facetting of the mask edges is a particular problem with Cl_2/Xe discharges.

11:40am **MI+EM-WeM11 Magnetoresistance Properties in Granular Silicide Thin Films Formed by High Dose Iron Implantation***, **M.F. Chiah**, W.Y. Cheung, S.P. Wong, I.H. Wilson,* The Chinese University of Hong Kong, Hong Kong

High dose iron implantation into silicon wafer has been performed with a metal vapor vacuum arc ion source (MEVVA) to doses ranging from $1*10^{16}$ to $2*10^{17}$ cm^{-2} at various beam current densities. The magnetoresistance (MR) effects in these implanted granular layers were studied at temperatures from 15K to 300K. A positive MR effect, i.e, an increase in the resistance at the presence of a magnetic field, was observed at temperatures lower than about 70K in samples prepared under appropriate implantation conditions. The magnitude of the MR effect, defined as $\Delta R/R_o = (R(H)-R_o)/R_o$ where R(H) and R_o denote respectively the resistance value at a magnetic field intensity H and that at zero field, was found to depend on the implantation dose, the beam current density. This is attributed to the beam heating effect during implantation which affects the formation of the microstructures. The ratio $\Delta R/R_o$ was found to attain high values larger than 500% for some samples at low temperatures. The dependence of the MR effects on temperature, implantation dose, substrate dopant concentration and beam current density will be presented and discussed in conjunction with results of Transmission Electron Microscopy and Mössbauer Spectroscopy. The phase of iron silicide, composition and depth of damaged layer were determined by spreading resistance, Rutherford backscattering and XRD measurements. This work is supported in part by a grant from the Research Grants Council of Hong Kong (Ref. No.: CUHK 374/96E)

Magnetic Interfaces and Nanostructures Technical Group Room 324/325 - Session MI+NS-WeA

Nanoscale Magnetics: Imaging and Fabrication

Moderator: S. Foss, Seagate Technology

2:00pm **MI+NS-WeA1 Using the Magnetic Force Microscope as a Quantitative Micromagnetic Probe***, **R. Proksch**,* Digital Instruments **INVITED**

The Magnetic Force Microscope (MFM) has developed into a popular tool for nanometer scale resolution imaging of a wide variety of magnetic samples. The routine <50nm spatial resolution rivals and sometimes exceeds electron based microscopies while not requiring operation in a vacuum or special sample preparation. Since the MFM is sensitive to the external magnetic field gradients of a sample, however, it does not directly yield quantitative values of either the external field or a sample's magnetization. A recent advance@footnote 1@ has allowed quantitative imaging of the localized field from a sample. It based on a magnetically soft tip that acts as a fluxgate sensor. An external field is applied to the MFM tip and sample until the response of the MFM is zeroed. This zeroing occurs when the external field cancels the local field at the MFM tip. The resulting quantitative images have the same spatial resolution of the MFM. Another recent development in MFM was the realization that the energy dissipated by an oscillating cantilever was quantifiable.@footnote 2,3@ Measurements of the energy dissipated by the MFM tip have been quantitatively compared to micromagnetic models.@footnote 4@ Measurements of other fundamental quantities such as the moment of a single magnetic particle and nucleation volumes in relaxing domain structures through dissipation observations will be presented. @FootnoteText@ @footnote 1@R. Proksch, G. Skidmore et al., Appl. Phys. Lett. 69, 2599 (1996). @footnote 2@P. Grutter, Y. Liu, P. LeBlanc, and U. Durig, Appl. Phys. Lett. 71, 279 (1997). @footnote 3@J. P. Cleveland et al., Appl. Phys. Lett. in press (1998). @footnote 4@Y. Liu, B. Ellman and P. Grutter, Appl. Phys. Lett. 71, 1418 (1997).

2:40pm **MI+NS-WeA3 Imaging Current Flow in Polycrystalline Bi2Sr2CaCu2Ox Superconductors by Magnetic Force Microscopy***, **F. Král**, D. Perednis,* ETH Zürich, Switzerland*; D.A. Bonnell,* The University of Pennsylvania, US*; G. Kostorz, L.J. Gauckler,* ETH Zürich, Switzerland

The measurement of magnetic fields induced by current flow can be used to visualize current transport paths in complex microstructures. Magnitudes of fields induced by currents typical of metallic conductors and of superconductors are within the range accessible by magnetic force microscopy. Finite element calculations indicate that conducting grains separated by as little as a hundred nm will be distinguished. The fields emanating from current in the complex textured microstructure of a Bi2Sr2CaCu2Ox based thick film in the superconducting state at temperatures below 60 K were clearly delineated. Magnetic field variations with the size and orientation of the textured grains that carry current were quantified. Obstructions to current flow are imaged.These measurements were accomplished on a commercial instrument modified to connect to a He cryostat and operate in medium vacuum.

3:00pm **MI+NS-WeA4 Imaging Magnetic Domains by Spin-Polarized Scanning Tunneling Spectroscopy***, **M. Bode**, M. Getzlaff, R. Wiesendanger,* University of Hamburg, Germany

The concept of spin-polarized scanning tunneling spectroscopy (SP-STS) promises the unique capability of magnetic imaging with a resolution down to atomic scales. We will show that the (0001)-surface of Gadolinium, which has a bulk Curie-temperature T@sub C@ = 293K, is ideally suited for the realization of SP-STS since Gd(0001) exhibits a d@sub z@@super 2@-like surface state. This surface state is exchange split in an occupied majority (spin-up) and an empty minority (spin-down) spin-part below T@sub C@. Already in a previous publication we have shown that both spin-parts appear as a double-peak structure in the tunneling spectra.@footnote 1@ Here we report on our experiments with magnetic thin film probe tips. In accordance with the spin-valve effect@footnote 2@ we found characteristic variations in the tunneling spectra which correlate with the direction of the external field, i.e. the differential conductivity of the particular spin-part of the surface state being parallel with the tip is enhanced on the expense of the counterpart being antiparallel. This allows the imaging of magnetic domains with the STM. The resolution obtained so far is approximately 20nm. The measured spin-asymmetry of approximately 40% (20%) at the majority (minority) part of the surface state is in good agreement with former spin-resolved (inverse) photoemission experiments. We will show that the application of thick Fe-coatings on the tip leads to a sudden contrast reversal probably caused by a switching of sample domains due to the strong magnetic interaction between tip and sample. @FootnoteText@ @footnote 1@R. Pascal, Ch. Zarnitz, M. Bode, M. Bode, and R. Wiesendanger, Appl. Phys A 65, 603 (1997). @footnote 2@M. Julliere, Phys. Lett. A 54, 225 (1975).

3:20pm **MI+NS-WeA5 Imaging Magnetization in Fe and Layered Fe/Co Films Using an Element-Specific Scanning Transmission X-Ray Microscope***, **J.B. Kortright**, S.-K. Kim, T. Warwick, G. Meigs,* Lawrence Berkeley National Laboratory

Magnetization distributions in demagnetized polycrystalline Fe films and in the individual Fe and Co layers of layered films were imaged with a scanning transmission x-ray microscope and circular polarizing filters using the strong magnetic circular dichroism at the Fe and Co 2p3/2 levels. Transmission images were obtained at roughly 200 nm resolution with high contrast that was reversed by reversing the saturated magnetization in the polarizing filters. Large, regular 180 degree domains dominate Fe films 20-30 nm thick. Smaller magnetization features (swirls, ripples, etc.) are observed at grain boundaries and near the tip of needle-shaped domains growing into or being consumed by larger domains. In layered films consisting of Fe and Co layers separated by a 2 nm SiC spacer the magnetization in each layer is entirely different from the single Fe film, revealing significant interaction between the two different layers in the demagnetizing process. Large 180 degree domains are absent, and are replaced by much smaller, more irregular magnetization distributions having characteristic dimensions of several microns and somewhat resembling stripe domains. The domains in the Fe and Co layers show some degree of spatial correlation, and some degree of antiferromagnetic alignment. These first imaging studies using a scanning transmission x-ray microscope in conjunction with a high resolution grating monochromator complement other recently demonstrated imaging techniques using x-rays, and point to new opportunities to quantitatively study magnetization distributions in a variety of samples. Technical aspects underlying these new capabilities will be reviewed. This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Division of Materials Science, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

3:40pm **MI+NS-WeA6 Substrate and Growth Related Nanostructural and Magnetic Properties in La@sub 0.67@SR@sub 0.33@MnO@sub 3@ Thin Films***, **M.E. Hawley**, G.W. Brown, C. Kwon, Q.X. Jia,* Los Alamos National Laboratory

