Monday Morning, November 4, 2002

Electronic Materials and Devices
Room: C-107 - Session EL+SC+MI-MoM

Semiconductors
Moderator: A. Rockett, University of Illinois

9:00am **EL+SC+MI-MoM3 Low-temperature Epitaxial Growth of the Wide Bandgap Semiconductor SiCAlN**, ***I.S.T. Tsong***, Arizona State University **INVITED**

Two compounds, SiC and AlN, normally insoluble in each other below 2000C, are synthesized as a single-phase solid solution thin film by molecular beam epitaxy (MBE) at 750C using a unimolecular precursor H3SiCN and Al atoms. The growth of epitaxial SiCAlN films with hexagonal structure takes place on 6H-SiC(0001) and Si(111) substrates. The surface morphology, microstructure, and composition of the films are analyzed by atomic force microscopy (AFM), cross-sectional transmission electron microscopy (XTEM), Rutherford backscattering spectrometry (RBS) and high-resolution electron energy loss spectroscopy (EELS). Two structural models for the hexagonal SiCAlN films are constructed based on first-principles total-energy density functional theory calculations, each showing agreement with experimental XTEM observations. The predicted fundamental bandgap is 3.2 eV for the stoichiometric SiCAlN, in good agreement with photoluminescence (PL) measurements. Bandgap engineering is a distinct possibility by varying the composition of the pseudo-binary (SiC)-(AlN) film.

9:40am **EL+SC+MI-MoM5 Evolution of Structure and Optical Properties of GaAsN Films Grown by Reactive Molecular Beam Epitaxy**, ***M.J. Reason***, *W. Ye, X. Weng, V. Rotberg, R.S. Goldman*, University of Michigan

Narrow gap nitride semiconductor alloys have shown significant promise for a wide range of electronic, optoelectronic and photovoltaic applications. At present, the ultimate limit of nitrogen solubility in GaAs, as well as the effects of growth conditions on stress relaxation and optical properties of narrow gap nitride films are not well understood. In this work, we have examined the evolution of nitrogen incorporation, strain relaxation, and optical properties of GaAsN films grown by solid-source molecular beam epitaxy using an N2-rf plasma source. The samples consisted of 500 nm buffer layers of GaAs grown at 580C and 20 nm layers of GaAs grown at 500C, both using a high arsenic flux; followed by 100-500 nm thick layers of GaAsN grown at 400C using a 10% N2/Ar gas mixture at a 0.15 sccm flow rate, with a variety of arsenic beam equivalent pressures (BEP). The structure and properties of the samples were investigated by reflection high energy electron diffraction (RHEED), multi-beam optical stress sensing (MOSS), high resolution x-ray rocking curves (XRC), nuclear reaction analysis (NRA), atomic force microscopy, and photoluminescence. For all of the arsenic fluxes studied, in-situ RHEED during the GaAsN layer growth reveals a pattern similar to that observed during the growth of the GaAs layers. As the arsenic BEP is increased, MOSS shows that the film stress decreases, indicating a lowering of the apparent nitrogen incorporation into GaAsN. Interestingly, variations in the absolute nitrogen concentrations determined from NRA analysis and a Vegard's law interpretation of XRC suggest significant nitrogen incorporation into interstitial sites. We will discuss the effects of arsenic flux on the stress relaxation and optical properties of a variety of GaAsN and InGaAsN films and heterostructures.

This work was supported in part by the DOE (Photovoltaics Beyond the Horizon Program), the Air Force Office of Scientific Research (MURI Program), and the TRW Foundation.

10:00am **EL+SC+MI-MoM6 Effects of LED Processing Steps on the Surface of Doped GaN Epilayers**, ***K.H.A. Bogart***, *D.D. Koleske, A.A. Allerman, A.J. Fischer, K.W. Fullmer, K.C. Cross, C.C. Mitchell*, Sandia National Laboratories

Gallium nitride (GaN)-based materials are critical for the creation of UV optoelectronic devices such as light-emitting diodes (LEDs). Ohmic contacts with low contact resistivities to p-type ($<1x10^{-3}\Omega cm^2$) and n-type ($<1x10^{-5}\Omega cm^2$) GaN are essential for improving optical device performance. Understanding the characteristics of p- and n-type GaN epitaxial layer surfaces and the interfaces formed with the contact metals is vital for optimization. Fabrication of an LED requires several processing steps including dicing, annealing, surface cleans (to remove native oxides), lithography, metal deposition, and plasma etching. The effects of processing steps on the surface morphology and electrical characteristics of the epitaxial materials and metal contacts have been investigated using scanning probe microscopies and the circular transmission line method (CTLM). One of the first LED processing steps is dicing a 50 mm wafer using photoresist for surface protection, which is later removed with solvents. For p-type GaN ($5x10^{17}cm^3$), AFM analysis showed that the surface roughness nearly doubled after photoresist exposure from an average of 0.24±0.05 nm to 0.50±0.10 nm. The source of the roughness increase was the formation of pits into the surface, ~1 nm in depth. In another LED processing step, n-type GaN is exposed by plasma etching a mesa structure into the p-type GaN overlayer. One half of a wafer with a 1.2µm n-type GaN ($1.7x10^{18}cm^3$) epitaxial film was plasma etched with chlorine-based chemistry. AFM analysis showed that the etched n-type GaN film (RMS=1.11±0.23nm) was not significantly more rough than non-etched n-type GaN film (RMS=1.70±0.59nm). However, after annealing ($500°C/N^2$), the plasma etched film had more Ohmic behavior by (CTLM) than did the non-etched film. More extensive experiments following the GaN epitaxial layers in processing will be presented and effects on contacts discussed.

10:20am **EL+SC+MI-MoM7 Hydrogen Removal Mechanisms from Gallium Nitride**, ***B.D. Thoms***, *Y. Yang, J. Lee*, Georgia State University **INVITED**

The reaction between hydrogen and GaN is important since hydrogen is often present (sometimes in abundance) during growth and processing and since it produces significant effects. For instance, the effect of hydrogen on the efficacy of Mg dopants has been widely reported and both annealing and electron exposures have been used to remove hydrogen. In addition, recombinative desorption of hydrogen is an important part of many dry etching processes. Removal of hydrogen requires both the transport of hydrogen to the surface and desorption from the surface. In this talk, the authors will discuss characterization of surface and subsurface hydrogen on GaN(0001) and its removal by annealing and by electron exposure.

11:00am **EL+SC+MI-MoM9 N-type Diamond Electronics With Nitrogen Doped Ultrananocrystalline Diamond**, ***J.E. Gerbi***, Argonne National Laboratory, *B.W. Alphenaar*, University of Louisville, *O. Auciello*, Argonne National Laboratory, *J. Birrell*, University of Illinois at Urbana-Champaign, *J.A. Carlisle, D.M. Gruen*, Argonne National Laboratory

Thin diamond films have extremely attractive properties for electronic device applications: high thermal conductivity, carrier mobility, and breakdown fields. However, efforts to create diamond based electronic devices have been hampered by the difficulty in incorporating dopants. Attempts to dope diamond films have resulted in low p-type carrier concentrations or unstable p-type surface layers. N-type doping has been even less successful, and it has not yet been possible to synthesize n-type diamond films with sufficiently high room-temperature conductivities. Ultra-nanocrystalline diamond (UNCD) is a fine-grained (3-5nm), phase-pure diamond material with atomically abrupt grain boundaries. Synthesized by microwave CVD using Ar-rich Ar/CH_4 plasmas, both the structure and electronic properties of UNCD can be tailored by doping with a controlled amount of N_2 in the plasma. As the N_2 content in the plasma increases to 20% , the grain size and grain boundary width of the UNCD films increase. This microstructural change correlates with a striking increase in room-temperature conductivity . Most importantly, nitrogen doped UNCD films are n-type with activation energies as low as 0.05 eV. This is striking, as traditional nitrogen substitutional doping of diamond produces a very deep state of 1.7eV, rendering the material useless for room-temperature applications. We use this material to demonstrate the first n-type diamond MESFET that can be operated at room temperature. We have characterized the films using Raman spectroscopy, NEXAFS, SIMS, Hall mobility measurements, and HRTEM, and measure device properties such as I-V curves and transconductance. The ohmic vs. Schottky behavior of various contacts to nitrogen doped UNCD as a function of growth chemistry has also been studied. A discussion of the microstructure-property relationship of nitrogen-doped UNCD films will be presented in the context of the UNCD-based MESFET performance.

11:20am **EL+SC+MI-MoM10 Electronic Structure and Spin-Polarization of Mn-containing Dilute Magnetic III-V Semiconductors**, ***L. Kronik***, *M. Jain, J.R. Chelikowsky*, University of Minnesota **INVITED**

The systematic use of electron spin, in addition to its charge, holds great promise for a new class of semiconductor devices with unprecedented functionality. Recently, Mn-containing, "dilute magnetic", III-V semiconductors have emerged as candidate materials for such a technology. They can potentially produce charge carriers with well-defined spin, yet are compatible with already existing semiconductor technologies. In order to assess the performance limits of such materials theoretically, we present first principles pseudopotential - density functional calculations for the

electronic structure of the dilute magnetic semiconductors $Mn_xGa_{1-x}As$ and and $Mn_xGa_{1-x}N$, with an experimentally relevant realistic x=0.063, in their ordered ferromagnetic phase. We predict that both materials allow, in principle, for a theoretical limit of 100% spin-injection, and that spin-polarized transport can be attained in both materials in the context of a simple band picture. This is because in MnGaAs, hybridization of As 4p and Mn 3d orbitals splits the valence band, resulting in a ~0.5 eV energy range where holes have a well-defined spin and an effective mass comparable to that of GaAs. In MnGaN, the situation is even more favorable: hybridization of Mn 3d and N 2p orbitals results in the formation of a ~1.5 eV wide impurity band, which supports effective mass transport. We will discuss the technological impact of these findings and compare our results to pertinent experimental data.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+EL-MoM

Spintronic Materials and Hybrid Devices
Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI+EL-MoM1 Spin-transport in Ferromagnet/Semiconductor Structures**, ***R. Jansen***, University of Twente, The Netherlands **INVITED**

Taking full advantage of electron spin in spin-electronics will eventually require an intimate integration of ferromagnetic and semiconductor materials. While device concepts are emerging, the understanding of spin transport in such hybrid ferromagnet/semiconductor structures is still at its infancy. We have focused on transport of non-equilibrium, hot-electron spins, for which spin currents can be controlled and manipulated via the electron energy and momentum. A particularly useful device for that purpose is the spin-valve transistor[1], consisting of a metallic spin-valve base, sandwiched between a semiconductor emitter and collector. Using the spin-valve transistor, we address the relative importance of interface, volume and thermal scattering of hot electron spins, and present new insight into the sources of spin-asymmetry in hot-electron transport.[2,3] From an application point of view, enhancing the output current of the transistor is desired. We demonstrate several routes to enhance the transfer ratio, culminating in an overall improvement by two orders of magnitude while preserving the low-field magnetic response above 200% at room temperature.[4] We also present transport in novel structures such as the magnetic tunnel transistor and the hot-electron spin-filter, and demonstrate that the latter allows room temperature injection of almost fully spin-polarized electrons into semiconductors.

[1] R. Jansen et al., J. Appl. Phys. 89, 7431 (2001).
[2] R. Jansen et al., Phys. Rev. Lett. 85, 3277 (2000).
[3] R. Vlutters et al., Phys. Rev. Lett. 88, 027202 (2002).
[4] O.M.J. van 't Erve et al., Appl. Phys. Lett. 80, to appear 20 may 2002.

9:00am **MI+EL-MoM3 Spin Dependent Electron Transport in Hybrid Ferromagnet/GaAs Structures at Room Temperature**, *S.J. Steinmuller, W.S. Cho, A. Hirohata, C.M. Guertler, G. Wastlbauer, T. Taniyama,* ***J.A.C. Bland***, University of Cambridge, UK

We report on the investigation of room temperature (RT) spin dependent electron transport in ferromagnet(FM)/GaAs hybrid Schottky barrier structures by photoexcitation. Spin accumulation in the GaAs was achieved by optical pumping with circularly polarised light. The photon helicity and the applied magnetic field were both introduced perpendicular to the plane of the film. Various FM materials were used (NiFe, Fe and Co) and investigated at different thicknesses (t=2.5nm, 5.0nm and 7.5nm). Furthermore an antiferromagnetic Cr sample was prepared as a reference. We measured the helicity-dependent photocurrent (PC), that is the difference in PC for illumination with right (i^+) and left circularly polarised light (i^-), for applied magnetic fields in the range from -2 T to 2 T as well as the spin polarisation $P=(i^+ - i^-)/(i^+ + i^-)$ of PC. NiFe and Fe showed a rather strong effect (P in the range 0.2-2%) increasing with film thickness, whereas almost no effect was observed in the Co. The magnetic field dependence of the helicity-dependent PC was in good agreement with polar MOKE measurements, proving that magnetic effects in the GaAs are negligible at RT. No field dependent effect was seen for the Cr as expected. Moreover we carried out measurements at different doping densities of the GaAs substrate (n- and p-type), showing the importance of the Schottky barrier in our experiment, and different photon energies. We also discuss the results of similar measurements on NiFe/Cu/Co spin valve structures. We show that our combined data provides strong support for our model of electron spin filtering at RT based on tunnelling of spin polarised electrons across the Schottky barrier followed by ballistic transport in the FM.

9:20am **MI+EL-MoM4 Tunneling Transport Across Reverse Biased Ag/Fe/Ag/GaAs Schottky Barriers**, ***D.A. Hite***, *S.E. Russek, D. P. Pappas*, National Institute of Standards and Technology

Electrical transport characteristics for the epitaxial Ag/Fe/Ag/GaAs(100) system have been studied under various growth conditions. The surfaces and structure of the multilayer were characterized by low energy electron diffraction and angle-resolved Auger electron diffraction at all steps of the fabrication. We have been able to prepare clean, well-ordered, epitaxial multilayers. The ultra-thin Ag buffer layer (~7 atomic layers) was prepared in a manner to create an ultra-thin layer to mediate the growth morphology of the Fe layer, to prevent the undesired intermixing associated with the Fe/GaAs system, and to create a tunneling barrier in reverse bias. In-situ conductance spectroscopy measurements were performed in order to characterize the rate of electron injection into the semiconductor as a function of bias voltage. We find that these multilayer diodes exhibit a reverse bias tunneling effect above 0.6 V. This is significant because it shows that we have been able to overcome the conductivity mismatch problem between the Fe and GaAs using an ultra-smooth, ultra-thin Ag buffer layer. The possibility of using these structures for direct spin injection from the Fe across the Ag/GaAs Schottky barrier will be discussed.

9:40am **MI+EL-MoM5 Modeling of Spin Injection into Disordered Semiconductors**, ***E.Y. Tsymbal***, University of Nebraska-Lincoln, *V.M. Burlakov*, University of Oxford, UK, *I.I. Oleinik*, University of South Florida **INVITED**

Spin injection into semiconductors is a topic of growing interest within the field of spin electronics. Developing a realistic model for spin injection is important both for the understanding of basic mechanisms that govern this phenomenon and for the application of spin injection in semiconductor devices. All the existing models so far either take into account a realistic band structure but neglect disorder within the semiconductor or consider phenomenologically defect scattering within a free-electron-type model. This talk will address the approach which combines an accurate description of the atomic structure, the electronic structure, and the conductance within a unique microscopic model. Within this approach the atomic structure is simulated using Metropolis MonteCarlo technique, the electronic structure is modeled using a multiband tight-binding approximation, and the conductance is calculated using the Landauer-Buttiker formalism including inelastic scattering. We will demonstrate results of the application of this model to amorphous silicon - a representative semiconducting material suitable for spin injection. We will discus decisive factors that control the efficiency of spin injection into disordered semiconductors.

10:20am **MI+EL-MoM7 Surface and Interface Properties of a Half-Metallic Alloy**, ***S.J. Jenkins***, *D.A. King*, University of Cambridge, UK **INVITED**

The ferrimagnetic semi-Heusler alloys have received considerable experimental and theoretical attention since the prediction in 1983 that they may show half-metallic behaviour (i.e. complete spin polarization at the Fermi level). Bulk properties of these alloys are now well understood. Nevertheless, application of these materials in practical situations is likely to be contingent upon the influence of their surface and interface properties, which have thus far been less thoroughly studied. This presentation will focus on recent calculations of the electronic structure of the NiMnSb(001) surface, with and without an Sb overlayer, carried out within the framework of density functional theory. Particular emphasis will be placed on the role of surface- and interface- localised electronic states in modulating the Fermi-level polarization.

11:00am **MI+EL-MoM9 Electrical Spin Injection from NiMnSb into GaAs**, ***W. Van Roy***, *P. Van Dorpe, V.F. Motsnyi, G. Borghs, J. De Boeck*, Imec, Belgium

We demonstrate electrical spin injection from NiMnSb into a GaAs light-emitting diode (LED). We compare single crystalline films grown epitaxially on GaAs(111)B with and without an additional AlAs tunnel barrier, and polycrystalline films grown on top of an AlO_x tunnel barrier on GaAs(001). The LEDs and NiMnSb films were grown by MBE in two chambers connected under vacuum. For the deposition of AlO_x tunnel barriers the samples were transported through air to a sputter system for the deposition of Al and oxidation in a controlled O_2 atmosphere. Spin injection was measured optically at T = 80 K. Electrons were injected with an in-plane spin-component. We used the oblique Hanle effect to transform this spin ensemble into an out-of-plane ensemble and used the circular polarization of the light emitted in the surface-normal direction as a measure of the electrical spin injection. The results were corrected for the out-of-plane tilting of the NiMnSb magnetization in the small oblique magnetic field, and for the MCD effect. We find electrical spin injection of up to 5% for polycrystalline NiMnSb films on top of an AlO_x barrier. The

spin injection drops with increasing bias voltage. The low values indicate a strongly reduced spin polarization for the polycrystalline NiMnSb films. Epitaxial NiMnSb films, especially on (111)B interfaces, are expected to show a much larger spin polarization for the conduction carriers. However, we did not yet observe spin injection from these films. This is attributed to the low interface resistance of this configuration in combination with a NiMnSb surface polarization that, although larger than for the polycrystalline films, is still short of 100%.

11:20am **MI+EL-MoM10 Epitaxial Growth and Annealing Studies of Single Crystal, Ferromagnetic Co_2MnGa of GaAs (100)**, ***D.M. Carr****, *S. McKernan, F.M. Abdulle, J.W. Dong, C.J. Palmstrom*, University of Minnesota

Spintronic devices that use electron spin in semiconductor devices are promising candidates for the next generation of electronic devices. Ferromagnetic metals with high spin polarization may be required for successful implementation of these devices. The Heusler alloys are a promising family of metals because the material properties such as lattice parameter, saturation magnetization, Curie temperature, and spin polarization can be altered by changing the elemental composition. In addition, their lattice parameters span most of the lattice parameters of the compound semiconductors. Films of the Heusler alloy Co_2MnGa have been epitaxially grown on GaAs (100) using molecular beam epitaxy. In situ reflection high-energy electron diffraction patterns and ex situ x-ray diffraction patterns of 300 Å thick films indicate single crystal growth with an out-of-plane lattice constant of 5.94 Å, which suggests tetragonally distorted growth since the bulk lattice parameter is 5.77 Å. Variable temperature vibrating sample magnetometry measurements show the Co_2MnGa films to be ferromagnetic with in-plane magnetization and a Curie temperature close to the bulk value of approximately 690 K. Ex situ annealing at different temperatures from 300 to 450 degrees C reveals an increase in the saturation magnetization and reduced coercivity for anneal times as short as 5 minutes at 425 degrees C. Annealed films exhibit a smaller out-of-plane lattice constant suggesting relaxation of the strained films. Cross sectional transmission electron microscopy studies will be used to characterize the level of interfacial reaction before and after annealing.

11:40am **MI+EL-MoM11 Growth Temperature Controlled Magnetism in Molecular Beam Epitaxially Grown Ni_2MnAl Heusler Alloys**, ***X.Y. Dong***, *J.Q. Xie, J.W. Dong*, T.C. Shih, S. McKernan, C. Leighton, C.J. Palmstrom*, University of Minnesota

The Heusler alloy Ni_2MnAl is thought to be either antiferromagnetic or ferromagnetic depending on its crystal structure, B2 (disordered Mn-Al sublattice) or $L2_1$.[1] This suggests that a ferromagnet/antiferromagnet interface should be possible to be formed with Ni_2MnAl by controlling its crystal structure. Single crystal Ni_2MnAl thin films have been grown by MBE on GaAs (001) using $Sc_{0.3}Er_{0.7}As$ interlayers. The effects of growth temperature on its structural and magnetic properties were studied. For all the films grown at different temperatures, streaky RHEED patterns were observed during the growth. The Ni_2MnAl / $Sc_{0.3}Er_{0.7}As$ / GaAs (001) films were single crystals with cube on cube epitaxial relationship. The Rutherford backscattering spectrometry channeling minimum yield, χ_{min}, of ~ 5 %, confirms a relatively good quality crystal. XRD and TEM show that the Ni_2MnAl films have a tetragonally distorted structure with its c axis oriented along the growth direction. Higher growth temperature tends to result in ferromagnetic films suggesting a more $L2_1$-like structure, while lower temperature growth gives rise to non-ferromagnetic behavior, suggesting a more B2-like structure. For the ferromagnetic Ni_2MnAl film, the Curie temperature was determined to be approximately 220K. The exchange bias effect was observed for Co (70Å) / Ni_2MnAl (360Å, B2-like structure) bilayers, suggesting that the low temperature grown Ni_2MnAl is antiferromagnetically ordered. Therefore the self exchange biased Ni_2MnAl bilayers can be expected to be grown by varying the temperature during the growth. In this presentation, the effect of growth temperature on the structural and magnetic properties will be emphasized as well as the approaches of making self exchange biased structures will be reported.

[1] F. Gejima, Y. Sutou, R. Kainuma, and K. Ishida, Metal. Mater. Trans. A 30A, 2721 (1999).

***** Falicov Student Award Finalist

Electronic Materials and Devices
Room: C-107 - Session EL+SC+MI-MoA

Metal-Semiconductor Interfaces
Moderator: C.J. Palmstrom, University of Minnesota

2:00pm **EL+SC+MI-MoA1 Spin Transport in Ferromagnet-Semiconductor Schottky Diodes**, ***P.A. Crowell***, *A.F. Isakovic, B.D. Schultz, J. Strand, C.J. Palmstrom*, University of Minnesota **INVITED**

We have completed an investigation of spin injection in semiconductor heterostructures using a Schottky contact between Fe and n-$Al_{1-x}Ga_xAs$ as an injector and an $Al_{1-x}Ga_xAs/GaAs/Al_{1-x}Ga_xAs$ quantum well (QW) as the detector. The injector and detector are combined in a single device in which the QW is placed in the depletion region of a p-n junction. The Schottky contact is δ-doped, so that a tunneling current can be obtained under moderate reverse bias.[1] The injected electrons recombine in the QW with holes from the p-contact, and the polarization of the resulting electroluminescence (EL) is used to infer the spin state of the recombining carriers. We demonstrate that the doping profile chosen for the QW has a dramatic effect on the apparent spin-detection efficiency. EL polarizations over 10% are obtained in optimally biased devices in which the QW is intentionally p-doped. The field-dependence of the EL polarization closely matches the magnetization of the Fe electrode. However, the largest polarizations are not observed from ordinary ground-state recombination in the quantum well. The maximum polarization observed from ground-state recombination is approximately 4% and appears to be less sensitive to the doping profile. In contrast, the EL polarization in control samples is less than 2%, does not track the magnetization of the ferromagnetic electrode and depends only weakly on bias voltage. The interpretation of these measurements will rely on a thorough understanding of the QW spin detector and the identification of background contributions. For example, we show using optical pumping measurements that the spin detection efficiency of the QW is a function of the bias voltage, as is the background photoluminescence polarization. This work was supported by DARPA, ONR, and NSF (MRSEC).

[1] H.J. Zhu et al., Phys. Rev. Lett. 87, 016601 (2001); A.T. Hanbicki et al., Appl. Phys. Lett. 80, 1240 (2002).

2:40pm **EL+SC+MI-MoA3 Characterization of an Fe/AlGaAs Tunnel Barrier Interface for Electrical Spin Injection**, *A.T. Hanbicki*, ***R.M. Stroud***, *B.T. Jonker*, Naval Research Laboratory

Electrical injection of spin-polarized carriers from a contact into a semiconductor is essential for the success of spintronic devices. Ferromagnetic metals are attractive contact materials because of their ample supply of spin-polarized electrons, but the use of these materials has been limited by small injection efficiencies in the diffusive transport regime.[1] The use of a tunnel barrier between a metal and semiconductor.however. should facilitate usable spin currents.[2] Recent experiments reported spin injection from Fe into a AlGaAs/GaAs-based LED which produced an electron spin polarization of 15% in the GaAs quantum.[3] This was attributed to tunneling through the Schottky barrier. We have characterized the Fe/AlGaAs contact reported in reference 3 to verify the tunneling nature of the contact and to investigate the physical nature of the interface. Samples were grown by molecular beam epitaxy and were specifically engineered to utilize the Schottky barrier between the Fe and the semiconductor as a tunnel contact. Current vs voltage measurements were made through the structure at different temperatures. The conductance shows an asymmetric parabolic dependence on the voltage. Further, there is a weak insulating-like behavior of the zero-bias resistance as a function of temperature, a reliable indication that this is a tunneling process based on the Rowell criteria for tunneling.[4] High-resolution TEM measurements indicate an atomically abrupt interface between the metal and semiconductor. Current-in-plane measurements and the relation of bias voltage to spin polarization will also be discussed. This work was supported by the DARPA SpinS program and ONR.

[1]G. Schmidt, et al, Phys.Rev.B 62, R4790 (2000)
[2]E.I. Rashba, Phys.Rev.B 62, R16267 (2000)
[3]A.T. Hanbicki, et al., Appl.Phys.Lett. 80, 1240 (2002)
[4]B.J. Jönsson-Åkerman, et al., Appl.Phys.Lett. 77, (2000).

3:00pm **EL+SC+MI-MoA4 A Schottky Tunnel Barrier Contact for Electrical Spin Injection into a Semiconductor**, ***B.T. Jonker***, *A.T. Hanbicki, G. Kioseoglou*, Naval Research Laboratory, *G. Itskos, R. Mallory, A. Petrou*, SUNY at Buffalo

Electrical injection of spin polarized electrons into a semiconductor heterostructure is a critical issue for semiconductor-based spintronic devices. While very encouraging results have been obtained using magnetic semiconductors as injecting contacts,[1] the desire for room temperature operation at low magnetic fields leads one to consider other materials and avenues. Ferromagnetic (FM) metals offer high Curie temperatures and can be rapidly switched (~ 300 ps) at low applied fields. However, theory has indicated that only very small spin injection (~0.01%) can be expected for typical FM metals as diffusive contacts.[2] We report here electrical spin injection from an Fe Schottky contact into an AlGaAs/GaAs LED structure, with spin injection efficiencies above 34% which extend to room temperature. These robust effects are attributed to spin tunneling[3] through the tailored Schottky barrier contact. The samples are grown by MBE, and the width of the depletion region at the Fe/AlGaAs interface is controlled by the semiconductor doping profile. Under reverse bias, electrons tunnel from the Fe into the semiconductor, and radiatively recombine in the GaAs quantum well. The circular polarization of the surface emitted electroluminescence (Faraday geometry) provides a quantitative, model independent measure of the QW spin polarization, and hence the injection efficiency.[1] The spin tunnel current is dominated by minority spin carriers, in contrast to previous work using Al_2O_3 tunnel barriers and a superconducting film detector. The temperature dependence of the polarization will also be discussed. These results will be compared with previous work[4] and theoretical modeling of Schottky barrier injection. Work supported by the DARPA SpinS program and ONR.

[1]R. Fiederling, et al Nature (1999); B.T. Jonker et al, PRB (2000)
[2]G. Schmidt et al, PRB (2000)
[3]E.I. Rashba, PRB (2000)
[4]H.J. Zhu et al, PRL (2001).

3:20pm **EL+SC+MI-MoA5 Contact Metallurgy for the Antimonide Based Compound Semiconductors**, ***S.E. Mohney***, *W.E. Liu, H.S. Wang, J.A. Robinson*, Penn State University **INVITED**

Antimonide based compound semiconductors are promising candidates for both high frequency, low power electronic devices and optoelectronic devices, and the performance of electrical contacts to these semiconductors is critical for some of the devices currently under development, particularly the electronic devices. Control of the interfacial reactions between the contact metals and the semiconductors is necessary during device processing and packaging since interfacial reactions between the metals and semiconductors occur at very low temperatures. Therefore, we have examined the condensed phase equilibria in the metal-III-Sb systems to guide our selection of shallow, thermally stable contact metallizations. We have performed thermodynamic calculations to estimate ternary phase diagrams in the transition metal-Ga-Sb, transition metal-In-Sb and selected metal-Al-Sb systems. We find that W, Re, and Os are the only transition metals predicted to be in thermodynamic equilibrium with both GaSb and InSb under the conditions considered in our calculations, while W is the only transition metal predicted to be in equilibrium with AlSb. Finally, we give an example of our use of the information we have gathered for the design of a very shallow, thermally stable low resistance ohmic contact to p-type GaInSb. Since we have observed using transmission electron microscopy that Pd reacts uniformly with GaSb at low temperatures, we chose a very thin layer of Pd as the first metal in our contact. We then deposited W because of our prediction that it would be in thermodynamic equilibrium with both GaSb and InSb and that it could serve as a diffusion barrier between layers. Finally, we capped the films with Au, which was important for lowering the metal sheet resistance. A contact resistance of 3 x 10^{-7} ohm-cm^2 was measured with good stability at 250 °C for 100 h, as verified using contact resistance measurements and Auger depth profiles.

4:00pm **EL+SC+MI-MoA7 Electrical Contact Behavior of Ni/C60/4H-SiC**, ***W. Lu***, Fisk University, *W.C. Mitchel*, Air Force Research Laboratory, *J.R. Landis*, University of Dayton Research Institute, *T.R. Crenshaw*, Fisk University, *S.R. Smith*, University of Dayton Research Institute, *W.E. Collins*, Fisk University

Ohmic contact formation of Ni/C60 film on n-type 4H-SiC was investigated. A C60 interfacial layer between Ni film and SiC improves ohmic contact properties significantly. The C60 film was deposited by Langmuir-Blodgett method prior to the Ni film deposition on SiC using DC sputtering method. High quality ohmic contact of Ni/C60/4H-SiC is formed after annealing at 800°C in Ar for two hours with a specific resistance of 1.6

x 10^{-6} Ωcm^2 for the SiC with a doping concentration of 1.8 x 10^{19}cm^{-3}. Raman spectra reveal that the formation of graphitic carbons by Ni catalytic effects result in the formation of ohmic contact on SiC, and the nano-size graphitic flakes identified by Raman spectroscopy play a key role for ohmic contact formation on SiC. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) show a direct relationship between the graphitized morphological features on the film and ohmic contact behavior.

4:20pm **EL+SC+MI-MoA8 Electrical Characterization of AlN MIS/MIM-structures**, ***F. Engelmark***, *J. Westlinder, I.V. Katardjiev, J. Olsson, S. Berg*, University of Uppsala, Sweden

The electrical properties of insulating ceramic films such as AlN, Ta_2O_5, HfO_2, ZrO_2, Al_2O_3, etc. are of substantial interest for a number of microelectronic and electro-acoustic applications owing to their chemical stability in harsh environments along with some very interesting electrical properties. In this work, emphasis has been put on the electrical properties of Aluminum nitride (AlN) films. Thin AlN films have been deposited onto Si(100) and Mo/Si(100) substrates. The sputter deposited Mo is polycrystalline, showing a predominant (110) orientation. AlN film growth is performed using different process conditions in a reactive PVD (Physical Vapour Deposition). Both fully textured (0002) polycrystalline and XRD amorphous films have been grown and studied. MIS- and MIM-structures have been fabricated and electrical properties such as dielectric constant, leakage current as well as their high frequency behaviour are investigated. The measurements indicate that the dielectric constant does not vary with crystallinity of the films, and remains constant at a value of 10. Further, the high frequency behaviour of the dielectric constant have been studied in the range 100 MHz to 20 GHz. The leakage current mechanism is also similar for different films and is believed to be Poole-Frenkel controlled. C-V (Capacitance-Voltage) measurements for MIS structures revealed the presence of charges in the interface between the substrate and the dielectric layer. Trapped charge density was estimated to be 3.5*10^{10} cm^{-2}.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+NS-MoA

Self-Assembly and Nanomagnetism
Moderator: D. P. Pappas, DOC/NIST/EEEL/Magnetic Technology Division

2:00pm **MI+NS-MoA1 Self-assembly and Magnetism in Novel Core-shell Microspheres**, ***E.L. Bizdoaca***, *M. Spasova, M. Farle*, Halbleiterphysik und Optik, TU Braunschweig, Germany

We report on the fabrication and characterization of new composite core-shell particles with a defined shape, composition and multilayer shell thickness. These colloids can be produced by the layer-by-layer technique.[1] They consist of a core of a polystyrene (PS) microsphere (640 nm diameter) coated with consecutive shells of Fe_3O_4 nanoparticles (12 nm diameter) / polyelectrolytes /Au nanoparticles (15 nm). For the formation of the gold shell Au nanoparticles encapsulated in a very thin layer of silica (2 nm) were used. Composite core-shell particles were self-assembled into 1D periodic long-chain structure (up to 600 μm) by magnetophoretic deposition.[2] The length and separation of the chains were found to depend on the magnitude of the magnetic field and on the concentration of the water-based colloidal solution. The self-organization and the homogeneity of the colloidal coating were characterized by transmission electron and atomic force microscopy. Magnetic properties were determined by angular dependent ferromagnetic resonance (FMR) and SQUID-magnetometry between 5 and 300 K. FMR reveals long-range magnetic order at 300 K due to the dipolar coupling and an easy axis in plane, along the chains. We report a reduced magnetic moment in comparison with the magnetite bulk value. The remanence magnetization and the coercivity field (240 Oe) are not temperature dependent between 5 and 300 K. Supported by Deutsche Forschungsgemeinschaft. .