Beyond achieving a target chemical composition, optimization of metal oxide thin film properties depends on a number of growth-determined factors: microstructure, defects, and stress. For CMR materials, these factors can lead to low Curie temperature, non-ideal temperature-dependent magnetization, undesirable domain structures, higher coercivity, and magnetic anisotropy. In particular, growth of these materials, which possess fairly large positive magnetostrictive constants, on lattice-mismatched substrates can result in residual stress-induced maze-like domains. This type of domain was observed by magnetic force microscopy (MFM) for some La@sub 0.67@Sr@sub 0.33@MnO@sub 3@ films grown on LaAlO@sub 3@ (compressive mismatch) and tied to substrate-induced stress and film thickness. Stress-induced elongation of the out-of-plane lattice parameter may be necessary but is not sufficient to produce these domains. Their existence has also not been correlated with processing parameters. To address some of these issues, we have grown films over a range of temperatures by pulsed-laser deposition on LaAlO@sub 3@ and SrTiO@sub 3@ (tensile mismatch) to determine the correspondence of lattice-induced strain and degree of granularity to magnetic properties. Nanostructure characterization (STM, AFM, and MFM) magnetization, and coercivity will be presented to show the relationship between growth and properties. Maze-like domain structures, with 150 to 200 nm separations, were observed for thicker films grown at 800@degree@C on LaAlO@sub 3@ versus weak diffuse domains for thin films and all films grown on SrTiO@sub 3@. Application of an increasing in-plane external magnetic field converted the maze-domains first into stripe domains with decreased spacing (with reduced out-of-plane magnetization) and then into diffuse in-plane structures. Field orientation versus magnetic structures will be included.

4:00pm **MI+NS-WeA7 Monodisperse Cobalt Nanocrystals and Their Assembly into Nanocrystal Superlattices: Building with Magnetic Artificial Atoms*, C.B. Murray*,** *S. Sun,* IBM T.J. Watson Research Center **INVITED**

We present chemical methods which yield cobalt nanocrystals uniform in size to + or - one lattice constant while simultaneously controlling crystal shape, structure and surface passivation. We use high temperature (200 - 300° C solution phase synthesis and size selective processing to produce organically passivated nanocrystals with size distributions less than 5%. These monodisperse transition metal nanocrystals self-organize during controlled evaporation to produce three dimensional superlattices (colloidal crystals, opals). The cobalt nanocrystals resemble "artificial atoms" sitting on regular close-packed superlattice sites, each separated by a selected organic spacer. The superlattices retain and enhance many of the desirable mesoscopic properties of individual cobalt nanocrystals and provide a model system for studies the electronic coupling of neighboring particles. The inter-particle spacing can be varied from intimate contact up to 40 Å separation. Superlattices can be prepared as either faceted colloidal crystals or as ordered nanocrystal thin films on a variety of optically and electronic addressable substrates (sapphire, silicon, etc.). Structural and magentic investigations of both dispersed and assembled nanocrystal systems will be presented.

4:40pm **MI+NS-WeA9 Fabrication and Characterisation of Micron Scale Magnetic Features*, C.N. Borca*,** *P.A. Dowben,* University of Nebraska, Lincoln

Different methods can be adopted to fabricate patterned thin films with features spatially restricted in the micron-scale regime. We are studying ferromagnetic films of cobalt and cobalt - palladium heterostructures fabricated by selective area deposition from organometalic compounds. We have developed this one-step deposition technique sufficiently to deposit pure metal features with excellent spatial resolution and in multilayer geometries. From the comparison between the continuous and patterned films we can conclude that the patterning of the films into arrays of discrete micron-scale features has a greater influence on the magnetic properties of the films than changes microstructure and film growth. We propose that this organometallic chemical vapor deposition (CVD) method represent a new approach for novel devices fabrication.

5:00pm **MI+NS-WeA10 Domain Behavior in Magnetic Nanostructures as Revealed by MOIF Observations*, R.D. Shull,*** *A.J. Shapiro,* National Institute of Standards and Technology*; V.I. Nikitenko, V.S. Gornakov,* Institute of Solid State Physics RAS, Russia

A magneto-optical indicator film (MOIF) technique has been used for imaging magnetic domains and applied to magnetic nanostructures, including granular metals, magnetic multilayers, and antiferromagnet (AF)/ferromagnet (FM) bilayers. In this technique, the sample domains are imaged by their effect on a garnet film with in-plane magnetization located immediately above the sample. In addition to static domain structures, dynamic information has been obtained by monitoring the domain pattern evolution upon the application of an external magnetic field. Fractal type domain walls were observed in Co/Ag granular metals with a two-step remagnetization process, non-homogeneous nucleation processes were observed in AF/FM bilayers with remagnetization behavior dependent upon field direction, and non-collinear spin configurations were detected in Cu/Co multilayers (electrodeposited on Si substrates) displaying giant magnetoresistance (GMR) effects during the remagnetization process. In these latter samples, the GMR magnitude was correlated with the spin reorientation mechanism. In all samples the effects of crystal lattice defects on the remagnetization process was documented, and found to be significant. The MOIF technique was also found to be capable of detecting not only the domain structure of the surface layer, but also that of subsurface layers in a multilayer morphology. In this presentation, a review of the domain statics and dynamics which have been observed in a variety of nanostructured material types will be discussed. Particular attention will be given to the origin of enhanced coercivity in a bilayer system with unidirectional anisotropy.

Thursday Morning, November 5, 1998

Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI-ThM

Magnetic Spectroscopies
Moderator: D.P. Pappas, National Institute of Standards and Technology

8:20am **MI-ThM1 Magnetic Characterization from Polarized Soft X-ray Scattering***, **Y.U. Idzerda,*** Naval Research Laboratory **INVITED**

With the explosive growth in spin-polarized electron transport studies for spin-tunneling, spin-transistor, and magnetoresistive device applications, the importance of layer switching, interfacial magnetic roughness, and magnetic domain correlation is becoming increasingly apparent. Since the spin conductance of a magnetic heterostructure is controlled by the relative orientation of the magnetic moment directions of the component layers on a local scale (within a few spin mean-free-paths), quantifying these mechanisms on this length scale would be very advantageous. Combining magnetic circular dichroism and resonant x-ray scattering, soft x-ray resonant magnetic scattering (XRMS) has a demonstrated capability to determine the order of layer switching, extract parameters which independently characterize the magnetic and chemical roughness of an interface, and statistically quantify magnetic domain correlations. Recent results for CoFe/Cu/SiN3/Si thin films grown with different Cu buffer layer thicknesses show conclusively from both the perpendicular roughness parameters and the in-plane correlation lengths that the interfacial magnetic roughness is much smoother than the interfacial chemical roughness. In Co/Cr/Co trilayer structures, angle and magnetic field dependent XRMS scans used in conjunction with MCD element-specific magnetic hysteresis loops are used to statistically determine that magnetic domains are vertically anti-correlated (preferrentially anti-aligned), indicating the presence of interlayer anti-ferromagnetic exchange coupling.

9:00am **MI-ThM3 Magnetic Structure of Cr Layers in Fe/Cr(001)Superlattices from X-ray Magnetic Dichroism***, **F. Perjeru,** M.M. Schwickert, W.J. Antel, T. Lin, G.R. Harp, M.A. Tomaz,* Ohio University*; W.L. O`Brien,* SRC Madison, Wisconsin

Element-specific magnetometry is used to determine the magnetic moments of Fe and Cr in Fe/Cr(001) superlattices as a function of Cr thickness from 0-50Å, using x-ray magnetic circular dichroism (XMCD) and x-ray magnetic linear dichroism (XMLD). XMCD and XMLD are sensitive to the average magnetization, , and average of squared magnetization,, respectively. High quality Fe/Cr(001) multilayers are prepared by sputter epitaxy and several AF coupling peaks between Fe layers are observed in these films. If antiferromagnetism is present in the Cr layer, it is expected that will be enhanced relative to , that is @sr@ (this assumes layer antiferromagnetism in the Cr with 180° alignment of atom-thick Cr layers). Comparatively, roughness at the experimental Fe/Cr interface might cause frustration which could suppress the antiferromagnetism in the Cr. From measurements of XMCD and XMLD from sputter deposited films, it was found that the Cr atoms have net spin polarization only near the Fe/Cr interface and @sr@ = . This leads to the conclusion that the Cr layers are mainly paramagnetic in the present multilayers, at room temperature. Further experiments are underway to repeat these measurements at 100K, where the tendency to antiferromagnetism within the Cr layer may be enhanced. Both room temperature and low temperature results will be presented.