[1] F. Caruso et al, Chem.Mater.13 (2001) 109.
[2] E. L. Bizdoaca et al, J. Magn. Magn. Mater. 240 (2002) 44.

2:20pm **MI+NS-MoA2 Magnetic Resonance and X-ray Magnetic Circular Dichroism of Monodisperse Co Nanoparticles**, ***U. Wiedwald***, *M. Spasova*, Technical University Braunschweig, Germany, *M. Hilgendorff*, Hahn-Meitner-Institut, Germany, *M. Ulmeanu, E.L. Bizdoaca*, Technical University Braunschweig, Germany, *M. Giersig*, Hahn-Meitner-Institut, Germany, *M. Farle*, Technical University Braunschweig, Germany

Monodisperse Co nanoparticles with an medium diameter of 12 nm (σ < 5%) are prepared by the thermolysis of $Co_2(CO)_8$.[1] After using a size-selective separation technique they are redispersed in toluene. For structural and magnetic investigations the samples are prepared by controlled evaporation of the solvent on various substrates. Detailed TEM analysis of the structure of Co nanoparticles shows that they consist of a 8-9 nm metallic Co core and a 1-2 nm thick CoO shell, both crystallized in fcc structure.[2] Angular dependent ferromagnetic resonance (FMR) of these arrays of Co nanoparticles reveals a remanent magnetization at 300 K that is due to long-range dipolar coupling between the nanoparticles.[3,4] A preliminary g-factor analysis yields a value of g = 2.15±0.02 that is close to bulk fcc value and in good agreement with the structural analysis. X-ray absorption fine structure (XAFS) shows a multiplet structure in the Co L_3 edge that is due to a superposition of metallic Co and Co in an oxidic environment. No evidence for x-ray magnetic circular dichroism (XMCD) at the $L_{2,3}$ edges is found for as prepared ex-situ samples for temperatures between 20 K and 300 K. After slight Ar^+ ion etching a well resolved XMCD signal with a strongly enhanced orbital-to-spin-moment ratio is observed. The results of the FMR and XMCD analysis will be compared and discussed in terms of the contributions from the antiferromagnetic CoO shell. This project is supported by the European Community, contract no. HPRN-CT-1999-00150 and the Access to Research Infrastructure action of the Improving Human Potential Programme. M. H. thanks the Deutsche Forschungsgemeinschaft, Az.: II C 10 - SPP 1072 for support.

[1] M. Hilgendorff et al., Aust. J. Chem. 54 (2001)
[2] M. Spasova et al., Proc. Spring MRS Meeting, San Francisco (2002), submitted
[3] U. Wiedwald et al., J. Vac. Sci. Technol. A 19 (2001)
[4] M. Spasova et al., J. Magn. Magn. Mat. 240 (2002)

2:40pm **MI+NS-MoA3 Surfactant-mediated Shape Control, Magnetism and Self-assembly of Cobalt Nanocrystals**, ***K.M. Krishnan***, *Y.P. Bao, M. Beerman*, University of Washington **INVITED**

Magnetic nanocrystals, monodisperse in size, shape and surface structure are now routinely synthesized by the rapid injection of an organometallic precursor into a hot coordinating solvent containing appropriate surfactants. The success of this method depends on temporally separating the nucleation and growth of the nanocrystals in solution and to control the precursor concentration to achieve size distribution focusing. In addition, careful choice of surfactant pairs that preferentially bond to different crystallographic planes of the growing nanocrystal can also be used to control the shape of the nanocrystals, including the preparation of high-aspect ratio particles or nanorods. For practical applications these nanocrystals must be organized into ordered arrays with well-defined inter-particle distances. In such nanocrystals, with a weak (van der Waals) attractive interaction between the metallic cores and a weak steric repulsion arising from the surfactant chains, entropy-driven self-assembly processes dominate. If particles of two different sizes are allowed to self-assemble, entropy driven wetting arising from depletion forces can be used to control the final organization. Use of solvent-nonsolvent pairs can be used to gently precipitate the nanocrystals into large scale ordered arrays. Details of the growth of Co nanocrystals with controlled size and shape, their subsequent self-assembly into ordered arrays, their characterization by a range of electron microscopy measurements and their isolated and collective magnetic behavior will be discussed.

3:20pm **MI+NS-MoA5 Structure and Magnetism of Colloidal Composite AgCo Nanoparticles**, ***M. Spasova***, Technishe Universität Braunschweig, Germany, *T. Radetic*, Lawrence Berkeley Laboratory, *N.S. Sobal*, Hahn-Meitner-Institut Berlin, Germany, *C. Raeder*, Technishe Universität Braunschweig, Germany, *M. Hilgendorff*, Hahn-Meitner-Institut Berlin, Germany, *U. Dahmen*, Lawrence Berkeley Laboratory, *M. Giersig*, Hahn-Meitner-Institut Berlin, Germany, *M. Farle*, Technishe Universität Braunschweig, Germany

Monodisperse, air-stable $Ag_{100-x}Co_x$ composite nanoparticles with a mean diameter of 12 nm have been synthesized by methods of colloidal chemistry.[1] The composition x was varied between 20 and 73 at.% Co. High resolution Transmission Electron Microscopy (TEM) and selected area electron diffraction have showed that the nanoparticles consist of precipitates of fcc Co and fcc Ag grains. No evidence for alloy formation was observed. Element-specific TEM images obtained by electron energy-loss spectroscopy and X-ray microanalysis indicate that Co is predominantly found in the surface region of the particles and the particles have an $Ag_{core}Co_{shell}$ structure. No Co oxide formation was observed in spite of Co being located at the particle surface. Magnetic properties of arrays of the nanoparticles on Si substrates were investigated by angular dependent ferromagnetic resonance and SQUID magnetometry between 5 and 300 K. The blocking temperature is found to depend on the particle composition. It increases with increasing Co content. At room temperature the nanoparticles containing 73 at.% Co are below and the $Ag_{55}Co_{45}$ nanoparticles are above their respective blocking temperatures. At lower temperatures contributions from additional magnetic phases are observed. The magnetization curves were analyzed as a function of temperature taking into account both paramagnetic and ferromagnetic contributions. The results

are discussed in context to contributions from the Co/Ag interfacial and surface magnetism. The work has been supported through EC contract no. HPRN-CT-1999-00150.

[1] N.S. Sobal at el., Nano Letters, in press.

3:40pm **MI+NS-MoA6 Study of the Magnetic Cluster/Superconductiviting Matrix Interface: the Co/Nb System**, ***V. Dupuis***, *L. Favre, M. Jamet, J. Tuaillon-Combes, P. Melinon, A. Perez,* DPM Lyon - France

Thin films consisting on pure Co nanoparticles embedded in a Nb superconducting matrix have been prepared from clusters preformed in the gas phase using the Low Energy Cluster Beam Deposition (LECBD) technique.[1] Such films are subsequently e-beam lithographied in view to prepare ultrahigh sensitivity Micro-SQUID magnetometer devices and to study the magnetization reversal mechanism of an individual nanocluster.[2] X-ray characterization experiments and Transmission Electron Microscopy performed on an assembly of cobalt clusters embedded in a niobium matrix have shown that such nanogranular films consist on crystallized fcc Co-grains in the form of 3 nm-diameter truncated octahedron (~ 1000 Co-atoms) randomly distributed in the polycrystalline niobium matrix. Sites of Co-atoms in the cluster core and at the cluster-matrix interface have been evidenced showing an alloyed Co-Nb interface concerned by almost one monolayer. On another hand, VSM magnetization measurements performed in the superparamagnetic regime evidenced a magnetic size of the Co-clusters lower than the one as deduced from TEM observations. So, in-situ complementary measurements under synchrotron radiation performed on Co/Nb bilayers grown in UHV confirm the presence of an alloyed Co_6Nb_7 interface which acts as a magnetically dead layer. Finally, from micro-SQUID measurements performed at 35 mK on one individual Co-cluster, we obtained a 3D-astroid shape corresponding to second order bi-axial anisotropy terms which can be attributed to surface anisotropy contributions ("Néel" model) underlying the main interfacial contribution in such nano-object.

[1] A. Perez et al. Materials Transactions, Special Issue on Nano-Metals 1, 42,1460 (2001).
[2] M. Jamet et al. Phys. Rev. Lett., 86, 4676 (2001).

4:00pm **MI+NS-MoA7 Magnetic Nanowires for Media and Devices Fabricated Using Copolymer Templates**, ***M.T. Tuominen***, *M. Bal, A. Ursache, Q. Xiao, J.T. Goldbach, T.P. Russell*, University of Massachusetts **INVITED**

Arrays of magnetic nanowires and nanowire devices were fabricated using nanoporous templates derived from self-assembling diblock copolymer films. Poly(styrene-methacrylate) (PS-PMMA) diblock copolymers as porous templates that were used to fabricate hexagonal arrays of vertical nanowires with densities of exceeding 1x10^12 per square inch. Electrodeposition within the template produces 10nm-scale magnetic cobalt nanowire arrays that exhibit large perpendicular coercivity and remanance making them potential candidates for ultrahigh-density perpendicular magnetic storage media. The internal crystal morphology of the nanowires, and consequently magnetic properties, can be manipulated and tuned by electrodeposition process parameters. The copolymer templates have been patterned laterally using conventional lithographic exposure to fabricate novel 3D magnetic nanowire devices. This includes current-in-plane magnetoresitive devices and current-through-wire switching field devices. Anisotropic magnetoresistance measurements show a sharp and complete magnetization reversal, indicating single-domain nanowire switching behavior. Such properties offer promising potential for new magnetic nanodevices built upon on single-domain elements. This work is supported by US National Science Foundation Nanoscale Interdisciplinary Research Team grant DMI-0103024 and Materials Research Science and Engineering Center grant DMR-9809365.

4:40pm **MI+NS-MoA9 Evolution of Fe Nanocluster Magnetism Grown on Pt(111)**, ***P. Bencok***, *S.S. Dhesi,* European Synchrotron Radiation Facility, France, *P. Ohresser,* Laboratoire pour l'Utilisation du Rayonnement Electromagnétique, France, *N. Brookes*, European Synchrotron Radiation Facility, France

The magnetic structure of nanoparticles is a fascinating research area with many new and unexpected results. For the preparation of nanostructures one may use a well chosen system with appropriate growth modes. Room temperature deposition of submonolayer Fe ultrathin films on Pt(111) results in the formation of single layer clusters whose size increases with the amount of Fe. The structure of the stable pseudomorphic fcc clusters was studied using scanning tunnelling microscopy. The clusters were grown and measured in-situ by x-ray magnetic circular dichroism of Fe $L_{2,3}$ edge at beamline ID8 of the European Synchrotron Radiation Facility in Grenoble. Sum rule analysis was used to extract the magnetic spin and orbital moments with changing cluster size. The clusters show superparamagnetic behaviour with blocking temperature in the range 10-250 K increasing with cluster size. The easy axis of magnetization is perpendicular to the surface for all the range of cluster sizes studied. The orbital moment of the clusters as well as its angular anisotropy (related to the magnetic anisotropy energy) is enhanced in comparison with the bulk value and increases with decreasing cluster size. This enhancement is given by the increase in the number of perimeter atoms as the cluster radius diminishes. The perimeter atoms have reduced atomic coordination leading to the higher orbital moment. The magnetic spin moment per atom is lower than for bulk Fe. This behaviour can be explained by changes in the local atomic structure that is very sensitive to the atomic volume.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+EL+SC-TuM

Ferromagnetic Semiconductors
Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI+EL+SC-TuM1 ab initio Magnetic Exchange Interactions in DMS and TiO_2**, ***M. van Schilfgaarde***, Arizona State University **INVITED**

The electronic structure of TM-doped TiO2 is studied within the ab initio local spin-density approximation and compared to more traditional TM-doped III-V DMS semiconductors. The conduction band of TiO2 consists mainly of Ti d character. Substituting a 3d TM for Ti, localized levels split off the conduction band; they are spin-split by an on-site exchange interaction and are responsible for the magnetism. The deepest level is of t2 symmetry and sweeps deeper in the gap in the series TM=V,Cr,Mn,Fe,Co. In the dilute alloy, the impurity level broadens into a narrow band. Thus the conductivity is expected to occur through a hopping mechanism, increasing with decreasing temperature as is observed in Co:TiO2. The character of this level is compared to TM d levels in the III-V DMS alloys (Cr,Mn,Fe):(Al,Ga,In)(N,P,As). Using a linear-response technique, the LSDA is mapped analytically onto a magnetic hamiltonian, which was used to investigate exchange interactions in random TM:TiO2 and (Cr,Mn):(Al,Ga,In)(N,P,As) alloys. Several novel phenomena will be described in the DMS case; for example Tc is predicted to increase monotonically with concentration for Cr:III-V, while for Mn:III-V Tc reaches a maximum at about 10% Mn concentration. The exchange interactions are found to have elements in common with both the carrier-mediated model and the double exchange/superexchange model, but also show important differences. For (V,Cr,Mn,Fe,Co):TiO2, the filling, magnetic moment and exchange interactions change systematically and are well described by a double exchange/superexchange model. However, for Tc to reach the observed RT in Co:TiO2, a source of holes is needed.

9:00am **MI+EL+SC-TuM3 $Co_xTi_{1-x}O_2$ Anatase Heteroepitaxy on Si(001)**, ***T. Droubay***, Pacific Northwest National Laboratory, *A.C. Tuan*, University of Washington, *S.A. Chambers*, Pacific Northwest National Laboratory

With a Curie temperature above 700K, high remanence, and respectable coercivity, Co-doped TiO_2 anatase ($Co_xTi_{1-x}O_2$) is one of the more magnetically robust dilute magnetic semiconductor (DMS) materials currently under investigation. The future of this material for near-term device use as a spin injector requires deposition on and compatibility with traditional semiconductors such as silicon. Successful growth of crystalline oxides on silicon without oxidizing the underlying substrate is a formidable challenge. Our goal in this work is to grow epitaxial $Co_xTi_{1-x}O_2$ on Si(001) by using a suitable template layer, and then determine the resulting magnetic and electronic properties. We have previously shown that polycrystalline $Co_xTi_{1-x}O_2$ grown on Si(001) with its native oxide is ferromagnetic at room temperature. We are now working on $Co_xTi_{1-x}O_2$ heteroepitaxy on Si(001) using an ultrathin epitaxial $SrTiO_3$ buffer layer to prevent formation of titanium silicide and SiO_2 at the interface that result from a thermodynamic instability. An added benefit of the $SrTiO_3$ buffer layer is to generate a nearly zero conduction band offset to Si, which is essential for efficient n-type spin injection. A detailed analysis of the growth and properties of this heteroepitaxial system will be presented.

9:20am **MI+EL+SC-TuM4 Epitaxial Growth and Properties of Co-doped TiO_2 Anatase on $LaAlO_3$(001)**, ***S.A. Chambers***, *T. Droubay, C.M. Wang, S.M. Heald, S. Thevuthasan, A.S. Lea, C.F. Windisch, Jr.*, Pacific Northwest National Laboratory, *R.F.C. Farrow, L. Folks, J.-U. Thiele, M.G. Samant, R.F. Marks*, IBM Almaden Research Center

We are investigating Co-doped TiO_2 anatase heteroepitaxy on $LaAlO_3$(001) by oxygen plasma assisted molecular beam epitaxy. This material is of considerable interest because it is ferromagnetic well above room temperature. Thus, it may be a useful DMS for spintronics. The use of a higher growth rate (0.04 nm/sec) results in the nucleation of nanocrystals of rutile, the more stable form of TiO_2, within the continuous anatase film. The density of rutile nanocrytals increases as the quality of the substrate surface decreases. A lower growth rate (0.01 nm/sec) results in a much better film morphology, although a low density of smaller nanocrystals remains. Unlike the fast-grown films, these films show no evidence for any phase other than anatase. A number of techniques reveal that Co substitutes for Ti in the lattice and exhibits a +2 oxidation state; there is no evidence for elemental Co in any form. Each Co(II) substitution for Ti(IV) requires an O^{-2} anion vacancy in order to maintain charge neutrality, and evidence for such a vacancy is forthcoming from preliminary Co K-shell EXAFS. Such vacancies do not generate free carriers because they are uncharged. Hall effect and XPS measurements show that the films are n-type, the most likely cause being the presence of O atom vacancies that form during growth. These vacancies are independent of the presence of Co, and are negatively charged, thereby providing a source of free electrons from shallow donor states. The magnetization depends critically on free carrier concentration, as expected for a DMS. The exact Curie temperature is currently being determined, but appears to be in excess of 700K.

9:40am **MI+EL+SC-TuM5 Ferromagnetism in Mn-implanted Single Crystal Oxides**, ***D.P. Norton***, *S.J. Pearton, B.S. Jeong, Y.W. Heo, A.F. Hebard, N.A. Theodoropoulou*, University of Florida, *L.A. Boatner*, Oak Ridge National Laboratory, *Y.D. Park*, Seoul National University, Korea, *R.G. Wilson*, Consultant

Several semiconducting oxides, including ZnO, offer significant potential in providing spin-based functionality. Theoretical predictions suggest that room-temperature carrier-mediated ferromagnetism should be possible in Mn-doped p-type ZnO. In this paper, we report on the synthesis and properties of magnetically-doped semiconducting oxides, including ZnO. While previous efforts report no ferromagnetism in Mn-doped ZnO that is n-type due to group III impurities (consistent with theory), we find ferromagnetism in n-type ZnO that is co-doped with Mn and Sn. Hysteresis was observed in magnetization versus field curves for Mn-implanted n-type ZnO:Sn. Differences in zero field-cooled and field-cooled magnetizations persists up to ~ 150 K for Sn-doped ZnO crystals implanted with 3 at % Mn. These results indicate that ZnO doped with Mn and Sn may prove promising as a ferromagnetic semiconductor for spintronics.

10:00am **MI+EL+SC-TuM6 Self-compensation in Manganese-doped Ferromagnetic Semiconductors**, ***S.C. Erwin***, *A.G. Petukhov*, Naval Research Laboratory

We present theoretical evidence that the observed hole compensation in manganese-doped ferromagnetic semiconductors is due to interstitial manganese. We show that under the non-equilibrium conditions used during growth, interstitial Mn is readily formed near the surface by a simple low-energy adsorption pathway. In GaAs, isolated interstitial Mn impurities are electron donors, each compensating two substitutional Mn acceptors under p-type conditions. We show that partial compensation is a prerequisite for ferromagnetic order below the metal-insulator transition, and that the Curie temperature is highest when 1/6 of the Mn is interstitial.

10:20am **MI+EL+SC-TuM7 Ferromagnetic Semiconductor Heterostructures**[1], ***N. Samarth***, Penn State University **INVITED**

The molecular beam epitaxy (MBE) of ferromagnetic semiconductor heterostructures provides model systems for exploring fundamental issues in semiconductor spintronics. We provide an overview of heterostructures that combine the ferromagnetic semiconductor (Ga,Mn)As with conventional III-V and II-VI semiconductors, as well as with the metallic ferromagnet MnAs. After an introduction to the properties of MBE-grown (Ga,Mn)As, we discuss two classes of heterostructures: (a) hybrid ferromagnetic metal/semiconductor tunnel junctions that allow us to unambiguously probe spin injection into semiconductors using all-electrical techniques and (b) hybrid ferromagnetic/semiconductor photodiodes that serve as toy spintronic "devices" whose photo-response is magnetically controlled.

[1] This work is carried out in collaboration with S. H. Chun, K. C. Ku, S. J. Potashnik, and P. Schiffer, and is supported by grants from NSF, ONR and DARPA

11:00am **MI+EL+SC-TuM9 Epitaxial Growth of the Diluted Magnetic Semiconductor Cr_xGe_{1-x}**, ***G. Kioseoglou***, *A.T. Hanbicki*, Naval Research Laboratory, *Y.D. Park*, Seoul National University, Korea, *S.C. Erwin, B.T. Jonker*, Naval Research Laboratory

Ferromagnetic semiconductors (FMS) provide an opportunity to control spin-dependent behavior in semiconductor device heterostructures. Although much effort has focused on III-Mn-V materials such as GaMnAs , the mechanism of ferromagnetic order remains unclear; in particular the precise roles played by the dopant and the semiconductor host. We have explored this issue recently by developing a new Group-IV FMS, MnGe.[1] Here we report our work to develop an elemental FMS using a different dopant, Cr-doped Ge. This choice was motivated partly by our density-functional theory (DFT) calculations, which indicate that CrGe and MnGe should have comparable Curie temperatures. We report the epitaxial growth of Cr_xGe_{1-x} and describe the structural, magnetic and transport properties. The samples were grown on GaAs(001) substrates by molecular beam

epitaxy at substrate temperatures of 40-500°C and the crystallinity was confirmed by the RHEED pattern. The Cr concentration used was 2-3% as determined from X-ray fluorescence. The RHEED pattern indicates single crystal growth for substrate temperatures above 200°C, with sharp 1x1 streaks. Growth at 40-70°C is initially single crystal, but the pattern becomes increasingly diffuse with film thickness. The samples are strongly p-type, and the hole density varies with the Cr concentration. SQUID measurements were performed on all samples to investigate the magnetic character of the Cr:Ge system. Samples grown at the higher growth temperatures exhibit only paramagnetic order. Co-doping with both Mn and Cr is also investigated. This work was supported by the DARPA SpinS program and ONR.

[1] Y.D. Park, et al., Science 295, 651 (2002).

11:20am **MI+EL+SC-TuM10 Cr-Doped III-V Ferromagnetic Semiconductors**, ***M.E. Overberg***, *G.T. Thaler, R.M. Frazier, C.R. Abernathy, S.J. Pearton, N.A. Theodoropoulou, A.F. Hebard*, University of Florida, *R.G. Wilson*, Private Consultant, *J.M. Zavada*, U.S. Army Research Office

Ferromagnetic semiconductors, consisting of a semiconductor host material doped with transition metal ions, are becoming increasingly prevalent in the literature as a candidate for incorporating the spin degree of freedom into device structures. To date, the vast majority of work in this area has centered on the incorporation of Mn into both II-VI and III-V materials by a variety of techniques. However, recent theoretical work has indicated that Cr may be a more suitable dopant for achieving room-temperature ferromagnetism within these materials.[1] In this paper, we will report on the preparation of GaCrN, GaCrP, and AlGaCrP by the direct implantation of Cr. The magnetic and magneto-transport (anomolous Hall Effect) properties of these films will be quantified both versus implantation dose (x=0.04, 0.06, 0.10) and versus post-implantation annealing, to identify an optimum combination of dose and annealing conditions. Analysis by SQUID magnetometry of the GaCrN with 6% Cr indicates the presence of a strong ferromagnetic phase with a Curie temperature above the 350 K limit of the magnetometer. High resolution x-ray diffraction (HRXRD) and transmission electron microscopy (TEM) results from the implanted films will also be presented to address the issue of the formation of second phases within these materials. HRXRD rocking curves of the implanted materials will also be used to trace the evolution of the implantation-induced lattice damage with annealing as well as strain-related effects due to the incorporation of Cr into substitutional lattice sites.

[1] K. Sato, and H. Katayama-Yoshida, Jap. J. Appl. Phys., Pt. 2, 40 (5B), p. L485 (2001).

11:40am **MI+EL+SC-TuM11 Suppression of Phase Segregation during MBE Growth of GaMnN Using Nitrogen-Hydrogen Plasma**, *Y. Cui*, ***L. Li***, University of Wisconsin-Milwaukee

Epitaxial growth of GaMnN by electron-cyclotron-resonance plasma-assisted molecular beam epitaxy using nitrogen-hydrogen plasma was studied by reflection high-energy electron diffraction, scanning electron microscopy, energy dispersive spectroscopy, and x-ray diffraction. The electron diffraction pattern changed from streaky to spotty when hydrogen was added to the nitrogen plasma, indicating that the effective N/Ga ratio was increased. Films grown with nitrogen plasma are phase segregated into GaN and manganese nitrides. In contrast, when nitrogen-hydrogen plasma was used, the films are single phase Ga1-xMnxN, with x can be as high as 0.06. These results indicate that phase segregation can be suppressed by adding hydrogen to the nitrogen plasma during growth.

Tuesday Afternoon, November 5, 2002

Molecular and Bio-Magnetism
Room: C-205 - Session MB+BI+OF-TuA

Molecular and Bio-Magnetism
Moderator: M. Grunze, Heidelberg Universität, Germany

2:00pm **MB+BI+OF-TuA1 Single-Molecule Magnets: A Molecular Approach to Nanoscale Magnetic Materials**, ***G. Christou***, *M. Soler, N. Aliaga-Alcalde, S. Bhaduri*, University of Florida, *W. Wernsdorfer*, Laboratoire Louis Neel - CNRS, France, *D.N. Hendrickson*, University of California at San Diego **INVITED**

Single-molecule magnets (SMMs) are molecules that function as single-domain magnetic particles which, below their blocking temperature, exhibit the classical macroscale property of a magnet, namely magnetization hysteresis.[1] SMMs owe their properties to a combination of a large ground state spin value and easy-axis-type anisotropy, which give a significant barrier to magnetization relaxation. SMMs thus represent a molecular (or bottom up) approach to new nanoscale magnetic materials, offering all the advantages of molecular chemistry (room temperature synthesis, purity, solubility in many solvents, a well defined periphery of organic groups, a crystalline ensemble of monodisperse units) as well as displaying the superparamagnetism of a mesoscale magnetic particle. They also display quantum tunneling of magnetization (QTM), emphasizing that they straddle the interface between the classical and quantum regimes. SMMs have many potential applications, but these require that their properties be both understood and controlled, particularly QTM. The Mn12 SMMs are the best understood. Various derivatives have been prepared differing in the organic groups, and it has been discovered that the magnetic properties (including QTM) can be significantly altered. This is also possible by adding additional electrons, and both the $[Mn12]^-$ (S = 19/2) and $[Mn12]^{2-}$ (S = 10) versions have been prepared. Mn4 SMMs with S = 9/2 have also been extensively studied. In some cases, two Mn4 SMMs occur as supramolecular dimers, [Mn4]2, and exchange interactions between them lead to interesting modifications of their QTM properties, establishing the feasibility of tuning the QTM in SMMs.[2]

[1] G. Christou, D. Gatteschi, D. N. Hendrickson, and R. Sessoli, MRS Bulletin 25, 66 (2000).
[2] W. Wernsdorfer, N. Aliaga-Alcalde, D. N. Hendrickson, and G. Christou, Nature 416, 406 (2002).

2:40pm **MB+BI+OF-TuA3 Density-Functional-Based Simulation of Molecular Magnets**, ***M.R. Pederson***, *N. Bernstein*, Naval Research Laboratory, *T. Baruah*, Georgetown University, *J. Kortus*, Max-Planck-Institute, Germany **INVITED**

Recently a class of transition-metal containing molecules have attracted significant experimental interest because they retain their magnetic orientation at relatively high temperatures and because they exhibit quantum tunneling of magnetism. These molecular magnets consist of approximately 70-200 atoms and are typically composed of 4-15 transition metal atoms which are held in place by organic ligands and anions. The fundamental figure of merit which governs these phenomena is the magnetic anisotropy which arises due to the spin-orbit interaction and other couplings between spin and spatial degrees of freedom. Recently, a quantum-mechanical method has been developed which allows for the density-functional-based determination of magnetic anisotropies in molecules and clusters.[1] We have used this method to calculate anisotropies in several molecular magnets which include: $Mn_{12}O_{12}(RCOO)_{16}(H_2O)_4$, $Fe_8O_2(OH)_{12}(C_6N_3H_{15})_6$, $Co_4C_5NH_4CH_2O)_4(CH_3OH)_4Cl_4$, and $[Mn_{10}O_4(2,2'\text{-biphenoxide})_4Br_{12}]^{4-}$. Our calculations show that good agreement between experiment and theory can be obtained. While the reorientation barriers and magnetic resonant tunneling fields are primarily determined from the second-order anisotropy hamiltonian,[1] higher-order effects can change these quantities by about ten percent. Further, such effects determine tunnel splittings and play a significant role in tunneling dynamics. Currently the primary source of such splittings is an active area of investigation. We have recently suggested that vibrationally induced changes in the spin-orbit interaction will contribute to higher-order anisotropies.[2] Further, computational results on the 4th-order magnetic anisotropy show that this interaction may provide a dominant contribution to the higher-order barriers and that it partially contributes to tunnel splittings. We discuss these calculations and compare our results to the experimental infrared work of Sushkov et al which shows that certain vibrational intensities are strongly perturbed by applied magnetic fields in the Mn_{12}-Acetate system.[3] A very brief review of the computational method, NRLMOL, used in this work will be included in the talk.

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3:20pm **MB+BI+OF-TuA5 Measuring and Manipulating Single Molecules Inside Living Cells**, ***J.S. Kanger***, *A.H.B. de Vries, J. Greve*, University of Twente, The Netherlands, *B. Krenn, R. van Driel*, University of Amsterdam, The Netherlands **INVITED**

For manipulating single molecules, techniques like AFM or optical tweezers are typically used. However, the actual actuators of these systems are relatively large, and therefore we are not able to manipulate single molecules that are situated deep inside the cell (for example inside the nucleus), without causing massive damage to the cell itself. We describe a conceptual simple arrangement for manipulating ultra small magnetic beads inside living cells using magnetic forces. By using magnetic forces to manipulate the bead, and a low yield HeNe laser to measure its position, we are able to generate a relatively high force, without damaging the cell. The setup is designed to measure the movement of a bead with nanometer precision, and apply picoNewton forces on it. Experimental results combined with model calculations show that a force of 15 pN is feasible for a ferrite bead of 50 nm diameter. If a bead is attached to a functioning protein the movement of this protein in the cell can be monitored and manipulated. We plan to apply this technique to the study of chromatin structure function relations inside the living cell. The magnetic force on a bead is proportional to the magnetization of the bead, and the gradient of the magnetic field. To produce a magnetic field that gives a gradient that is controllable both in direction and strength we constructed a four pole configuration. The tips of these poles (5 µm width and height) are placed 20 µm from each other, which leaves enough space to place a cell, with a magnetic bead in the nucleus, between the poles. The magnetic field is guided from external coils to the poletip that becomes magnetically saturated (1.8 Tesla). The pole tips are produced in the cleanroom facilities of our university. Bead position detection is done by back focal plane interferomtery. A low-yield HeNe laser will is focused on the bead. The combination of the laserbeam and, and the forward scattered light gives a interference pattern on a quadrant detector, which is depended on the position of the bead in the focus.

4:00pm **MB+BI+OF-TuA7 Synthesis and Functionalization of Nanoparticles**, ***A. Ulman***, Polytechnic University **INVITED**

The talk will focus on metal and metal oxide nanoparticles. A one-phase synthesis of thiolate-functionalized metallic nanoparticles will be described, and further chemical reactions, such as surface-initiated polymerization and attachment of DNA bases will be presented. Sonochemical preparation of oxide and mixed oxide nanoparticles will be reported. We have demonstrated, for the first time, that sonication is a very efficient method for coating of γ-Fe_2O_3 and other oxide nanoparticles. The attachment of enzymes to γ-Fe_2O_3 nanoparticles will be described.

Magnetic Interfaces and Nanostructures
Room: Exhibit Hall B2 - Session MI-TuP

Aspects of Magnetism

MI-TuP1 Enhanced Magnetoresistance in Ferromagnetic Vertical Single Electron Transistor, ***S. Haraichi***, *T. Wada*, National Institute of Advanced Industrial Science and Technology, Japan

Recently, such novel phenomena as enhancement of magnetoresistance and magneto-Coulomb oscillation have been found in ferromagnetic single electron transistors (SET). However, because the areas of the ferromagnetic-insulator- ferromagnetic (FIF) tunnel junctions were as large as 0.02 ???, extremely low temperature as 20 mK was required to obtain Coulomb blockade and spin-dependent tunneling transport simultaneously. In order to elucidate the mechanism of those phenomena at relatively high temperatures and to realize such novel devices as spin-memories and spin-transistors, FIF tunnel junctions with 10 nm sizes are necessary. We have developed Si based inorganic electron beam resist process suitable for integration by which 10 nm resolution can be achieved. Using this process, nanometer-scale vertical FIF tunnel junctions are fabricated with high reliability. In this paper, we will report a fabrication process for ultra-small ferromagnetic vertical SET by modifying the above inorganic resist process, and the electrical characteristics especially spin-dependent tunneling transport of fabricated devices. The enhanced magnetoresistance changes over several times in the Coulomb blockade (CB) region in magnetic fields of around 100 mT at 14 K, while that changes only several % in the outside of the CB region. This strong enhancement is explained by the higher-order tunneling process.