9:20am **MI-ThM4 On the Nature of Resonant Photoemission in Gd***, **J.G. Tobin,** K.W. Goodman,* Lawrence Livermore National Laboratory*; S.R. Mishra, W.J. Gammon,* Virginia Commonwealth University*; T.R. Cummins, G.D. Waddill,* University of Missouri, Rolla*; G. van der Laan,* Daresbury Laboratory, England, UK

The phenomenon of "resonant photoemission" occurs when, in addition to a direct photoemission channel, a second indirect channel opens up as the absorption threshold of a core level is crossed. A massive increase in emission cross section can occur, but the nature of the process remains clouded. Is it truly "resonant photoemission" or merely the incoherent addition of a second emission channel? Using novel magnetic linear dichroism in photoelectron spectroscopy experiments and computational simulations, we can now clearly demonstrate that temporal matching of the processes as well as energy matching is a requirement for true "resonant photoemission." The photoemission of 4f and 5p electrons from rare-earth metals and their compounds is strongly enhanced when the photon has just enough energy to excite a 4d electron to an unoccupied 4f level, leading to a process called "resonant photoemission". In a generic picture, the indirect channel of the resonant photoemission is interpreted as due to a process where a 4d electron in the initial state is first excited to the unoccupied 4f level, forming a tightly coupled, bound intermediate state, 4d core hole plus 4f electrons. Then a decay via autoionization occurs into the final state, thus producing a final state indentical to that obtained by a direct photoemission process for the ejected electron. The transition rate is greatly enhanced if the excited state decay is by a Coster-Kronig or a super-Coster-Kronig process. The key question is whether these processes are coherent or incoherent: should the overall intensity be treated as a squaring of the sum of the amplitudes (coherent) or summing of the squares of the amplitudes (incoherent)? A true "resonant photoemission" process should be coherent, involving interference terms between the direct photoemission and indirect photoemission channels. Possibly, incoherence would give rise to the loss of photoemission characteristics in the process, with a domination of auger-like properties. To this problem we have applied the new photoelectron spectroscopy technique of magnetic linear dichroism in angular distributions (MLDAD). This technique is related to but distinct from the techniques of magnetic xray circular dichroism (MXCD) in photoelectron spectroscopy and xray absorption. The key is that while large dichroic effects in ferromagnets can be observed with MXCD-photoemission and MXCD-absorption, the large MLDAD effects in ferromagnets is solely a photoemission, not an absorption-driven, process. This is because the chirality which gives rise to magnetic sensitivity is due to the vectorial configuration in MLDAD as opposed to the intrinsic chirality of circularly polarized xrays in the MXCD techniques. In absorption, where there is an essential averaging over all emission angles, the vectorial chirality is lost. Thus, MLDAD is the perfect measurement to distinguish between photoemission and absorption processes. Angle-resolved photoemission in a magnetic system should show an MLDAD effect: xray absorption and thus auger emission will show no MLDAD effect. It is this test which we have applied to the "resonant photoemission" of the Gd5p and Gd4f emissions.

10:00am **MI-ThM6 Combined Spin Polarized Photoemission and Inverse Photoemission of Rare Earth Surface States***, **T. Komesu,** C. Waldfried, P.A. Dowben,* University of Nebraska, Lincoln

The surface of gadolinium has been a subject of much controversy over past years, as to what extent spin mixing and/or Stoner-like exchange coupling are the predominant ingredients of magnetic ordering. The contention is stimulated by the complication that the Gd(0001) surface state is located in the direct vicinity of the Fermi level. For strained Gd(0001) grown of Mo(112), the situation is far worse.@footnote 1@ The surface state is composed of partially occupied spin majority and minority states that extend across the Fermi level into the unoccupied region. Consequently, the magnetic and electronic structure of the Gd(0001) surface cannot be studied by a single experimental technique. Rather the two complementary techniques of photoelectron spectroscopy (PES) and inverse photoemission spectroscopy (IPES) are necessary for a comprehensive investigation of the Gd(0001) surface electronic structure. In this work, we study the surface magnetic structure of strained Gd(0001) through a combination of spin-polarized PES, and spin-polarized IPES. We also find that oxygen antiferromagnetically aligns the surface for strained Gd(0001) which is distinctly different from the case of unstrained Gd(0001).@footnote 2@ @FootnoteText@ @footnote 1@C. Waldfried, T. McAvoy, D. Welipitiya, E. Vescovo and P. A. Dowben, submitted; C. Waldfried, T. McAvoy, D. Welipitiya, P. A. Dowben and E. Vescovo, Europhys. Lett. (1998) in press @footnote 2@D. N. McIlroy, C. Waldfried, D. Li, J. Pearson, S. D. Bader, D. -J, Huang, P. D. Johnson, R. F. Sabirianov, S. S. Jaswal and P. A. Dowben, Phys. Rev. Lett. 76, 2802 (1996)

10:20am **MI-ThM7 X-ray Dichroism Studies of Induced Magnetism in Magnetic Multilayers***, **G.R. Harp,** M.A. Tomaz, W.J. Antel, M.M. Schwickert, T. Lin, F. Perjeru,* Ohio University **INVITED**

X-ray magnetic circular dichroism (XMCD) and linear dichroism (XMLD) are applied to study the element-specific magnetization in Fe/TM(001) superlattices (here TM = V, Cr, Co, Ni, Nb, Mo, Ru, Rh, Pd, Ta, W, Pt). Within the Fe layers (5-20 Å thickness) we observe a wide variety of behaviors, from strong enhancement to complete suppression of the magnetic moment. The details depend on the spacer material and the crystal structure of the superlattice (bcc, fcc, or hcp). The real power of x-ray dichroism, however, is seen in studies of the spacer layer moments, which are often quite small. Various behaviors are observed depending on the spacer material. For ferromagnetic elements (Ni, Co) a strong moment enhancement is sometimes observed (Ni) or sometimes not (Co). For nonmagnetic elements, the induced magnetization may be parallel or antiparallel to that of the Fe. This induced magnetic moment may be confined to the interface region (e.g. Cr), may decay slowly toward the layer interior (e.g. V), or may be almost ferromagnetic, in the sense that the average moment per atom is constant over a range of thicknesses (e.g. Pt). Additionally, x-ray magnetic LINEAR dichroism can probe antiferromagnetic arrangements within spacer layers. As an example, XMLD is applied to the Fe/Cr system to search for commensurate antiferromagnetism within the Cr layers.

11:00am **MI-ThM9 A Controversy Over the Magnetic Structure of Mn Overlayers on Fe and the Role of Oxygen Impurities@footnote 1@***, S. Banerjee,* University of Wisconsin, Milwaukee*; W.L. O'Brien,* University of Wisconsin, Madison*; B.P. Tonner,* University of Wisconsin, Milwaukee

The magnetic coupling across the Fe-Mn interface for ultrathin films of Mn grown on Fe has recently been the focus of both experimental and theoretical research efforts, but without substantial agreement. For example, experimental results claim both parallel@footnote 2@ and antiparallel@footnote 3,4@ magnetic coupling between a submonolayer Mn film and the Fe substrate. This disagreement is made even more interesting by a theoretical analysis which shows that the interlayer magnetic coupling between Mn and Fe is very sensitive to both lattice spacing and valence band structure.@footnote 5@ In an effort to better understand the interface magnetic coupling of this model system we have made a series of x-ray magnetic circular dichroism (XMCD) measurements on the Mn-Fe interface for different Mn coverages, on Fe substrates with both the fct and bcc crystal structures. In addition we investigated the effects of small exposures to oxygen on the magnetic order and coupling for coverages up to one monolayer. The Mn/Fe system is extremely reactive, and shows changes in magnetic state with exposures times as low as 10 minutes at 2 X 10@super -10@ Torr. Our findings show that the chemical state of Mn has a tremendous effect on the magnetization at the Fe-Mn interface while the in plane lattice constant and crystal structure do not. The effect of oxygen exposure is to ferromagnetically align the Mn atoms with an orientation antiparallel to the Fe. The intrinsic magnetic state of Mn on Fe, found by extrapolation to zero exposure to contaminating gases, is that of zero magnetic moment at room temperature. @FootnoteText@ @footnote 1@Work supported by the National Science Foundation DMR and performed at the Wisconsin Synchrotron Radiation Center. @footnote 2@S. Andrieu et. al., Phys. Rev. B 57, 1985 (1998). @footnote 3@O. Rader, W. Gudat, D. Schmitz, C. Carbone, and W. Eberhardt, Phys. Rev. B 56, 5461 (1997). @footnote 4@J. Dresselhaus et. al., Phys. Rev. B 56, 5461 (1997). @footnote 5@ R. Wu and A.J. Freeman, Phys. Rev. B 51, 17131 (1995).