MI-TuP2 Iron-silicide Phases Formed in Fe/Si Multilayered Films, ***J.S. Park***, Hanyang University, Korea, *Y.V. Kudryavtsev*, Institute of Metal Physics, Ukraine, *J. Dubowik*, Institute of Molecular Physics, Korea, *J.Y. Rhee*, Hoseo University, Korea, *Y.P. Lee*, Hanyang University, Korea

Fe/Si multilayers films (MLF) can have the interfacial layers of various iron silicides and were recently discovered to have an antiferromagnetic (AF) coupling in the as-deposited state. An ion-beam mixing (IBM) allows us to overcome either thermodynamic or kinetic barriers by employing the energetic particles, to surpass the limit of solid solubility and to achieve the compositional and structural metastability. Fe/Si MLF with various sublayer thicknesses were made by RF sputtering onto glass substrates and an IBM was also performed. The structural properties before and after the IBM turned out to be very different. A study of the optical and magneto-optical (MO) properties of the as-deposited MLF reveal that neither $FeSi_2$ nor ε-FeSi could be considered as the spacer layer providing the strong AF coupling, but that a B2-phase nonmagnetic metallic FeSi compound is spontaneously formed between Fe sublayers during deposition. The IBM of the Fe/Si MLF has been performed at room temperature (RT) by using Ar^+ ions with an energy of 80 keV, a dose of $1x10^{16}$ ions/cm^2 and a flux of $1.5x10^{-6}$ A/cm^2. The magnetic properties were measured at RT by vibrating-sample magnetometry and ferromagnetic-resonance spectroscopy. The ion-beam treatment has led to noticeable changes in the structural and physical properties of Fe/Si MLF : the formation of a new phase, which is characterized by a crystalline silicide structure, a low coercivity and a Curie temperature of about 550 K. The obtained results can be explained if a metastable $FeSi_2$ silicide with a B2-type structure is supposed.

MI-TuP3 Dynamic and Static Measurements on Epitaxial Fe/Si/Fe, ***B.K. Kuanr***, University of Colorado at Colorado Springs, *M. Buchmeier*, Forschungszentrum Juelich GmbH, Germany, *Z. Celinski*, *R.E. Camley*, University of Colorado at Colorado Springs

Strong antiferromagnetic interlayer exchange coupling across an insulating spacer is in increasing demand for high-density magnetic recording. For example such structures can be used as artificial antiferromagnets in spin valves. We report here the interlayer exchange coupling of epitaxial Fe(10 nm)/Si(t)/Fe(8 nm) trilayers as a function of Si thickness studied by Ferromagnetic Resonance (FMR), Brillouin Light Scattering (BLS) and Magneto Optic Kerr Effect (MOKE) measurement techniques. A very strong antiferromagnetic (AF) interlayer exchange coupling (>6 mJ/cm^2) was observed at a spacer Si thickness of 0.7 nm. The bilinear J_1 and biquadratic J_2 coupling constants are determined from (i) the fitting of the angular variation of the resonance field (H_{res}) from FMR (ii) the field variation of the frequencies for the Damon-Eshbach (DE) surface modes (both optic and acoustic with non-zero k) and (iii) the fitting of longitudinal MOKE hysteresis loops. We obtain a higher H_{res} along the easy-axis than along the hard-axis and the magnetizations of the two Fe films are canted. The eight-fold like symmetry of H_{res} as a function of the angle observed at room temperature, is due to the competition between the four-fold anisotropy and AFM interfacial coupling energy. This behavior vanishes at 24 K due to a strong increase of AFM coupling in comparison to four-fold anisotropy. From the fitting of temperature variation of H_{res} curves, we obtain the temperature variation of the bilinear and biquadratic exchange coupling constants. This strong coupling can be related to the highly resistive Si spacer between epitaxial Fe layers.

MI-TuP4 Investigations on the Peculiar Magneto-optical and Magnetic Properties of Au-Fe Alloy Films and Au/Fe Multilayered Films, ***K.W. Kim***, Sunmoon University, Korea, *R. Gontarz*, Institute of Molecular Physics, Poland, *Y.V. Kudryavtsev*, Institute of Metal Physics, Ukraine, *Y.P. Lee*, Hanyang University, Korea

In this study, the peculiar magneto-optical (MO) and magnetic properties of Fe-Au alloy films and Au/Fe multilayered films (MLF) were investigated. $(3.0 \text{ nm Fe} / t_{Au})_{20}$ MLF (where / t_{Au}= 1.0, 2.0, 2.5 and 3.0 nm) were prepared by rf-sputtering onto glass substrates with a Au buffer layer of 20 nm in thickness. We also prepared Au, Fe and $Au_{1-x}Fe_x$ ($0 < x < 1$) films of about 100 - 150 nm in thickness by face-to-face sputtering onto a glass substrate at room temperature (RT). The structures of Au/Fe MLF and Au-Fe alloy films were analyzed by using the low- and high-angle x-ray diffraction (XRD). The MO equatorial Kerr effect and optical properties of the samples were measured at RT in a spectral range of 248 - 1130 nm (5.0 - 1.1 eV) and 235 - 2500 nm (5.3 - 0.5 eV), respectively. To understand the magnetic properties of $Au_{1-x}Fe_x$ alloy films more quantitatively, the magnetic circular dichroism (MCD) measurement was performed at 2B1 beamline of Pohang Light Source (Pohang, Korea). It was elucidated that alloy-like regions are spontaneously formed near the interfaces between Au and Fe sublayers during the Au/Fe MLF fabrication. The MCD results reveal that the orbital magnetic moment of the constituent Fe atoms in the bcc Fe-Au alloy film is about twice larger than that of pure Fe, which implies a hybridization between Fe and Au atoms. It is thought that the prominent feature observed in the UV range of the MO response of Au/Fe MLF results not from the quantum confinement, but probably from an enhanced magnetic moment of Fe (and/or an induced magnetic moment of Au).

MI-TuP5 Magnetoresistance and Magnetic Behavior of Manganite-based Multilayers, ***M. Sirena***, *M. Granada, L.B. Steren, N. Haberkorn, J. Guimpel*, C.N.E.A., Argentina

We have studied the physical and structural properties of multilayers based on manganite compounds. Different ferromagnetic (FM) spacers, insulator (B1) and metallic (B2), have been used in order to compare the magnetoresistance (MR) effects and interlayer coupling of both kind of systems. Multilayers based on high polarized manganites are specially interesting for developing magnetic devices with high tunneling MR, spin filters, etc. A/B1 and A/B2 multilayers (A: $La_{0.55}Sr_{0.45}MnO_3$, B1: $La_{0.9}Sr_{0.1}MnO_3$ and B2: $La_{0.67}Ca_{0.33}MnO_3$) have been grown by DC sputtering on MgO and $SrTiO_3$ substrates. X-ray diffraction patterns have been fitted to obtain information about the interface and roughness interdiffusion. The results show that the samples grow strongly textured in the c-direction, perpendicular to the sample surface, with a multilayered structure. The similar structure and lattice parameters of the samples make these films specially attractive to build multilayers with interfaces of good quality. We have studied the dependence of the transport and magnetic properties of these systems with the interlayer and top-layer thickness. Both A/B1(B2)/A trilayers present properties similar to those observed for the $La_{0.55}Sr_{0.45}MnO_3$ film. Magnetization vs. field measurements performed in both systems, show a single FM loop indicating that the A layers are always ferromagnetically coupled. The FM nature of the interlayer in the A/B1/A case is probably the origin of the FM coupling. In the A/B2/A trilayers, on the other hand, the FM coupling above its Curie temperature could be mediated by short-range ordered zones in the LaCaMnO interlayer. No extrinsic MR, associated with the multilayered structure was observed in the whole temperature range, probably due to the presence of FM coupling between the metallic layers, as suggested by magnetization measurements.

MI-TuP6 Current Induced Magnetoresistance in Co/Cu/Cu Multilayers, ***J.-D. Suh***, Electronics and Telecommunications Research Institute, Rep. of Korea

We have investigated the magnetic properties fabricated by e-beam lithography from a Co/Cu/Co multilayer. Current induced magnetoresistance properties for current flowing perpendicularly through the layers with a high current density of 10^8A/cm^2 are systematically studied as a function of device size, magnetic layer thickness and temperature. A

current induced magnetic switching is observed in multilayer structures with diameters as small as 100 nm. The results are explained by spin transfer model. In this study, we shall discuss the relation between nanostructured geometry of magnetic Co/Cu/Co multilayer and current induced magnetic switching in detail.

MI-TuP7 Patterned Nanostructures of Permalloy on Al_2O_3 Barrier Grown by an Electrodeposition, ***S. Kenane***, *L. Piraux*, Université Catholique de Louvain, Belgium, *J. Carrey, K. Bouzehouane, J.-M. George*, CNRS/THALES, France

Abstract Dots of Ni80Fe20 were grown by electrodeposition on the top of a thin alumina barrier at preferential nucleation centers. The particle sites were induced by indentation with a conducting tip atomic force microscopy (AFM) on the alumina barrier (figure 1). Figure 1 shows regular spheres of Ni80Fe20 which all have practically the same size. The size of the dots (sphere) can be controlled by varying the time deposition. The behavior of the current has been confronted to a theoretical nucleation-growth model. Using a conducting atomic force microscope, we characterize the resistance of the defects on which the dots nucleate. Preliminary electrical transport measurements were performed on the permalloy dots.

MI-TuP8 Magnetism of Ultrathin Co Films on Flat and Vicinal (001) Surfaces, *S. Pütter, N. Mikuszeit, J. Hoyer*, ***H.P. Oepen***, University of Hamburg, Germany

The magnetic properties of ultrathin Co films on Cu(1 1 13) and Pt(001) have been investigated by means of the magneto-optic Kerr effect (MOKE). Due to the symmetry breaking of the vicinal Cu(1 1 13) a uniaxial magnetic behavior is found. Magnetic anisotropies of first and second order are derived from the hard axis hysteresis curves revealing a field-driven spin-reorientation transition. The thickness dependence of the magnetic anisotropies is explained in the framework of strain relieve. The Kerr ellipticities perpendicular and parallel to the step edges are different. The difference is due to a canting of magnetization that causes a superposition of longitudinal and polar Kerr effect. Utilizing a recently proposed procedure[1] to deconvolute the mixed Kerr signals the canting angle is determined and found to be thickness dependent. By means of MOKE the quasi static magnetic susceptibility is measured during Co growth on Pt(001). The parallel susceptibility was obtained for in-plane orientation of magnetization. Around one monolayer a susceptibility peak indicates the onset of ferromagnetism in the pseudomorphic Co layer. For higher thicknesses the fcc Co film exhibits a fourfold symmetry with <110> as easy axes.

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MI-TuP9 Spin Polarized Vacuum Tunneling in Field Emission from Co-Coated W(111) Tips, ***K.L. Man***, *R. Bryl*, Hong Kong University of Science and Technology, *R. Zdyb*, Arizona State University, *T.C. Leung*, National Chung Cheng University, China, *C.T. Chan*, Hong Kong University of Science and Technology, *E. Bauer*, Arizona State University, *M.S. Altman*, Hong Kong University of Science and Technology

Ultrathin Co films are grown on the W(111) surface as the basis for spin polarized vacuum tunneling in field emission and scanning tunneling microscopy. The growth morphology, structure and magnetism are studied with conventional and spin polarized low energy electron microscopy (LEEM/SPLEEM) and diffraction (LEED) and first principles total energy calculations. Quasi-layer-by-layer growth of thick pseudomorphic Co films is observed at 380K, while Stranski-Krastanov growth and transformation to a (6x6) closed-packed structure are observed at higher temperatures. Pseudomorphic Co/W(111) is ferromagnetically ordered at 380K when film thickness exceeds 7.6 ML. Although only in-plane magnetization is found, a strong influence of substrate atomic steps is seen in the magnetization easy axis and magnetic domain structure. Spin polarization in vacuum tunneling is assessed by a Mott electron spin polarimeter coupled to a field emission microscope. High spin polarization (typically 20%, maximum 50%) in field emission from Co-coated W(111) tips and polarization manipulation achieved by pulsed magnetic field encourage further development.

MI-TuP10 Transition Metal Ion-implanted GaN and Its Magnetic and Structural Properties*, *J.S. Lee, Z.G. Khim*, ***Y.D. Park***, Seoul National University, Korea, *S.N.G. Chu*, Agere Systems, *G.T. Thaler, M.E. Overberg, C.R. Abernathy, S.J. Pearton*, University of Florida

We report on the magnetic and structural properties of Co, Cr, and V ion-implanted epitaxial GaN films on sapphire substrates. Dilute magnetic semiconductors (DMS) with ferromagnetic ordering near or above room temperatures have been reported in Mn doped GaN[1] and Co doped TiO2,[2] subsequent to predictions from a near-field model for GaN doped with a relatively high concentration of Mn.[3] Theoretical treatment of ferromagnetic ordering in DMS systems have progressed to include low carrier density regimes[4] and incorporation of other magnetic impurities.[5] We have found from SQUID magnetization measurements that (Ga,Co)N and (Ga,Cr)N show ferromagnetic ordering below ~ 78 K and ~ 51 K respectively, while (Ga,V)N shows paramagnetic behavior. Structurally from TEM and Selective Area Diffraction Pattern (SADP) data, we have observed that the ion-implantation and subsequent annealing process leaves the expected residual damage in the form of dislocation loops, but no detectable second phases, which corresponds well with the observed modest coercive fields (~100 Oe for (Ga,Co)N) of the samples. By sharp contrast, the presence of ferromagnetic metallic clusters at dimensions below our detection limits would have expected coercivities in the range of thousands of Oersteds.

* This work is partially supported by SNU Research Foundation, KOSEF, and Samsung Electronics Endowment through CSCMR.

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MI-TuP11 The Effect of the Ferromagnet/Antiferromagnet Interface on Magnetic Properties of Fe/$KCoF_3$ System, *L.M. Malkinski, T. O'Keevan, R.E. Camley*, ***Z. Celinski***, University of Colorado at Colorado Springs, *D. Skrzypek*, University of Silesia, Poland

The Molecular Beam Epitaxy (MBE) system was used to grow Fe/$KCoF_3$ bilayers, a ferromagnet-antiferromagnet system. Depending on deposition conditions the fluoride can be grown on the single crystal Fe layer in either single crystal or polycrystalline forms. Structural properties of our samples were carefully studied using X-rays, Reflection High Energy Electron Diffraction (RHEED) and tunneling electron microscopy. The structure of the fluoride determines the ferromagnet/antiferromagnet interface and significantly modifies magnetic properties, which were measured using Ferromagnetic Resonance (FMR) and SQUID magnetometry. We observed changes in the exchange bias which correspond to different structural states of the antiferromagnet. This could result in different spin compensations at the Fe/$KCoF_3$ interface in single crystal and polycrystalline samples. The interface also had a dramatic effect on the four-fold magnetocrystalline anisotropy of Fe. For the samples with polycrystalline $KCoF_3$, the anisotropy thickness dependence for the single crystal Fe film, with thickness d ranging from 0.9 to 3 nm, showed a deviation from the usual 1/d dependence. The temperature dependence of the four-fold anisotropy of the samples with single crystal fluoride was typical of single crystal Fe films. However, the films with polycrystalline fluoride exhibited a distinctly different temperature behavior. The anisotropy for these samples increases significantly with decreasing temperature. The enhancement of the anisotropy was most pronounced for the samples with the thinnest Fe film changing by a factor of 3 from room temperature to low temperature. This effect is probably due to a specific morphology of the interface between the ferro- and antiferromagnet. In addition, a large rotational magnetic anisotropy, associated with the interaction between Fe and $KCoF_3$, was evaluated from the temperature dependence of the FMR fields.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI-WeM

Magnetic Recording: GMR, Tunneling, and Media
Moderator: W.H. Rippard, NIST

8:20am **MI-WeM1 Perpendicular Recording Media Near 100 Gbit per square inch**, ***D. Weller***, *B. Lu, Y. Kubota, J. Ahner, G. Ju, X. Wu, D. Karns, A. Sunder*, Seagate Research, *C.H. Chang, C. Brucker, R. Ranjan*, Seagate Recording Media Operations, *M. Kryder*, Seagate Research **INVITED**

Media noise suppression via reduced grain and magnetic cluster size and at the same time thermal stability are general requirements to advancing magnetic recording technology to higher areal densities, beyond 100 Gbit per square inch. In perpendicular recording, using a hard/soft dual layer media scheme, one seeks to use magnetically harder media. Such media sustain smaller stable grains and can be written owing to the improved write field geometry that perpendicular pole heads in conjunction with soft magnetic underlayers offer over the conventional ring head geometry used in longitudinal recording. Modeling suggests, that this technology is extendible to areal densities of the order of Terabit per square inch. In this paper, we review current-state-of the art perpendicular media and review testing results near 100 Gigabit per square inch recording densities. The key challenges relate to controlling average grain sizes and their distributions as well as intergranular exchange coupling in the hard layer and at the same time generating a low noise, high permeability soft magnetic underlayer. We have fabricated both CoPtCr-type alloy and CoCr/Pd-type multilayer media and obtained grain sizes of D=10.5+/-2.2nm and D=13.1+/-2.5 nm, respectively. These media have full remanence squareness (S=1), negative onset fields for reversal > 2000 Oe, thicknesses in the range 10-18 nm and are thermally stable. The soft underlayer material is an amorphous FeCoB alloy with 1.9 T flux density and a static permeability of >400; it is stabilized into a single domain, noise free state, via an induced radial magnetic anisotropy field > 50Oe. The spacer between the soft underlayer and hard layer is an alloy seed layer structure of total thickness less than 5 nm. This interlayer controls the microstructure of the subsequent recording layer and is key to enhancing the performance of perpendicular media.