11:20am **MI-ThM10 Morphology of Mn Films on Fe(001)@footnote 1@***, **A.D. Davies**, D.T. Pierce, J.A. Stroscio, R.J. Celotta,* National Institute of Standards and Technology

Manganese and iron thin film structures have shown promise for studying indirect exchange coupling and for investigating novel magnetic thin film systems. As a function of temperature and stress, Mn has a large variety of structural and magnetic states, so it is particularly important to fully characterize the structure in these films to understand the magnetic behavior. Here we report on scanning tunneling microscopy (STM) measurements of epitaxial Mn films up to ~10 atomic layers grown on Fe(001) at 155 ± 10 °C. The film growth and structure varies dramatically with film thickness and exhibits a range of unusual spatial inhomogeneities. At this growth temperature, the growth is nearly layer-by-layer and shows a decrease with thickness in the island density of ~25 times. Concurrent with this length scale change, the island shape changes from facets along directions to oriented facets. While the atomic-layer height for submonolayer films is difficult to define due to electronic differences, the atomic step height of the second Mn layer is 1.44 ± 0.07 Å and surface step heights of all subsequently thicker films are 1.61 ± 0.03 Å. For films beyond ~2 atomic layers, curious small regions are observed that are a fraction of an atomic step high. The height, shape, frequency, and location of these regions vary with film thickness. The film structure is markedly different in the vicinity of steps on the Fe substrate at almost every coverage. This difference and other observed aspects of the growth suggest that the growth is very sensitive to local stress. @FootnoteText@ @footnote 1@ Supported in part by the Office of Naval Research.

11:40am **MI-ThM11 Light Scattering Cross Section for Mode Crossing of Spin Waves in Magnetic Films***, **F. Nizzoli**,* University of Ferrara and INFM, Italy*; J.M.V. Ngaboyisonga,* Makerere University, Uganda*; L. Giovannini,* University of Ferrara and INFM, Italy

The dispersion curves of spin waves in magnetic films show a typical behavior as a function of the surface wave vector, film thickness and in-plane propagation angle, i.e. mode repulsion between the surface mode and bulk modes. The purpose of this work is to study theoretically the Brillouin light scattering (BLS) intensity from spin waves versus the surface wave vector Q in case of mode repulsion in a magnetic film of thickness d, under the condition Qd nearly equal to 1. In such a case both dipole and exchange interactions are equally important and must be included. The calculations, for a 85 nm thick iron film, are performed within the macroscopic partial waves approach of Rado-Hicken and Cochran-Dutcher, based on the solution of the Landau-Lifshitz equation of motion of the magnetization with the proper boundary conditions. It is found that the BLS cross section shows an antiresonant behavior close to the gap between the modes. We have investigated the physical meaning of this behavior by analyzing the different contribution of the partial waves to the cross section . For Q below the gap three relevant partial waves interfere destructively, while the opposite occurs for a wave vector above the gap. The interference effects, responsible for the Fano-type antiresonant behavior of the total scattering intensity, are explained in terms of a sudden change of the dynamic magnetization across the film, when mode repulsion occurs. The effect of the magnetic anisotropy on the antiresonant behavior of the BLS cross section is also investigated.

Thursday Afternoon, November 5, 1998

Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI-ThA

Structure & Magnetism of Surfaces & Interfaces

Moderator: J.G. Tobin, Lawrence Livermore National Laboratory

2:00pm **MI-ThA1 Exchange Coupling in Co/Au/Co Sandwiches**, ***T. Duden***, *E. Bauer,* Arizona State University

The evolution of the magnetic domain structure during the growth of the Co layer on top of (111)-oriented Au spacer layers deposited onto a W(110) surface is studied by spin-polarized low energy electron microscopy. Pronounced biquadratic coupling is found not only at the nodes of the bilinear coupling but generally above the spin reorientation transition in the top layer. This produces a wrinkled magnetization or magnetization waves in the top layer. The results are discussed in the light of the various mechanisms which can lead to biquadratic coupling.

2:20pm **MI-ThA2 Experimental and Model Theoretical Dispersions of Unoccupied Metallic Quantum Well States in Cu/fccCo/Cu(100) and Related Systems**, ***A.G. Danese***, *F.G. Curti, R.A. Bartynski,* Rutgers University

The dispersion with parallel momentum (k @sub ||@) of unoccupied metallic quantum well (MQW) states in the Cu/fccCo/Cu(100) system has been measured using inverse photoemission and modeled using a phase accumulation approach. For Cu films in the 2 - 4 monolayer range, a state close to the Fermi level is observed to have a flat dispersion near the neck of the Cu Fermi surface along the @GAMMA@-BAR X-BAR direction of the two dimensional Brillouin zone. Appearance of this state coincides with a hybridization gap in the Co minority spin bands. The calculation shows that the large effective mass of this state is the result of the rapid change in the scattering phase shift across the gap. The periodicities with which MQW states cross the Fermi level at the center and at the neck of the Cu Fermi surface, which correspond to the long and short period oscillatory magnetic coupling in this system, are well reproduced by the calculation. Furthermore, the observed phase shift of the short period magnetic coupling when the ferromagnetic layer is changed from Fe to Co to Ni layers can be attributed to changes in the position of this hybridization gap with respect to the Fermi level across this series. The effect of this behavior on the strength of the short period magnetic coupling in these systems is discussed.

2:40pm **MI-ThA3 Spin-Polarized Quantum Well States**, ***K.N. Altmann***, *W.L. O'Brien, D.J. Seo, J. McKay,* Synchrotron Radiation Center, Univ. of Wisconsin, Madison*; F.J. Himpsel,* University of Wisconsin, Madison*; P. Segovia, A. Mascaraque, E.G. Michel,* Univ. Autonoma Madrid, Spain*; A. Naermann, J.E. Ortega,* Univ. del Pais Vasco, San Sebastian, Spain

Quantum well states are intimately connected to the oscillatory magnetic coupling observed in magnetic multilayers.@footnote 1,2,3@ The spin-polarization of these states is non-trivial since they reside in a non-magnetic spacer material. We have grown Cu/Co/Cu-(100) quantum wells in a chamber containing RHEED, SMOKE, MBE, and sputtering facilities. The high quality of our fcc-Co(100) layers is evidenced by the extremely low coercivity of < 1 Oe, which indicates minimal pinning of the domains at defects. These films were transferred in situ to a spin-polarized, angle-resolved photoemission system that uses undulator radiation from the SRC. Quantum well states with s,p and d character were observed when depositing films with sharp interfaces at low temperature and annealing them to room temperature. Also, a surprisingly-strong photon energy dependence was observed, even at energies of 70-80 eV, which needs a rethinking of the excitation process for "two-dimensional" quantum well states. Some of the quantum well states appear to be split, either due to multiple layer thicknesses, or due to a highly-unusual "inverted" magnetic splitting. Scanning tunneling spectroscopy measurements are in progress to find the layer-by-layer change in the energy of quantum well states. @FootnoteText@ @footnote 1@J.E. Ortega and F.J. Himpsel, Phys. Rev. Lett. 69, 844 (1992). @footnote 2@P. Segovia, E.G. Michel, and J.E. Ortega, Phys. Rev. Lett. 77, 3455 (1996). @footnote 3@F.J. Himpsel, J.E. Ortega, G.J. Mankey, and R.F. Willis, Adv. Phys., in press.

3:00pm **MI-ThA4 Systematic Measurement of Exchange Coupling Across the Periodic Chart of 3-d Transition Elements to Understand Magnetization In Ferromagnetic Mn Alloys@footnote 1@**, ***W.L. O'Brien,*** University of Wisconsin, Madison*; S. Banerjee, B.P. Tonner,* University of Wisconsin, Milwaukee

Ultrathin films of Mn alloyed with Fe, Co and Ni have magnetic properties quite distinct from their bulk counterparts with same composition. Even the sign of exchange coupling in the ultrathin films are opposite to those of bulk alloys. For example, Mn impurities in bulk Fe are ferromagnetic with the magnetization of Mn parallel to the Fe magnetization, while we find that ultrathin alloys of the same composition are ferrimagnetic with an antiparallel coupling between Mn and Fe. Bulk Mn-Co alloys with dilute Mn concentration are ferrimagnetic with antiparallel coupling between Mn and Co whereas ultrathin films of same composition have the magnetization of Mn parallel to the Co. Finally, bulk 1:1 MnNi is an antiferromagnet, while the ultrathin alloys of same composition are ferromagnetic with Mn magnetization parallel to the Ni magnetization. To explore how widespread are these substantial differences in the magnetic phase diagrams of the ultrathin films, as compared to bulk, we performed a systematic measurement of the magnetic coupling for V, Cr, Mn, Fe, Co and Ni overlayers to Fe, Co and Ni substrates. The sign of the exchange coupling can be summarized by a simple electron counting rule. In this analysis of the periodic chart, we do not find parallel magnetic coupling when the sum of the formal atomic number of d electrons per atom (overlayer plus substrate) is less than 12. Considering this d=12 rule, Mn is located in a special position in the periodic table near the transition region between parallel and antiparallel coupling with Fe, Co and Ni. This rule works both for atomically clean surfaces, and surfaces modified by chemisorption. @FootnoteText@ @footnote 1@Work supported by the National Science Foundation, DMR, and performed at the Wisconsin Synchrotron Radiation Center.

3:20pm **MI-ThA5 Epitaxial Fe and Co Layers on Cu Crystals**, ***J. Kirschner***, Max-Planck-Institut für Mikrostrukturphysik, Germany **INVITED**

Fe and Co exhibit a multitude of structural and magnetic phases when deposited on to high-index planes of fccCu. Much work has been done on films made by thermal deposition or sputter deposition. We added pulsed laser deposition (PLD) in UHV and chemical deposition, and studied similarities and dissimilarities. Most striking effects are observed for pulsed laser deposition, which may alter the growth mode (from 3D growth for thermal deposition (TD) to layer-by-layer growth for PLD), magnetic anisotropies (from perpendicular (TD) to in-plane (PLD) for Fe/Cu(100), and magnetic moments (from low-spin (TD) to high-spin (PLD) for Fe/Cu(111). Co deposited electrochemically on to Cu(100) grows pseudomorphically up to 5 monolayers and non-pseudomorphically beyond. This has been found by in-situ surface x-ray diffraction. Effects of reduced dimensionality ocurr at surfaces and at steps. In the former case an oscillatory behaviour of the surface magnetization with one monolayer period has been observed by magneto-optical second harmonic generation. Magnetic nano-wires may be created by step edge decoration on stepped Cu(111). These resemble one-dimensional Ising chains (which has no net magnetization at thermal equilibrium), but show magnetic hysteresis at low temperature.

4:00pm **MI-ThA7 Fermi Surface Study of Pseudomorphic Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@ Thin Films on Cu(100)**, ***M. Hochstrasser***, *F.O. Schumann*, R.F. Willis,* Pennsylvania State University*; T.R. Cummins, G.D. Waddill,* University of Missouri, Rolla*; S.R. Mishra, J.G. Tobin,* Lawrence Livermore National Laboratory*; E. Rotenberg,* Lawrence Berkeley National Laboratory

We report angle resolved photoemission studies of the electronic behavior of ultrathin epitaxial layers of fcc structured binary alloys, Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@, deposited by molecular beam epitaxy on Cu(100) substrates. In particular, we have used Fermi surface mapping to monitor changes in the Fermi surface with increasing magnetization density. Fermi surface mapping has shown to be a valuable method to investigate for example the collapse of the exchange splitting between the upper and lower d-band in Ni@footnote 1@ and surface electronic states of hydrogen adsorbed on W(110).@footnote 2@ Co@sub 1-x@Ni@sub x@ and Fe@sub 1-x@Ni@sub x@ binary alloys show a different behavior in the bulk. Co@sub 1-x@Ni@sub x@ is structurally and magnetically well-behaved. In particular the magnetic moment varies linearly as a function of concentration. This is in sharp contrast to fcc Fe@sub 1-x@Ni@sub x@ which displays a magnetic instability at ~65% Fe content. An extended regime of fcc stability is possible via epitaxy on Cu(100).@footnote 3@ We investigated the changes in the Fermi surfaces of Fe@sub 1-x@Ni@sub x@ and Co@sub 1-x@Ni@sub x@ pseudomorphic film alloys depending on various concentrations of Ni in a large photon energy regime and compared these measurements with the known Fermi surface of Ni(100), Cu(100) and Co(100). We observe a change in the Fermi surface with increasing magnetization density e.g. number of holes in the d-band by changing the stoichiometry of our samples. @FootnoteText@ *present address: Department of Chemistry and Material Science, Lawrence Livermore National Laboratory, U.S. @footnote 1@T. Greber et al., Phys. Rev. Lett. 79, 4465 (1997). @footnote 2@E. Rotenberg et al., Phys. Rev. Lett. 80, 2905(1998). @footnote 3@F.O. Schumann et al., Phys. Rev. Lett. 79, 5166 (1997).

4:20pm **MI-ThA8 Growth Study of FePt(001) L1_0 ordered alloys using a Temperature Wedge Method***, **M.M. Schwickert**,* Ohio University*; M.F. Toney, M.E. Best, J.-U. Thiele, L. Folks,* IBM Almaden Research Center*; G.R. Harp,* Ohio University*; D. Weller,* IBM Almaden Research Center

The L1_0 ordered phase of FePt has unique properties like enhanced magneto-optical Kerr effects and large magnetic anisotropy. Of particular interest is the formation temperature and growth kinetics of this phase. Fully ordered material has been synthesized using MBE growth at temperatures as low as 500oC. Spontaneous ordering induced by surface diffusion with a 0.2 eV barrier height was found.@footnote 1@ The present study aims at a combinatorial mapping of growth temperatures and seed techniques of MBE type, (001) and (110) oriented FePt films on MgO substrates. We have developed a temperature wedge technique in which temperature gradients of several hundred Kelvin can be established. Respectively, electron beam evaporated films show systematic dependencies of magnetic, magneto-optic and structural properties as function of "wedge" position, corresponding to temperature. Magnetic hysteresis properties and anisotropy fields were characterized with a polar and transverse Kerr looper with spatial resolution. Structural data including quantification of the long range chemical ordering S as function of temperature were obtained from x-ray diffraction measurements. Finally we report on a combined AFM/MFM study of these films, revealing the equilibrium magnetic domain structure in correlation with topographic features. @FootnoteText@ @footnote 1@R.F.C. Farrow et al., Appl. Phys. Lett. 69, 116 (1996)

4:40pm **MI-ThA9 The Effect of Oxygen on the Growth and the Surface Magnetism of Iron Films***, R. Moroni, F. Bisio, M. Salvietti, M. Canepa, **L. Mattera**,* University of Genova, Italy

The effect of oxygen on the growth and the surface magnetism of iron films has been investigated by Helium Reflectivity (HR) and Spin Polarized Metastable Deexcitation Spectroscopy (SPMDS) during the growth of Fe on an O(1X1)-Fe adlayer. HR and SPMDS measurements are performed contemporarily, providing real time information on defect density (HR) and electronic and magnetic properties (SPMDS) at surface as the growth proceeds. At room temperature, on O(1X1)-Fe, iron grows layer-by-layer, the oxygen atoms acting as surfactants. The intensity of the features induced by O@sub 2p@ and Fe@sub 3d@ states in the electron distribution curves detected following the deexcitation of metastable atoms remain unchanged during the growth indicating that the surface composition is constant: the oxygen atoms remain segregated at surface by position exchange with incoming iron atoms. Helium reflectivity and magnetization intensity oscillate in-phase during growth: significant oscillations of the magnetization intensity are observed in perfect phase with the cyclic order/disorder transitions. Such a behaviour provides a real time, direct experimental evidence of the strong correlation between structural order and magnetization intensity.

5:00pm **MI-ThA10 Magnetic Properties of Ultrathin Fe/Gd and Gd Thin Films***, **C.S. Arnold**,* National Institute of Standards and Technology, US*; D.P. Pappas,* National Institute of Standards and Technology

Ultrathin films of magnetic transition metals are known to grow amorphously on rare-earth substrates. Magnetically, these films exhibit a strong perpendicular anisotropy and antiferromagnetic coupling of the transition metal to the rare earth atoms at the interface. Fe films 1- 4 monolayers thick grown on Gd substrates conform to this behavior, but also exhibit a reorientation phase transition (RPT) with temperature. This RPT is unlike those of ultrathin films on non-magnetic substrates because it is driven by the loss of magnetic order in the substrate as the bulk Gd Curie temperature is approached. Spin-polarized secondary electron polarimetry and SMOKE susceptibility measurements are employed to study the surface, bulk and interfacial magnetization as a function of temperature and Fe thickness. A partial thickness-temperature phase diagram is constructed. A second focus of the work is a comparison of surface and bulk magnetization vs. temperature in thin Gd films. The existence of a magnetic surface state is well established by spin-polarized spectroscopies, but direct comparisons of surface and bulk macroscopic magnetizations are rare in the literature. An earlier experiment using MOKE and electron spin-polarimetry to measure M(T) for the bulk and surface respectively is repeated.