9:20am **MI-WeM4 High Frequency Noise Measurements in Spin-Valves**, ***N.A. Stutzke***, Boise State University, *S.E. Russek*, NIST, Boulder, *S.L. Burkett*, Boise State University

High-frequency magnetic noise in magnetoresistive devices, being developed for read-sensor and magnetic random access memory applications, may present fundamental limitations on the performance of sub-micrometer magnetic devices.[1] High-frequency magnetic noise arises from intrinsic thermal fluctuations of the device magnetization. High-frequency noise spectroscopy provides a powerful tool to characterize the dynamics and response of multilayer magnetic devices. In this study, the noise characteristics of micrometer-dimension spinvalves have been investigated at frequencies in the range of 0.1-6 GHz. 1/f noise dominates at frequencies below this range. High-frequency noise measurements as a function of temperature, bias current, and magnetic field are obtained for IrMn-exchange biased spinvalves using a 50 GHz spectrum analyzer, low-noise amplifier, and a cryogenic microwave probing system. Temperature is varied from 100-400K. The magnetic noise is obtained by taking the difference between the noise spectrum of the device in a saturated and unsaturated state. The data can be fit to simple models that predict the noise power to be proportional to the imaginary part of the free-layer magnetic susceptibility.[2] Noise is observed to shift to higher frequencies and decrease in amplitude with decreasing temperatures. This is consistent with an increase in magnetostatic anisotropy due to the increase in the saturation magnetization as the temperature is lowered. There are some important differences between the high-frequency noise measurements and direct measurements of the device susceptibility (both at the device and wafer level). The noise measurements show a smaller damping constant (a smaller ferromagnetic resonance linewidth) and show additional features due to the presence of additional magnetostatic modes.

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9:40am **MI-WeM5 Theory of Spin-dependent Tunneling**, ***J. Mathon***, City University, UK **INVITED**

Rigorous theory of the tunneling magnetoresistance (TMR) based on the real-space Kubo formula and fully realistic tight-binding bands fitted to an ab initio band structure is decribed. It is first applied to calculate the TMR of two Co electrodes separated by a vacuum gap. The calculated TMR ratio reaches some 65% in the tunneling regime but can be as high as 280% in the metallic regime when the vacuum gap is of the order of the Co interatomic distance (abrupt domain wall). It is also shown that the spin polarization P of the tunneling current is negative in the metallic regime but becomes positive P~35% in the tunneling regime. Calculation of the tunneling magnetoresistance of an epitaxial Fe/MgO/Fe(001) junction is also described. The calculated optimistic TMR ratio is in excess of 1000% for an MgO barrier with 20 atomic planes of MgO and the spin polarization of the tunneling current is positive for all MgO thicknesses. Finally, it is demonstrated that the TMR ratio calculated from the Kubo formula remains nonzero when one of the Co electrodes is covered with a copper layer. It is shown that nonzero TMR is due to quantum well states in the Cu layer which do not participate in transport. Since these only occur in the down-spin channel, their loss from transport creates a spin asymmetry of electrons tunneling from a Cu interlayer, i.e. nonzero TMR. Numerical modelling is used to show that diffuse scattering from a random distribution of impurities in the barrier may cause quantum well states to evolve into propagating states, in which case the average TMR tends to zero but large quantum oscillations of TMR about zero average remain.

10:20am **MI-WeM7 In-Situ Conductance Measurements of Giant Magnetoresistive Multilayers**, ***A.T. McCallum***, *S.E. Russek*, National Institute of Standards and Technology

In-situ conductance measurements can detect the changes in electronic structure during deposition of a multilayer with submonolayer resolution. Here, we present conductance verses thickness data, taken every half monolayer, for both top and bottom pinned spin valves at different temperatures. These measurements can clearly identify bulk scattering processes and interfacial scattering. For example, our data shows adding Co onto Cu adds strong interfacial scattering mechanisms. The conductance verses thickness data were compared to a Boltzmann transport equation (BTE) model. Bulk conductivities were measured by extending the measurements out to large layer thicknesses. Bulk electron mean free paths were calculated from the measured conductivites and the results of other experiments. Transmission probabilities and specular reflection probabilities were deduced from this model. The spatial distribution of current density in the multilayer, was then calculated using the BTE model. In-situ conductance measurements were used to characterize thin oxide layers, which are used as insulating barriers in magnetic tunnel junctions and specularly reflecting surfaces in giant magnetoresistance devices. For these applications it may be necessary to completely oxidize one layer of metal and not oxidize the metal underneath. The dynamics of oxidizing an Al surface were observed using in-situ conductance measurements and a vibrating crystal thickness monitor. The thickness monitor measures the oxygen uptake over time while in-situ conductance measures the amount of Al oxidized and the change in specularity due to the oxide. Using these techniques we characterized several oxidization procedures to detemine the details of the oxidization process and to find an optimum oxidization procedure.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI-WeA

Magnetization Dynamics
Moderator: S.E. Russek, NIST, Boulder

2:00pm **MI-WeA1 Investigation of Magnon Generation by a dc Current through a Point Contact/Magnetic Multilayer Junction**, ***W.H. Rippard***, *M.R. Pufall, T.J. Silva*, National Institute of Standards and Technology

We have studied the spin-momentum transfer (SMT) effect with mechanical point contacts and several types of magnetic multilayers, exhibiting both ferromagnetic (FM) and antiferromagnetic (AF) exchange-coupling. Electron spins flowing though a magnetic multilayer transfer angular momentum between the individual layers. At sufficiently high current densities, the resultant spin torque is large enough to induce magnetization dynamics.[1-5] Previous work using point contacts has shown that there is an abrupt step in the dc resistance, and corresponding peak in dV/dI, when the current reaches a critical value Ic. The linear dependence of Ic on applied magnetic field suggests a correlation with magnon generation. Earlier data were obtained from AF coupled films, with fields applied perpendicular to the film. In our measurements, we have explored a variety of parameters. We found that spin-momentum transfer is a robust effect, occurring for a wide range of experimental conditions. SMT-related phenomena are observed for both in-plane and out-of-plane fields, for AF exchange-coupled multilayers grown at both the 1st and 2nd GMR maxima, and for FM-coupled multilayers. Also, the dependence of Ic on field can vary substantially from contact to contact. Peaks in dV/dI can persist (albeit with reduced magnitude) down to zero applied field for AF-coupled samples. Multiple peaks can also occur, implying multiple excitation modes. For FM-coupled multilayers the SMT effects have large ~0.5 W steps in the dc resistance at the critical current, implying the onset of surprisingly large excitations. The persistence of SMT down to zero applied field suggests application of SMT as a novel high-frequency oscillator.

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2:20pm **MI-WeA2 Mechanical Detection of Ferromagnetic Resonance in Micron-size YIG Disk**, ***V. Charbois***, *O. Klein*, C.E.A. Saclay, France, *V.V. Naletov*, Kazan State University, Russia

We present room temperature measurements by Magnetic Resonance Force Microscopy (MRFM) of the ferromagnetic resonance (FMR) spectra on a normally magnetized YIG disk (with thickness 4.75µm and radius 80µm). The analysis of the influence of the tip for different probe-sample separation h led us to distinguish two cases. In the weak coupling regime, when the bias field generated by the tip is smaller than a few hundred Gauss, the prominent change is a shift of the entire spectrum to lower applied fields as h decreased. The result can be quantitatively understood within the framework of the Damon and Eshbach model. In the strong coupling regime, the additional inhomogenous field produced by the tip can be used to localize new magnetostatic modes underneath the probe[2] (this allows local spectroscopy to be performed). However, in the case of YIG, the spatial extension of these modes is limited to 4µm. Simultaneous measurements of FMR both by standard susceptibility and mechanical detection demonstrate the higher sensitivity of MRFM[1] and its ability to measure smaller sample (in this case the spectroscopic response of the entire sample is obtained). Imaging of the magnetostatic modes can be performed by taking advantage of the localized probe. Ideally one should work at small h (to achieve high spatial resolution) with a tip producing a weak stray field (e.g. a tip coated with a thin film of ferromagnetic material). The last advantage of this technique is that it is sensitive to the longitudinal magnetization and thus it provides information complementary to conventional microwave susceptibility measurements.

[1] V.Charbois, V.V.Naletov, J.Ben Youssef and O.Klein, J.Appl.Phys 91, 7337 (2002).
[2] V.Charbois, V.V.Naletov, J.Ben Youssef and O.Klein, to be published in Appl.Phys.Lett. (June 24th issue)

2:40pm **MI-WeA3 Spin Wave Dynamics in Structured Magnetic Media**, ***S.O. Demokritov***, University Kaiserslautern, Germany **INVITED**

Spin waves are the fundamental dynamic eigen-modes of a magnetic system. The knowledge of the spin-wave properties in the small-amplitude limit is mandatory to understand the dynamic properties of a magnetic system in general. This presentation covers the recent results obtained on spin wave excitations in arrays of magnetic elements using Brillouin light scattering spectroscopy (BLS). Confinement of spin waves in magnetic elements leads to dramatic changes of the spin wave dispersion and density of states. The observed lateral quantization of spin wave modes in an element is one consequence of the confinement. The quantization conditions are determined by the stripe width, and by the boundary conditions at the lateral edges of the stripe. It is shown, that these conditions result in an effective "pinning" of a purely dipolar nature due to the inhomogeneity of the dynamic internal field near the stripe edges. An additional analysis of the BLS-intensity as a function of the transferred wavevector provides information on the mode profiles. According to the scattering theory from confined modes, the BLS-intensity of a given mode is determined by the Fourier-components of the mode profile. Thus, light scattering can be used as a "Fourier-microscope" and can provide information on the distribution of the dynamic magnetization in the elements with the resolution better than 200 nm. Another striking effect of magnetic confinement is a strongly inhomogeneous static internal magnetic field in the element. This inhomogeneity creates potential wells for spin waves near the edges of the elements. The size of the wells is much smaller than the lateral size of the element. The dynamic magnetic susceptibility in the well shows a strong maximum, causing a localization of low frequency spin wave modes in the well, which is experimentally confirmed using BLS-Fourier-microscope.

3:20pm **MI-WeA5 Spin Wave Excitations by Low Energy Electrons in Fe**, ***M.R. Vernoy***, *H. Hopster, D.L. Mills*, University of California, Irvine

A new spectrometer for spin polarized electron energy loss spectroscopy (SPEELS) has been constructed. The spectrometer is based on 127° cylindrical sectors as monochromator and analyzer, with the analyzer being rotatable for angle dependent measurements. A standard GaAs negative-electron-affinity photoemitter source is coupled to the monochromator and provides spin polarized electrons with polarization values around 25 %. SPEELS measurements were performed on thick (several 100 Å) epitaxial Fe films grown in situ on GaAs(100) substrates. The Fe films were remanently magnetized by a magnetic field pulse and SPEELS spectra were taken with the incoming beam polarization parallel or antiparallel to the magnetization. The primary energy used was 20 eV and an energy resolution of 25 meV (FWHM) was achieved. Strong spin asymmetries are detected in the energy loss spectrum. In addition to the well known Stoner excitation spectrum at high energies there is a distinct loss structure at small energies (100-300 meV) due to spin wave excitations. This spin wave energy loss structure has a highly asymmetric shape with a sharp onset around 100 meV, a maximum around 165 meV and a tail extending out to 350 meV. This peak shape can be explained by excitation of a continuum of bulk spin waves due to the non-conservation of q-perpendicular in the excitation process. We shall present comparison between the measured spectra and model calculations which employ a very simple description of the excitation process, and a Heisenberg model to describe spin waves at the crystal surface.

3:40pm **MI-WeA6 Dynamical Investigation of Transient Magnetic Anisotropy in $Ni_{80}Fe_{20}$**, ***R. Lopusnik****, *J.P. Nibarger, T.J. Silva, Z. Celinski*, National Institute of Standards and Technology

The values of static and dynamic uniaxial anisotropy in thin permalloy films are anomalously different by a factor of 2. The dynamic response of different thickness films are measured with a pulse inductive microwave magnetometer. The time-resolved precessional response was measured as a function of the applied bias field varying from 0 to 8 kA/m. The frequency range varies from 700 MHz to 3 GHz. Spectroscopic analysis of the data yields quantitative information about the intrinsic gyromagnetic properties of the films. The observed dependence can be fitted to high precision with the Kittel formula for ferromagnetic resonance to extract anisotropy field H_k, the spectroscopic factor g etc. The static anisotropy field value was obtained by a quasi-static measurement of a hysteresis loop along the magnetic hard axis. In this case, the saturation field corresponds to the anisotropy field of the sample. To understand this effect, variable angle measurements were performed for several different orientations of the uniaxial anisotropy with respect to the applied bias field. For each angle the value of the dynamical anisotropy was obtained. The angular dependence of the anisotropy can be fitted to a cosine function, but with an additional angle-independent offset field of ~400 A/m. The modulation amplitude of the fitted cosine function is equal to the static anisotropy field value of ~320 A/m. Both the cosine amplitude and angle-independent offset are found to

* Falicov Student Award Finalist

be independent of film thickness below 100 nm. We interpret the constant offset field as a transient component of the magnetic anisotropy that only affects dynamical response at time scales below 10 ns. Similar behavior has been observed using magneto-optical methods.[1] In these recently reported studies, an initial fast response of the magnetization was followed by very slow increase over a much longer time scale. We will discuss possible explanations, including non-linear dynamics and eddy currents.

[1] M. Bauer, R. Lopusnik, J. Fassbender, B. Hillebrands, J. Bangert, and J. Wecker, J. Appl. Phys. 91, 543 (2002); M. Pufall and T. Silva, IEEE Trans. Mag. 38, 129 (2002)

4:00pm **MI-WeA7 A New Equation for Magnetization Dynamics Based Upon Transverse Relaxation Processes**, ***T.J. Silva***, *R. Lopusnik*, *J.P. Nibarger*, National Institute for Standards and Technology, *T. Gerrits*, University of Nijmegen, The Netherlands

We present a new equation for magnetodynamic response, derived from the Bloch-Bloembergen formulation for spin relaxation phenomena. The new equation is vectorial and adapted for all possible field geometries. The longitudinal and transverse relaxation rates are constrained to insure conservation of the magnetization. As such, the new equation is amenable to finite-element micromagnetic simulations. Subject to the constraint of constant magnetization, the longitudinal relaxation rate cannot be constant during free induction decay in unbiased ferromagnetic films. However, if the transverse relaxation rate is held constant, the resulting equation is of the Landau-Lifshitz form but with an additional dependence of the damping term on longitudinal field. The field dependence strongly renormalizes the relaxation times for thin films in small bias fields such that MHz transverse relaxation rates for undressed excitations can result in nanosecond damping times in a thin film geometry. Such strong renormalization allows for a significant contribution by weak spin-orbit effects to the overall damping of precessional excitations in thin film structures. Inverse field dependence for the damping parameter in thin films is predicted by the new equation, in agreement with recent data obtained by inductive and optical methods.[1] In addition, highly viscous response is predicted when the magnetization is subject to large magnetic field pulses along the hard axis of uniaxial anisotropy films, also in agreement with recent observations of metastable states in homogeneous Permalloy films.[2] Implications for device performance and data storage applications will be discussed.