Magnetic Interfaces and Nanostructures Technical Group
Room Hall A - Session MI-ThP

Magnetic Interfaces and Nanostructures Poster Session

**MI-ThP1 Comparison of Cl@sub2@ and F@sub2@ Based Chemistries for the Inductively Coupled Plasma Etching of NiMnSb Thin Films*, J. Hong,* *J.A. Caballero, E.S. Lambers, J.R. Childress, S.J. Pearton,* University of Florida, Gainesville

Plasma etching chemistries based on BCl@sub3@/Ar, BCl@sub3@/H@sub2@ and NF@sub3@/Ar were studies for patterning NiMnSb Heusler Alloys thin films and associated Al@sub2@O@sub3@ barrier layers under Inductively Coupled Plasma. Using BCl@sub3@/Ar discharges, high etch rates (@>=@1µm) were achieved either at high source power (1000W) or high dc self bias (-300V) and etch rates showed a strong dependence upon source power, ion energy and gas composition. Hydrogen addition to the BCl@sub3@ created new species (HCl) in the plasma, leading to the fast etching for NiMnSb, in contrast to the situation of Ar addition. Selectivities of @>=@8 for NiMnSb over Al@sub2@O@sub3@ were obtained in BCl@sub3@-based discharges. On the other hand, NF@sub3@/Ar discharges provided a narrow process window for the etching of NiMnSb and etch rates of NiMnSb were much lower compared to BCl@sub3@. The surface of NiMnSb etched with NF@sub3@/Ar was smoother with RMS surface roughness of 1.4nm measured by Atomic Force Microscopy than the surface produced with BCl@sub3@/Ar. In terms of near surface chemistry, etched surface with NF@sub3@/Ar revealed Mn-enriched, indicating the existence of involatile Mn etch products, whereas Mn-deficiency at the near surface was obtained with BCl@sub3@/Ar.

**MI-ThP2 Magnetic Moment of fcc Fe in [Fe/Pd@sub x@Rh@sub 1-x@] Multilayers*, T. Lin,* *M.A. Tomaz,* Ohio University*; W.L. O'Brien,* University of Wisconsin, Madison*; T.K. Sham,* University of Western Ontario, Canada*; G. Retzlaff,* University of Wisconsin, Madison, US*; G.R. Harp,* Ohio University

Results are presented of the magnetic state of fcc Fe in [Fe/Pd@sub x@Rh@sub 1-x@ 10Å] superlattices with x = 0-100%. It was found that 10Å Fe layers have an fcc structure and undergo a magnetic phase transition from paramagnetic to ferromagnetic with increasing x. Its magnetic moment increases to a maximum near x=50%, and then decreases monotonically with increasing x. For thicker Fe layers, a similar behavior is observed, except that the magnetic phase transition can be suppressed. This behavior is explained in terms of small structural variations of the superlattices due to the different lattice constants of Pd and Rh. The sample structures are characterized using x-ray diffraction, and are characterized magnetically using magneto-optic Kerr effect magnetometry and x-ray magnetic circular dichroism.

MI-ThP3 Interface Alloying and Deterioration of the Magnetic Properties in Co/Cu(001)*, S. van Dijken, L.C. Jorritsma,* ***T. de Vries****, B. Poelsema,* University of Twente, The Netherlands

The initial growth of Co-films on Cu(001) and their magnetic properties are studied in a wide temperature range using helium diffraction (TEAS), high resolution low energy electron diffraction (SPA-LEED) and sensitive magneto-optical (SMOKE) measurements. TEAS shows that first an almost perfect bilayer is grown even at relatively low temperatures (250 K). Its microcopic origin is discussed. SPA-LEED data reveal a distinct anomaly in the temperature dependence of the island separation occurring at about 325 K, where the drastic decrease of the separation and a clear broadening of the separation distribution function is attibuted to an increased interface alloying. This morphological change coincides with a substantial decay of the Curie temperature, Tc, of a 2 ML thick Co film as detected with SMOKE measurements and compared to those found for films grown between 250 and 300 K. A lower Tc is also found for different reasons (film roughness!) at deposition temperatures below 225 K.

MI-ThP4 Unique Photoelectron Spectrometers for Spin-Polarized Photoemission Studies*, G.D. Waddill,* *A. Jones, T.R. Cummins,* University of Missouri, Rolla*; J.G. Tobin,* Lawrence Livermore National Laboratory*; S.R. Mishra,* Virginia Commonwealth University*; D.P. Pappas,* National Institute of Standards and Technology*; R. Negri, E. Peterson,* Physical Electronics, Inc.*; R. Gunion,* ESG Consulting*; M. Hochstrasser, R.F. Willis,* Pennsylvania State University

The design and performance of two novel photoelectron spectrometers for elementally-specific spin-polarized measurements of magnetic surfaces and thin films are presented. Both instruments combine a large diameter hemispherical electron energy analyzer with a unique electron detection scheme that can be switched in situ between spin-dependent and spin-independent measurements. Spin-polarization is determined by use of a mini-Mott detector. Spin-independent measurements can be made using an energy dispersive multi-channel electron detection scheme. One instrument has a fixed angle between the incident photons and the detected photoelectrons, while use of a novel electron lens system enables this angle to be varied through a wide range for the second instrument. Both instruments are based at the Advanced Light Source (the fixed angle instrument at the Spectromicroscopy Facility, and the variable angle instrument at the Elliptically Polarized Undulator). Results of preliminary investigations of both magnetic and nonmagnetic materials using variants of magnetic x-ray linear and circular dichroism will be presented. The work at UMR and PSU was supported by the Department of Energy, Office of Basic Energy Sciences (DE-FG02-96ER45595). The work at LLNL was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48. The Spectromicroscopy Facility, the Elliptically Polarized Undulator, and the Advanced Light Source were constructed and are operated with the support of the Department of Energy, Office of Basic Energy Sciences.

MI-ThP5 Minor Loops in a Bimodal Magneto-Optical Medium*, R.A. Fry,* *L.A. Bennett, E. Della Torre,* The George Washington University

Bimodal magnetic behavior was recently encountered in a (0.3nm Co/1.2nm Pt)@sub 15@ multilayer magnetic film with perpendicular magnetization by using an automated magneto-optical Kerr effect (MOKE) magnetometer.@footnote 1@ In the two separate magnetic transitions, differences in the ratio of the Kerr rotation to ellipticity were noted. To explain this behavior, it was postulated that there are two different magnetic entities (layers) in this material, each with a characteristic switching field, Kerr rotation, and Kerr ellipticity. To further investigate the magnetization behavior in this material, including magnetic exchange interactions between the two magnetic species, a series of minor loop experiments was performed. From the major loop data, two critical switching field values were observed, H@sub K1@ and H@sub K2@, where H@sub K1@ > H@sub K2@. H@sub K1@ is the smallest reversal field required to fully saturate the material, and H@sub K2@ is the field at which the observed step in the loop occurs. From the minor loops, a third critical field is identified as H@sub K3@. The observed magneto-optical behavior can be explained by defining two interacting magnetic entities, A and B, with intrinsic coercivities, H@sub A@ and H@sub B@. H@sub K1@ is the sum of H@sub A@ and the interaction field (H@sub i@); H@sub K2@ is the sum of H@sub B@ and H@sub i@; and, H@sub K3@ is the sum of -H@sub B@ and H@sub i@. The height of the minor loop is directly related to where on the major loop the reversal is initiated. By using minor loop MO measurements, the observed bimodal magnetization behavior was decomposed into two individual loops which are mutually interacting. From this decomposition, the intrinsic coercivities of the individual magnetic entities, as well as the interaction field between them, was obtained. This paper presents the experimental data and the excellent fit to this proposed model. We thank Dr. R.F.C. Farrow for providing these samples and N.I.S.T. for financial support. @FootnoteText@ @footnote 1@R.A. Fry, L.H. Bennett, E. Della Torre, R.D. Shull, W.F. Egelhoff, Jr., R.F.C. Farrow, and C.H. Lee, to be presented at Seventh International Conference on Magnetic Recording, (1998)

MI-ThP6 X-Ray Magnetic Linear Loops (XMLL)*, M.M. Schwickert*, Ohio University*; W.L. O'Brien,* University of Wisconsin, Madison*; G.R. Harp,* Ohio University

The x-ray magnetic linear dichroism (XMLD) in absorption relies upon the dichroic contrast of two perpendicular magnetization states. We introduce a novel variation to the conventional XMLD experiment which we term XMLL. We have observed the photoabsorption of linearly polarized light while rotating the magnetizaton vector M via an applied magnetic field with frequency w. Extracting the magnetic information from the absorption background leads to the x-ray magnetic linear loops (XMLL). The presented results were obtained by using linearly polarized synchrotron radiation at the L_3 absorption edge of Fe. In accordance with the M^2 dependence of the XMLD effect, we have found that the XMLL frequency spectrum is dominated by 2w, as opposed to possible w or 4w contributions. We applied this technique to Fe/Cr(001) multilayers that are antiferromagnetically exchange coupled. In low magnetic fields when the sample is in the spin-flop state the XMLLs are inverted as compared to ferromagnetic samples, such as Fe thin films. XMLL results for these samples are presented and we discuss applications of XMLL as a characterization tool especially suited to antiferromagnetic materials.