[1] T. J. Silva, T. M. Crawford, IEEE Trans. Magn. 35, 671 (1999).
[2] P. Kabos, S. Kaka, S. E. Russek, T. J. Silva, IEEE Trans. Magn. 36, 3050 (2001).

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+SS-ThM

Magnetic Spectroscopies
Moderator: D.A. Hite, NIST

8:20am **MI+SS-ThM1 Photoemission and X-Ray Absorption Measurements on the CMR Materials $La_{1-x}Ca_xMnO_3$ and $La_{1-x}Sr_xMnO_3$**, ***N. Mannella***, University of California at Davis, *A. Rosenhahn*, Lawrence Berkeley National Laborarory, *S. Mun*, Intel Corporation, *S.-H. Yang*, IBM Almaden Research Center, *Y. Tomioka*, *Y. Tokura*, Joint Research Center for Atom Technology, Japan, *C.S. Fadley*, Lawrence Berkeley National Laboratory

We report core and valence photoemission results obtained with synchrotron radiation for a set of high quality single-crystal CMR samples, namely $La_{1-x}Ca_xMnO_3$ and $La_{1-x}Sr_xMnO_3$ with x ranging from 0 to 0.4. The measurements were performed after cleaving the crystals in situ in UHV, yielding very clean and stoichiometric surfaces. X-ray absorption spectroscopy (XAS) and high-resolution valence band measurements at temperatures above and below the Curie temperature will also be discussed. The Mn 3s core level spectra show the expected multiplet splitting in binding energy, an effect which can sensitively probe the spin state of magnetic atoms. Our data reveal a non-linear dependence of the multiplet splitting on the hole concentration x, contrary to what one would expect in the simplest picture according to which hole doping causes a corresponding number of Mn^{3+} ions to become Mn^{4+}. These results may indicate an inadequacy of the conventional model based on the nominal Mn^{3+} - Mn^{4+} valence states. We have also measured Mn 3s spectra as a function of temperature. Our data suggest a short-range-order magnetic transition above the bulk Curie temperature, yielding a quantitative estimate of temperatures higher than T_C at which the material shows magnetic order of local character. This work was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, under Contract No. DE-AC03-76SF00098.

8:40am **MI+SS-ThM2 MOKE Studies of Magnetic Coupling in $Co/Cr_2O_3/CrO_2$**, ***R. Cheng***, *A.N. Caruso*, *L. Yuan*, *S.-H. Liou*, *P.A. Dowben*, University of Nebraska-Lincoln

CrO_2 is an attractive material for spin-polarized electron tunneling because of the high electron polarization and is among the predicted half metallic ferromagnets (metallic for one spin direction while insulating for the other spin direction, i.e. 100% spin polarization). Because the native surface layer of CrO_2 is Cr_2O_3, by evaporating Co thin films (5~20 nm) on top of epitaxial CrO_2 films on TiO_2 (100) substrates, a $Co/Cr_2O_3/CrO_2$ trilayer can be readily fabricated. >From in situ MOKE studies and ex situ SQUID measurements for the magnetic $Co/Cr_2O_3/CrO_2$ trilayers, the characteristic behavior of ferromagnetic-paramagnetic-ferromagnetic coupling above room temperature was observed. The thickness of Co and the temperature dependence of the magnetic hysteresis loops, obtained from MOKE, indicate different shapes, and the coercive fields show strong but not monotonic temperature dependence. These results indicate that there are changes in magnetic coupling and magnetization orientation particularly apparent as the temperature approaches the T_c of CrO_2.

9:00am **MI+SS-ThM3 Polarized X-Rays and Magnetic Interfaces**, ***H. Ohldag***, Stanford Synchrotron Radiation Laboratory, *A. Scholl*, *E. Arenholz*, Advanced Light Source, *F. Nolting*, Swiss Light Source, *Y. Acremann*, *J. Stohr*, Stanford Synchrotron Radiation Laboratory, *F.U. Hillebrecht*, Forschungszentrum Karlsruhe, Germany, *S. Maat*, *M.J. Carey*, IBM Almaden Research Center **INVITED**

While interfaces are supposed to dominate the behavior of magnetic multilayer their identification and characterization remains an experimental challenge. A prominent example is the loop shift (exchange bias) and the coercivity increase found if a ferromagnet (FM) is coupled to an antiferromagnet (AFM). Although exchange bias was discovered over 40 years ago our understanding of its origin is still poor. We use dichroism x-ray absorption spectromicroscopy in a photoemission electron microscope to study the magnetic coupling between AFM NiO(001) and FM Co. We observe large (1-20mm) AFM domains at the surface of bare NiO(001) single crystals. Upon in situ deposition of thin FM Co layers (1.5nm) a reorientation of the AFM axes takes place. The uniaxial anisotropy axes of the FM and the AFM are then aligned parallel domain by domain. Spectroscopy data show that the Co deposition causes a chemical reaction and formation of an interfacial CoNiOx layer. Microscopy images reveal its polarization to be aligned parallel to the Co layer. Upon annealing both, the uniaxial anisotropy and the amount of interfacial spins increases indicating the direct link between interfacial polarization and parallel exchange coupling. A small fraction of interfacial spins does not follow the external field. These so called pinned moments lead to an additional vertical shift in the hysteresis loop of the interfacial spins. The number of pinned spins can be diretly correlated to the size of the exchange bias field. Our findings clearly show that a proper description of magnetic coupling in Co/NiO as well as in other AFM/FM systems needs to consider the properties of a distinct interfacial layer that can deviate significantly from the bulk properties of each material.

[1]H. Ohldag, A. Scholl et al., PRL 86(13), pp. 2878, 2001.
[2]F. U. Hillebrecht, H. Ohldag et al., PRL 86(15), pp. 3419, 2001.
[3]H. Ohldag, A. Scholl et al., PRL 87 art. no 247201, 2001.

9:40am **MI+SS-ThM5 A Compact Angle Resolving Spin-Polarized Photoemission Spectrometer for "Double Polarization" X-ray Diffraction Spectroscopy of Magnetic Nanostructures**, ***S.A. Morton***, University of Missouri-Rolla, *J.G. Tobin*, Lawrence Livermore National Laboratory, *G.D. Waddill*, University of Missouri-Rolla

Recent studies of spin dependent x-ray photoelectron diffraction from magnetic nanostructures excited with circularly polarized photons have demonstrated that the technique can provide a powerful probe of element specific atomic scale magnetic structure; however, the asymmetries involved are low, typically 1-2%. Calculations suggest that combining excitation via circularly polarized photons with spin polarized photoelectron detection in a "double polarization" experiment should lead to a 5-10 fold increase in asymmetry. However combining high angular resolution XPD with spin resolving capability poses significant experimental challenges. The authors describe a unique new compact angle resolving spin spectrometer currently being developed at the Advanced Light Source, Lawrence Berkeley National Laboratory. This combines a large (11 inch) diameter fixed hemispherical analyzer with a novel rotatable input lens system allowing data with +-1 degree angular resolution to be acquired for any combination of incident and emission angles, including normal incidence/ normal emission: a geometry critical for certain magnetic measurements. The analyzer is equipped with both multichannel detection for spin integrated spectroscopies, such as magnetic linear or circular dichroism, and a Mott detector capable of resolving the photoelectron spin polarization along the two perpendicular axis of the rotational plane. Rapid switching between spin integrated and spin resolved modes is achieved by focusing the photoelectrons through a small hole in the detector of the hemispherical analyzer and into the compact mini-Mott detector situated immediately behind the channelplates. The spectrometer system also incorporates additional sample growth and characterization facilities such as co-evaporation from multiple deposition sources, LEED and Auger together with sample heating and cooling to provide a comprehensive system for the preparation and analysis of magnetic nanostructures.

10:00am **MI+SS-ThM6 In-plane Vector Magnetometry on Rectangular Co Dots using Polarized Neutron Reflectivity**, ***K. Temst***, *M.J. Van Bael*, *J. Swerts*, *D. Buntinx*, *C. Van Haesendonck*, *Y. Bruynseraede*, K.U. Leuven, Belgium, *H. Fritzsche*, Hahn-Meitner-Institut Berlin, Germany, *R. Jonckheere*, IMEC vzw, Belgium

We have measured the off-specular polarized neutron reflectivity of a periodic array of rectangular magnetic polycrystalline Co-dots, which were prepared by a combination of electron beam lithography and molecular beam deposition. The dots have a strong shape anisotropy, imposed by a length-to-width ratio of 4:1. The intensity of the off-specular satellite reflection was monitored as function of the magnetic field parallel to the rows of dots and in the plane of the film, allowing us to analyze the magnetization reversal process using the four spin-polarized cross-sections. Analysis of the neutron reflectivity provides in-plane vector magnetometry during magnetization reversal. The neutron reflectivity data are complemented by micromagnetic simulations.

10:20am **MI+SS-ThM7 Magnetism of Adatoms and Clusters**, ***P. Gambardella***, Ecole Polytechnique Fédérale de Lausanne, Switzerland **INVITED**

In the last ten years, x-ray magnetic circular dichroism (XMCD) has found widespread application as an element-specific magnetometry tool in the study of magnetic thin films. Here we show that x-ray absorption spectroscopy (XAS) and XMCD can be successfully employed to probe diluted transition-metal systems with surface impurity concentration as low as 3×10^{12} atoms cm^{-2}, thus leading to the direct characterization of the electronic and magnetic configuration of impurity systems as well as supported nanostructures. Combined XAS-XMCD provide simultaneous

information about the the d-valence state and related spin and orbital moment of transition-metal atoms that is not accessible by traditional techniques such as, e.g., magnetic susceptibility, resistivity, and electron paramagnetic resonance measurements. A first fundamental issue is how the magnetic moment of surface adatoms depends on the interaction with the host conduction electrons. We show that Fe, Co, and Ni, owing to d-electron localization, display large spin and orbital moments on low electron density simple-metal substrates which are progressively quenched as the surface electron densitiy increases.[1] A second fundamental issue is how the interaction with the substrate and adjacent adatoms influnces the magnetic anisotropy of the system. We report giant magnetic anisotropy values up to 3.3 meV/atom for Co clusters and atomic wires on Pt surfaces. A clear correlation is established between the atomic coordination, the magnitude of the orbital moment and the anisotropy energy, with implications for magnetic ordering phenomena.[2]

[1] P. Gambardella et al., Phys. Rev. Lett. 88, 047202 (2002).
[2] P. Gambardella et al., Nature 416, 301 (2002).

11:00am **MI+SS-ThM9 Probing Buried Interfaces with Soft X-ray Standing Wave Spectroscopy: Application to the Fe/Cr Interface**, ***S.-H. Yang***, *B.S. Mun*, Lawrence Berkeley National Laboratory, *N. Mannella*, University of California, Davis, *S.K. Kim, J.B. Kortright, J. Underwood, F. Salmassi, E. Arenholz, A. Young, Z. Hussain, M.A. van Hove*, Lawrence Berkeley National Laboratory, *C.S. Fadley*, University of California, Davis

We will discuss a novel type of non-destructive method for spectroscopically studying buried nanometer-scale interfaces and other nanostructures with soft x-ray standing waves. Strong standing waves with a period of 4.0 nm and approximately 3:1 contrast ratios are created via Bragg reflection from a synthetic multilayer of form [B4C/W]40. By growing a wedge-shaped Fe/Cr bilayer on top of this multilayer, the mechanical translation of the sample exposed to a fixed and finely focussed synchrotron radiation beam is converted into a translation of the standing wave through the interface. Analyzing various core photoelectron intensities as a function of angle and beam position permits deriving layer thicknesses and interface mixing/roughness scales. Magnetic circular dichroism in photoemission from the 2p and 3p levels of Fe and Cr further permits deriving the positions and widths of regions with decreased (increased) ferromagnetic alignment for Fe (Cr), showing that normally antiferromagnetic Cr becomes ferromagnetic just below the center of the interface but with antiparallel alignment with respect to Fe, and that the equal-concentration region in the center of the interface strongly inhibits magnetic alignment for both species along the direction of net magnetizations that is probed. The magnetically-altered regions in both metals are only 1-2 atomic layers in thickness. 3s spectra from Fe and Cr further indicate that the local spin moments on both atoms do not change on crossing the interface. This standing wave-plus-wedge method should have a range of applications for the characterization of magnetic and non-magnetic nanostructures and their interfaces. Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, under Contract No. DE-AC03-76SF00098.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+NS-ThA

Magnetic Imaging
Moderator: G.D. Waddill, University of Missouri-Rolla

2:00pm **MI+NS-ThA1 Atomic-scale Surface Magnetic Structures of Mn_3N_2 Observed by Spin-polarized Scanning Tunneling Microscopy**, ***H. Yang***, *A. Smith*, Ohio University

The development of spin-polarized scanning tunneling microscopy (SP-STM) has made possible the imaging of surface magnetic structures in real space down to the atomic scale.[1] In this talk, we will discuss the magnetic structure of Mn_3N_2 (010) surface investigated using SP-STM with antiferromagnetic (AFM)-coated tungsten (W) tips. The Mn_3N_2 film was grown by molecular beam epitaxy. The surface structure of the film was studied in-situ. Normal STM images of Mn_3N_2 (010) obtained using W tips reveal row structures, corresponding to Mn atoms at the intersection of surface and N vacancy planes which occur every third atomic layer.[2] By using AFM-coated W tips, we observed a modulation in the height of the rows, which is attributed to the spin-polarized effect in which the tunneling current has a component which depends on the angle between the surface and tip magnetic moments. The row modulation implies that the Mn moments are ferromagnetic within a row but AFM from row to row. We show, using a new method, that it is possible to extract the magnetic component, which is proportional to the integrated local magnetization density of states.[3] The extracted magnetic component is compared with various surface spin models, which will be discussed. This work is supported by NSF under Grant No.9983816.

[1] S. Heinze, M. Bode, A. Kubetzka, O. Pietzsch, X. Nie, S. Blugel, and R. Wiesendanger, Science, 288, 1805 (2000).

[2] H. Yang, Hamad Al-Brithen, Arthur R. Smith, J. A. Borchers, R. L. Cappelletti, and M. D. Vaudin, Appl. Phys. Lett., 78, 3860 (2001).

[3] D. Wortmann, S. Heinze, Ph. Kurz, G. Bihlmayer, and S. Blugel. Phys. Rev. Lett., 86, 4132 (2001).

2:20pm **MI+NS-ThA2 Spin-Orbit Effects on Fe/W(110) Revealed by Scanning Tunneling Spectroscopy**, ***M. Bode***, University of Hamburg, Germany, *S. Heinze*, IBM Research Division, *A. Kubetzka, O. Pietzsch*, University of Hamburg, Germany, *X. Nie, G. Bihlmayer*, Forschungszentrum Jülich, Germany, *S. Blügel*, Universität Osnabrück, Germany, *R. Wiesendanger*, University of Hamburg, Germany

We have studied the dependence of the spin-averaged tunneling current on the direction of the magnetization experimentally on the well-defined model system Fe/W(110) with its well-known magnetic structure at the nanometer scale.[1,2] We found by scanning tunneling spectroscopy (STS) and first-principles calculations that the surface electronic structure of an Fe double layer on W(110) depends on the orientation of the magnetization. From a detailed analysis of the electronic structure we deduce how the signature of the magnetization direction is imprinted via the spin-orbit interaction. Our analysis reveals that it is not the splitting of bands but changes of the orbital character of certain bands which affects the tunneling current. As an important implication of this effect the magnetic nanostructure of surfaces can be investigated with a conventional nonmagnetic tip, similar to an earlier proposal by Bruno et al.[3] The underlying physics of the spin-orbit dependent differential conductivity can be considered as the static limit of the magnetic linear x-ray dichroism or the ballistic or tunneling analogon of the anisotropic magnetic resistance of ferromagnets.

[1] O. Pietzsch et al., Phys. Rev. Lett. 84, 5212 (2000).

[2] M. Bode et al., Phys. Rev. Lett. 86, 2142 (2001).

[3] P. Bruno, Phys. Rev. Lett. 79, 4593 (1997).