MI-ThP7 Nonlinear Magneto-Optical Kerr Effect in Co-Cu Nanogranular Films*, **T.V. Misuryaev**, E.A. Ganshina, S.V. Guschin, T.V. Murzina, O.A. Aktsipetrov,* Moscow State University, Russia

Magnetic nanostructures and surfaces of magnetic materials have attracted a lot of attention recently because of the observation of new magnetic effects which are not observed in the bulk materials. Apart from magnetic phenomena such as giant magnetoresistance and oscillatory coupling through nonmagnetic spacers magnetic nanostructures can reveal significant nonlinear-optical effects induced by magnetization, e.g. the giant nonlinear magneto-optical Kerr effect (NOMOKE). Magnetization induced optical second harmonic generation (MSHG) has been demonstrated to be effective, sensitive and versatile probe of macroscopic magnetic properties of surfaces and buried interfaces. In this paper both magneto-optical Kerr effect (MOKE) and NOMOKE are studied in granular films composed by nanocrystals of Co in Cu matrix. The samples of Co-Cu granular films were prepared by the co-deposition of Co and Cu on fused quartz substrate. The films thickness is about 200 nm. The mean size of Co nanocrystals is about 60 nm for the Co@sub 0.42@Cu@sub 0.58@ film measured by STM technique. The output of a Q-switched YAG:Nd@super +3@ laser at 1064 nm, with a pulse duration of 15 ns and an intensity of 2 MW/cm@super 2@ is used for the MSHG studies. MOKE spectra for Co@sub 0.42@Cu@sub 0.58@ film are measured in the energy range of 1.2-3.6 eV. The azimuthal anisotropy of the SHG intensity observed can be attributed to the existence of a polar axis in the structure of the Co-Cu granular films, which gives rise to a bulk electrodipole susceptibility. This polar structure can be caused by a predominant regular asymmetry of the filmvacuum interface during film processing. MSHG is studied in the polar, longitudinal and transversal NOMOKE configurations. The magneto-induced rotation the second harmonic (SH) wave polarization, the magneto-induced shift of the SH wave phase (the MSHG interferometry) and magneto-induced changes in the SHG intensity are measured. For all configurations, the NOMOKE parameters exceed the MOKE parameters at least by an order of magnitude. The interference in the far-field region of the SH fields generated by the interface and bulk nonmagnetic and magneto-induced contributions to the nonlinear polarization is suggested as a mechanism of the NOMOKE enhancement.

Magnetic Interfaces and Nanostructures Technical Group
Room 324/325 - Session MI-FrM

Magnetization Dynamics and Magneto-Optics

Moderator: J. Unguris, National Institute of Standards and Technology

8:20am **MI-FrM1 Magnetization Dynamics: A Study of the Ferromagnet/Antiferromagnet Interface and Exchange Biasing**, ***R.E. Camley**,* University of Colorado, Colorado Springs **INVITED**

We use a method which employs a dynamic calculation of magnetization motion to find both the static configuration and the spin wave excitations in a ferromagnet/antiferromagnet layered structure. Our results for the static structure are similar to those found in Koon's model; i.e. in zero applied field the ferromagnet points perpendicularly to the easy axis of the antiferromagnet, and the surface spins of the antiferromagnet are in a surface spin flop configuration. The calculated hysteresis curve for this structure shows a small exchange bias, in agreement with typical experimental results. We explore how this bias depends on the parameters of the antiferromagnet and on the nature of the interface coupling. The spin wave modes are developed using the same simple model. The frequency of the lowest spin wave in the ferromagnet shows a dramatic dip when the ferromagnet spins begin to rotate - where the hysteresis curve drops as the field is reduced from the saturated state. The spin wave modes in the ferromagnet should be easily observed by Brillouin Light Scattering. The spin waves in the antiferromagnet also show dramatic changes as the antiferromagnet structure is changed.

9:00am **MI-FrM3 Switching Field Measurements of Longitudinal Magnetic Recording Media***, **A. Moser**, D. Weller, M.E. Best,* IBM Almaden Research Center **INVITED**

Media stability is one of the key issues in the development of future high density magnetic recording media, as it determines the lifetime of a disk. At short time scales the coercivity strongly increases and recording information requires high write fields. Both, media stability and enhanced coercivity at short time scales can be examined using switching field measurements H@sub CR@ as a function of the magnetic field pulse width t. The data can be analyzed within the framework of the Arrhenius-Neel law using the equation H@sub CR@ = H@sub 0@ (1 - [C log(t f@sub 0@)]@super n@).@footnote 1@ Here, the constant C describes the stability of the media and is related to the viscosity parameter. H@sub 0@ is an intrinsic switching field related to the anisotropy field H@sub K@, f@sub 0@ is an attempt frequency (of the order of 10@super 9@ Hz) and n is an exponent which takes values between 1/2 and 1. By measuring H@sub CR@ over more than 9 decades in time using a novel experimental method, we can determine both the stability parameter C and the switching field H@sub 0@ for a series of CoPtCr media of different thicknesses.@footnote 2@ These samples have varying areal moment densities Mrt between 0.17 and 0.39 memu/cm@super 2@ and remanence coercivities H@sub CR@ between 500 and 2500 Oe at a pulse width of 1 s. It will be shown that H@sub CR@ can vary by more than a factor of 3 over the observed range of pulse widths. The results are compared to conventional signal decay measurements and to experimental and theoretical results found in literature.@footnote 3@ @FootnoteText@ @footnote 1@M.P. Sharrock, IEEE Trans. Magn. 26, (1990) 193. @footnote 2@Samples provided by M. Doerner, IBM Storage Systems Division, 5600 Cottle Rd., San Jose, CA 95193 @footnote 3@M.Yu, M.F. Doerner, D.J. Sellmyer, MMM-Intermag ?98, San Francisco, Jan. 6-8, 1998

9:40am **MI-FrM5 Magnetic Properties of Submicron Magnetic Wires Fabricated by e-beam Lithography Investigated by using GMR Effect***, **T. Ono**, H. Miyajima,* Keio University, Japan*; K. Shigeto, K. Mibu, N. Hosoito, T. Shinjo,* Kyoto University, Japan

The magnetization reversal study of a single submicron magnetic wire is presented. The magnetization reversal in a single submicron magnetic wires can be very sensitively observed by utilizing the giant magnetoresistance (GMR) effect.@footnote 1@ GMR is the electrical resistance change accompanied with the change of magnetic structure. This means, in turn, the magnetic structure of the system can be determined from the resistivity measurements. In a wire case, the magnetic shape anisotropy restricts the direction of the magnetization to be parallel or antiparallel along the wire axis. The GMR change is directly proportional to the magnitude of the switching layer magnetization. A single NiFe(40nm)/Cu(20nm)/NiFe(5nm) trilayer wire 500 nm in width was prepared. An artificial neck was introduced in the wire. The temperature dependences of the nucleation field and the propagation velocity of the magnetic domain wall in the wire were studied by using the GMR effect. The result clearly shows that the artificial neck works as a pinning center for the magnetic domain wall. The temperature dependence of the nucleation field in a single submicron magnetic wire was investigated by measuring the coercive field at which the electrical resistance abruptly changes by the GMR effect. The nucleation field shows a thermal excitation behavior down to 5 K. The study at lower temperatures, down to 50 mK, is now in progress. By measuring the time dependence of the resistance during the magnetization reversal, the propagation velocity of the magnetic domain wall was estimated. Under the external magnetic field of 90 Oe, the velocity in the NiFe layer (40 nm in thickness and 500 nm in width) is about 5 cm/s at 77 K, the velocity of which is much smaller than that reported by Sixtus and Tonks for bulk NiFe wire in 1931.@footnote 2@ @FootnoteText@ @footnote 1@T. Ono, H. Miyajima, K. Shigeto and T. Shinjo, Appl. Phys. Lett. 72, 1116 (1998). @footnote 2@K.J. Sixtus and L. Tonks, Phys. Rev. 37, 930 (1931).

10:00am **MI-FrM6 Magnetic Reversal on Vicinal Surfaces***, R.A. Hyman,* Georgia Institute of Technology*; **M.D. Stiles**,* National Institute of Standards and Technology*; A. Zangwill,* Georgia Institute of Technology

Ultrathin films of magnetic material on non-magnetic vicinal substrates may be the simplest systems that exhibit non-uniform magnetization reversal. These systems can be modeled by equally spaced and infinitely long step edges separating flat terraces. The intrinsic four-fold anisotropy of the terraces is augmented by uniaxial anisotropy localized at the step edges. For in-plane magnetization, the zero temperature behavior of these systems depends on two dimensionless parameters: the ratio of the step anisotropy energy to the domain wall energy on the flat terraces, and the ratio of the terrace length to the domain wall width. Numerical results give a rich phase diagram for the hysteresis loop structure as a function of these two parameters. In some cases, simple analytic formula for the domain wall depinning field can be derived that agree well with numerical work. For some values of the system parameters, the calculated hysteresis curves exhibit the shifted loop structure found in experiments. The reversal processes are a combination of domain nucleation at step edges, depinning due to domain wall interactions, and coherent rotation in the center of flat terraces. No sharp transition separates the limit of reversal by coherent rotation from that of reversal by domain wall depinning from steps. Instead, there is a smooth crossover from coherent rotation dominated reversal to domain wall depinning dominated reversal and most major loop structures are obtained in both limits.

10:20am **MI-FrM7 Magneto-optics: Science and Technology***, **M. Mansuripur**,* University of Arizona **INVITED**

The current trend in rewritable optical data storage is toward the use of novel techniques to achieve densities and data rates that are superior to those achievable in hard disk magnetic recording. After a brief review of the magneto-optical properties of amorphous rare earth-transition metal alloys, we describe the methodology and potential advantages/disadvantages of solid immersion lens (SIL), front-surface recording, magnetic super resolution (MSR), land & groove recording, and partial-response-maximum-likelihood (PRML) detection schemes. We point out the differences between magneto-optical and phase-change media, which are the contenders for the rapidly developing market in Rewritable Digital Versatile Disk (DVD) products.

11:00am **MI-FrM9 Magnetism of Oxide NiO/@alpha@Fe@sub 2@O@sub 3@ Multilayers Studied by Magneto-Optical Faraday Effect***, **N. Keller**, M. Guyot, R. Krishnan,* Université de Versailles - CNRS, France

Magneto-optical Faraday measurements were performed on magnetic oxide NiO/@alpha@Fe@sub 2@O@sub 3@ multilayers. These samples have been prepared by pulsed laser deposition technique. The magnetic particularity of this model system is given by the antiferromagnetism of both base oxides NiO and @alpha@Fe@sub 2@O@sub 3@, which can only form the ferrimagnetic nickelferrite, NiFe@sub 2@O@sub 4@, by interdiffusion at the interfaces. The magnetism of this interlayer compound can be used as a local probe for the study of interdiffusion. Increasing the number of interfaces and hence the number of ferrimagnetic layers should lead to a regular increase of the total magnetic moment. Surprisingly, we observed a pronounced oscillation of the total magnetic moment with the number of interface layers.@footnote 1@ This oscillation can only be accounted for by assuming an antiparallel alignment of the moments of each interlayer with respect to the neighboring interlayers. The magneto-optical Faraday rotation was measured in the range from 1.5 eV to 3 eV on samples with a different number of interfaces. The ellipticity of the Faraday rotation shows a similar energy dependence when compared to Kerr spectra (rotation and ellipticity) of bulk NiFe@sub 2@O@sub 4@ taken from the literature. Especially two crystal field excitations at 2.3 eV at 2.8 eV appear in both spectra. However, normalization of the ellipticity by the number of interfaces doesn't show in the entire spectral range a unique dependence. At energies higher then ~2.1 eV a non - negligible difference can be observed in the normalized ellipticity for samples with different numbers of interface. @FootnoteText@ @footnote 1@N.Keller, M. Guyot, A. Das, M. Porte, R. Krishnan, Solid State Comm. 105 (1998) 333-337

11:20am **MI-FrM10 Magnetooptical Characterization of Layered Structures using Variable Angle of Incidence Generalized Magnetooptical Ellipsometry (VA-GME)***, **A. Berger**, M.R. Pufall,* University of California, San Diego

Recently, we have developed the technique of Generalized Magnetooptical Ellipsometry (GME) which allows a complete optical and magnetooptical characterization of a ferromagnetic bulk material.@footnote 1@ The technique combines the advantages of a generalized ellipsometric approach, enabling us to retrieve the maximum amount of information from a reflection experiment, with a high sensitivity measurement which allows for a precise determination of the relatively small magnetooptical material constants. In the present study, we have extended the concept of GME to multiple measurements with variable angle of incidence (VA). This not only allows for a consistency check of the previously performed magnetooptical bulk measurements, but in addition it enables us to characterize more complex layered structures by a simultaneous analysis of the VA-GME data sets. The experiments are performed with an experimental setup almost identical to the previously reported one, using a HeNe-Laser as a light source and 2 linear polarizers as the polarization sensitive elements.@footnote 1@ The sample orientation and the position of the detector arm of the ellipsometer are rotatable to allow for a variable angle of incidence. As a first test structure we have used a thick permalloy film with a SiO@sub 2@ overcoating. The magnetooptical structure analysis was then performed by a least square-fit procedure of the entire VA-GME data set. The consistency of the results was checked by a conventional ellipsometric measurement and by a self-consistent comparison of independently measured VA-GME data sets for different in-plane orientations of the magnetization. Our results clearly demonstrate the successful extension of GME to a variable angle of incidence measurement technique, which allows a complete optical and magnetooptical characterization of layered magnetic materials. This work has been supported by the ONR-N000-1495-10541, NSF-DMR-94-00439, and the CMRR at UCSD. @FootnoteText@ @footnote 1@A. Berger and M. R. Pufall, Appl. Phys. Lett. 71, 965 (1997)

11:40am **MI-FrM11 Magnetization Induced Optical Second Harmonic Generation as a Readout of Thin Film Magnetic Memories***, **T.V. Murzina**, A.A. Fedyanin, A.V. Melnikov, T.V. Misuryaev, O.A. Aktsipetrov,* Moscow State University, Russia

The search for new materials for the magnetic memory devices gives rise to the search for new nondestructive readout techniques. In the present paper magnetization induced second harmonic generation (MSHG) is suggested as a readout for thin magnetic film-based memories. The advantage of the MSHG probe is a high sensitivity of quadratic nonlinear-optical response to the magnetic properties of nanostructures and low-dimensional systems. The fundamental wavelength can be chosen far from electronic resonance. That makes the MSHG probe nondestructive, while the MSHG wavelength can be resonant and thus provide an effective MSHG output sensitive to the magnetic state of the memory. In this paper, the results of systematic MSHG studies in thin magnetic films are presented which demonstrate the potential of this probe as a readout for thin film-based magnetic memories. Three systems are studied: Gd-containing Langmuir-Blodgett (LB) films, rare-earth iron garnet films, and magnetic Co-Cu nanogranular films. The output of a Q-switched YAG:Nd@super +3@ laser at 1064 nm, a pulse duration of 15 ns and an intensity of about 1 MW/cm@super 2@ is used as a fundamental radiation. DC-magnetic field up to 1.5 kOe is applied to the films in a longitudinal NOMOKE configuration. The MSHG readout is shown to be based either on the magneto-induced rotation of the polarization of the second harmonic (SH) wave polarization or on the magnetoinduced changes in the SHG intensity and magnetoinduced changes of the SH wave phase. It is shown that in nonresonant conditions, i.e. as both the fundamental and SH wavelength is far from electronic resonance of a magnetic film, the probability of the misreading (readout error) is rather small. Apart from three magnetic systems studied, the MSHG readout can be potentially used for a wide variety of magnetic storages based on thin film structures.

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