2:40pm **MI+NS-ThA3 Magnetic Imaging and Spectroscopy of $Fe_xNi_{(1-x)}$ Thin Films on Cu(111)**, ***Y. Sato***, *T.F. Johnson, S. Chiang*, University of California, Davis, *M. Hochstrasser, J.G. Tobin*, Lawrence Livermore National Laboratory, *A. Scholl*, Lawrence Berkeley National Laboratory, *J.A. Giacomo, D.B. Hoffman*, University of California, Davis

We are studying the system of FeNi/Cu(111) to understand the surface/interface magnetism relevant to the application of the giant magnetoresistive effect to magnetic recording heads. We have used X-ray Magnetic Linear Dichroism (XMLD) and Photoemission Electron Microscopy (PEEM) at the Advanced Light Source, and Low Energy Electron Microscopy (LEEM). Using XMLD, the dichroism signals from both the Fe and Ni peaks were measured, and the asymmetries were calculated. Both the Fe and Ni asymmetries as a function of temperature have been fit to the theoretical curve to extract the critical exponent β. Preliminary analysis indicates that for thicker films, the values are consistent with 3D mean-field magnetic models. As a function of Fe concentration x, the total weighted asymmetry, $A_T = xA_{Fe}+(1-x)A_{Ni}$, where A_{Fe} and A_{Ni} are the respective elemental asymmetries, shows a monotonic increase from 2% to a maximum of 8.5% for x~65%, near the bulk Invar concentration. For higher x, the asymmetry is quenched, indicating a magnetic transition taking place in the film system. This magnetic instability for high x agrees with the trends in Curie temperature as a function of x, as measured from XMLD spectra, PEEM data, and previous work on FeNi/Cu(100).[1] The PEEM images show a change in the domain structure of the films for x~42-55%. The domain structures are defined well by 180° domain walls, and their size is much bigger than for other concentrations. The magnetization appears to align along one of the crystal axes. Low Energy Electron Microscopy images of the growth of the films will also be shown.

[1] F.O.Schumann, S.Z.Wu, G.J.Mankey, R.F.Willis Phys.Rev.B 56, 2668 (1997).

3:00pm **MI+NS-ThA4 Falicov Award Presentation**

3:20pm **MI+NS-ThA5 Magnetic Resonance Force Microscopy at Millikelvin Temperatures**, ***H.J. Mamin***, *R. Budakian, D. Rugar*, IBM Almaden Research Center **INVITED**

Magnetic resonance force microscopy (MRFM) offers the promise of combining the spectral resolving power and three-dimensional imaging capabilities of magnetic resonance with the high resolution of scanning probe techniques. The greatest payoffs are expected once it is possible to detect and manipulate individual spins. There is now evidence that one of the greatest obstacles to reaching this goal is that of thermally-driven fluctuations in the magnetic tip, which interfere with the quantum state of the spins. For this reason, we have begun an effort to perform MRFM at millikelvin temperatures in a dilution refrigerator. Some essential technical improvements have been incorporated, included detection of the cantilever displacement with ultralow optical powers, and ultra-efficient generation of microwave fields using a superconducting resonator. Using this newly developed apparatus, we have successfully demonstrated MRFM on an ensemble of electron spins at millikelvin temperatures. We are investigating various nonequilibirum effects, including spin relaxation times, which will have important implications for the feasibility of single spin detection.

4:00pm **MI+NS-ThA7 Magnetic Force Microscopy Study of Various Lithography Patterned Magnet Arrays**, ***X. Zhu***, *P. Grutter*, McGill University, Canada, *V. Metlushko*, University of Illinois at Chicago, *B. Ilic*, Cornell University, *Y. Hao, F. Castano, S. Haratani, C.A. Ross, B. Vogeli, H.I. Smith*, Massachusetts Institute of Technology

Magnetic force microscopy (MFM) with in-situ magnetic field has been used to study lithography pattered magnet arrays: elongated elements, rings, disks, empty squares and sub 100 nm pseudo spin valve structures (PSV) (NiFe/Cu/Co). Great care has been taken to reduce the MFM tip stray field induced irreversible distortion by choosing a constant height mode, using small magnetic moment tips, operating in vacuum, and using a digital PLL.[1]This allows us to study the details of magnetic structures. For example, the nature of the head-to-head domain wall in a permalloy ring can be revealed, and the vortex structure with a core singularity in a permalloy disk can be found by high resolution imaging. In the PSV structures, the parallel and two different antiparallel configurations for both magnetic layers (NiFe and Co) in an element can be distinguishable. A local hysteresis loop technique has been developed to study the switching behavior of individual elements.[2] In a permalloy disk, the abrupt switching due to a nucleation or annihilation process has been revealed by monitoring cantilever frequency shift at a fixed location above the disk while sweeping the external magnetic field. In a PSV structure, the abrupt switching for both individual layers is clearly distinguishable. The hysteresis loop of patterned arrays can be obtained by MFM in the presence of an external magnetic field. The anisotropy induced by interdot coupling can be found in a closely packed square lattice disk array which shows a much smaller nucleation field along the (100) direction than the (110) direction. In the PSV structures, the layer coupling and the broad switching field distribution have been investigated through major and minor hysteresis loop obtained by MFM.

[1] X. Zhu, et al., J. Appl. Phys., May (2002).

[2] X. Zhu, et al., to be published in Appl. Phys. Lett.

4:20pm **MI+NS-ThA8 Magnetic Dipoles in Patterned Magnetic Metal Dot Arrays**, ***T.-H. Kim***, *J.H. Choi, Y. Kuk*, Seoul National University, South Korea

Magnetic dipole arrangement was studied with scanning tunneling microscope and magnetic force microscope (MFM) in patterned magnetic

metal dot arrays. Magnetic dot arrays on silicon substrate were made by following procedures: (1) electron beam lithography, (2) shadow mask deposition, (3) electro-chemical anodizing of aluminum layer and successive deposition of magnetic metals. MFM image reveals individual magnetic dipole with small dot-dot interaction. The correlation between the shape anisotropy with the direction of magnetization will be discussed.

Magnetic Interfaces and Nanostructures
Room: C-205 - Session MI+TF-FrM

Magnetic Thin Films and Surfaces
Moderator: P.A. Dowben, University of Nebraska-Lincoln

8:20am **MI+TF-FrM1 Structure and Magnetism of Ultra Thin Fe Films Grown on CoGa(100)**, ***L.K. Verheij***, *T. Balster, D.A. Kovacs, R. David, R. Franchy*, Forschungszentrum Jülich, Germany

The structure and magnetic properties of thin Fe layers deposited on CoGa(100) (misfit 0.5 %) were investigated by low energy electron diffraction (LEED), by helium scattering (TEAS), and by the magneto optical Kerr effect (MOKE). For room temperature deposition we observe well defined intensity oscillations of the specular helium intensity under anti-phase conditions. Upon increasing the growth temperature to 550 K the amplitude of the oscillations and their number increases substantially. At both growth temperatures a tendency for double layer growth is found up to a film thickness of about 10 ML. The magnetic properties of the Fe films appear to depend on the experimental conditions during growth and on the preparation of the substrate surface. Films with a magnetization with the easy axis parallel to the surface and with the easy axis perpendicular to the surface have been grown. The Curie temperature of the Fe films increases from 240 K to 600 K when the thickness is increased from 1 to 2 ML. Above 650 K, the film is unstable due to intermixing. The relation between the changes of the structure and the magnetic behavior with preparation are discussed.

8:40am **MI+TF-FrM2 Surface Morphology and Magnetization Reversal**, ***R.A. Lukaszew***, *Z. Zhang*, University of Toledo, *R. Clarke*, University of Michigan

We have studied the azimuthal dependence of the magnetization reversal on annealed and non-annealed (001) epitaxial Ni films of the same thickness and deposited under the same conditions on MgO. The coercive field in non-annealed films exhibit 4-fold symmetry as expected from the symmetry of the crystal. The annealed films exhibit an additional uniaxial symmetry superimposed to the four-fold symmetry. STM images of the surface of the annealed films indicate self-assembled periodic stripe nano-patterning, while STM images of the non-annealed films show typical mounded surfaces. Cross sectional TEM studies performed on the annealed films will be correlated with the surface morphology and with the magnetic anisotropy.

9:00am **MI+TF-FrM3 Lande g-factor Variation with Thickness in Ultrathin Permalloy Films**, ***J.P. Nibarger***, *R. Lopusnik, T.J. Silva*, National Institute for Standards and Technology

We have found a variation in the Lande g-factor with thickness in sputtered polycrystalline Permalloy films capped with Cu. The variation of the g-factor is correlated with damping in the absence of an applied bias field. Films were grown on a sapphire substrate with a 5 nm Ta adhesion layer, followed by 10, 25, 50, or 100 nm of NiFe, and finally capped with a 5 nm layer of Cu. Static anisotropy values were obtained using a static inductive magnetometer and the effective saturation magnetization was found using an alternating gradient magnetometer. A pulsed inductive microwave magnetometer (PIMM) was used to extract dynamical information.[1] Using the static values and the Kittel equation for thin films, we extracted the induced uniaxial anisotropy, the Lande g-factor, and the Landau-Lifshitz phenomenological damping parameter, α, from the PIMM measurements. The g-factor increases with decreasing thickness for films below 50 nm, as does also the damping in zero applied field. In addition, the effective saturation magnetization decreases with decreasing thickness, presumably due to surface anisotropy effects. The increase in the g-factor is interpreted as an indicator of enhanced spin-orbit coupling for thinner films: As the films become thinner and thinner, the relative magnitude of the spin-orbit coupling at interfaces becomes dominant. We will discuss the role of spin-orbit in damping by conduction electron scattering, as well as implications for the transport of spin angular momentum in nano-scale magnetic heterostructures.

[1] T. J. Silva, C. S. Lee, T. M. Crawford, C. T. Rogers, J. Appl. Phys. 85, 7849 (1999)

9:20am **MI+TF-FrM4 Determination of the Spin-Spin Coupling Strength in Ultrathin Magnetic Films**, ***N.A.R. Gilman***, *R. Zhang, R.F. Willis*, Penn State University

We present a model of spin-spin coupling in itinerant ferromagnets which provides insight into the observed linear decrease of the Curie temperature with decreasing ultrathin film thickness.[1] The slopes of plots of Tc versus ultrathin film thickness reflect the strength of the spin-spin coupling and the effective range of the spin-spin interactions. Experimental results for alloys of Fe, Co and Ni show this range of spin-spin interactions decreasing with increasing bulk Curie temperature. Measurements of their Fermi surfaces[2] show a direct correlation with the concentration of holes in the d-band.

[1] R. Zhang and R.F. Willis, Phys. Rev. Lett. 86, 2665 (2001).
[2] M. Hochstrasser et al. Phys. Rev. B 60, 17030 (1999).

9:40am **MI+TF-FrM5 Effect of Spatial Confinement on Magnetism: Films, Wires and Dots of Fe**, ***J. Shen***, Oak Ridge National Laboratory **INVITED**

The last decade has witnessed a remarkable transfer of basic science to practical devices in the area of magnetic recording. In less than 10 years, the discovery of a phenomenon that occurs in artificially structured thin films of magnetic and nonmagnetic materials, known as giant magnetoresistance (GMR), had developed into a $100B/yr business in the market of hard disk drive alone. This advance was a result of learning how to grow these films coupled with a basic understanding that allowed optimal tuning of their properties. As efforts to reduce device size scales have continued, it has become increasingly attractive to investigate the magnetic properties of artificial structures with even smaller dimensions and lower dimensionality-nanowires and dots. Using a combination of novel synthesis methods, including laser molecular beam epitaxy, step decoration growth, and buffer layer assisted growth; we have developed a generic way to grow nanometer-sized films, wires and dots on a common template with the s ame areal density. The ability to grow magnetic nanostructures with differing dimensionalities on the same template means that we can now study the effect of spatial confinement on magnetism and transport. This is crucial to the development of nanometer-scaled spintronic devices, an area in which the next breakthrough in information technology may be anticipated.

10:20am **MI+TF-FrM7 Growth and Magnetic Properties of Artificial $L1_0$ Fe-Co Alloy**, *G. Farnan*, ***Z. Gai***, *A.P. Baddorf, J. Shen*, Oak Ridge National Laboratory

Iron-cobalt alloys are of interest due to their high magnetic moment and Curie temperature, and to the strong magnetic character of both constituents. In bulk, Fe and Co are totally miscible, with B_2 structure being the only ordered alloy phase. In this work, we use modern laser molecular beam epitaxy to artificially grow a new ordered Fe-Co alloy phase, i.e., $[Fe(1ML)/Co(1ML)]_n$ $L1_0$ phase, which consists of alternatively stacked monatomic layers of Fe and Co. By monitoring reflection high energy electron diffraction (RHEED) oscillations during the growth, precise amounts of iron and cobalt were deposited onto a Cu(001) single crystal substrate in ultra high vacuum. In-situ scanning tunneling microscopy images showed almost perfect layer-by-layer morphologies, while low energy electron diffraction (LEED) patterns and Auger electron spectroscopy data collected after each whole layer deposition showed that the fcc phase with layered composition was preserved up to seven monolayers. Ex-situ X-ray diffraction results include new diffraction features confirming the existence of the Fe-Co $L1_0$ alloy. The magneto-optic Kerr effect (MOKE) results showed that the alloy was ferromagnetic with easy axis in plane. After seven monolayers deposition a structural change was observed by LEED and RHEED, and was reflected in a dramatic increase in coercivity and Curie temperature observed in the MOKE study.

[1] Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

10:40am **MI+TF-FrM8 The Effects of Growth Temperature and Composition on the Magnetic Properties of Ni_2MnIn_x Epitaxial Films Grown on InAs (001)**, ***J.Q. Xie***, *J.W. Dong, J. Lu, X.Y. Dong, T.C. Shih, S. McKernan, C.J. Palmstrom*, University of Minnesota

Injecting spin-polarized electrons into a semiconductor from a ferromagnetic material is an emerging concept for novel electronic devices.[1] InAs is the semiconductor of choice because of its high electron mobility and the ease to form an ohmic contact to it. Although no elemental ferromagnet is lattice matched to InAs, the lattice mismatch between the Heusler alloy Ni_2MnIn and InAs is only 0.2%. In bulk, Ni_2MnIn is reported to have a cubic ($L2_1$) crystal structure with a lattice constant a_0 = 6.069 Å and a Curie temperature ~ 314 K. Recent theoretical studies showed that the band structure alignment between Ni_2MnIn and InAs would enhance the injection of the minority spins, suggesting that Ni_2MnIn may be a good choice for spin injection as a ferromagnetic contact.[2] In this presentation, we report on the epitaxial growth of Ni_2MnIn thin films on InAs (001) by molecular beam epitaxy. Determination of the crystal structure of Ni_2MnIn

and effects of ordering and composition on magnetic properties of Ni_2MnIn are emphasized. Our transmission electron microscopy studies indicate the pseudomorphic growth of Ni_2MnIn in the B2 structure on InAs (001) with an orientation relationship of $Ni_2MnIn(001)$ || InAs(001) and $Ni_2MnIn<100>$ || InAs<100>. Magnetic measurements show that the Ni_2MnIn films have a Curie temperature ~ 170 K. The lower Curie temperature compared to the bulk value (~ 314 K) is believed to be due to the growth of Ni_2MnIn in the B2 structure. To improve the ordering of Ni_2MnIn thin films, effects of substrate temperature and interfacial layer are investigated. Composition was found to affect the Curie temperature dramatically. For $Ni_2MnIn_{1.7}$, a Curie temperature as high as ~ 290 K was obtained.

[1]S. A. Wolf et al., Science 294, 1488 (2001).
[2]K. A. Kilian and R. H. Victora, J. Appl. Phys. 87, 7064 (2000).

11:00am **MI+TF-FrM9 Structure and Magnetic Properties of Thin Fe Films Grown on InAs(100)**, ***G. Witte***, *L. Ruppel, Ch. Woell, S.F. Fischer, U. Kunze, T. Last*, Ruhr-University Bochum, Germany

On account of its large spin transfer length (i.e. Rashba effect) InAs constitutes a promising material for future spintronic applications. Of particular interest in this context are details of the growth and properties of thin ferromagnetic films on this substrate. Here we report on a combined LEED, XPS and SQUID study of epitaxially grown Fe-films on the indium rich InAs(100)-c(8x2)/(4x2) surface with a particular emphasize on interface alloying and its influence on the magnetic properties. While deposition at room temperature leads to the appearance of a distinct (1x1) LEED pattern for films thicker than 2nm indicating an epitaxial growth of Fe(100) films, the corresponding XPS data reveal the presence of an iron-arsenide species which floates at the surface upon further film growth. Postdeposition annealing causes no improvement of the film quality but enhances the amount of arsenic at the surface. Surprisingly, rapid flash annealing of the films above 700K leads, however, to a thermal dissociation and desorption of the surface arsenic which is accompanied by a change of the film morphology and formation of disconnected islands. This suggests that the epitaxial growth of Fe films on InAs(100) is stabilized by the surface arsenide via a "surfactant effect". Corresponding ex-situ SQUID measurements for 10nm Fe films capped by a 20nm Ag film revealed bulk like magnetic properties over a temperature range of 5-300K. In contrast to that thin Ag films of only 1nm are not sufficient to prevent a partial oxidation of the Fe films as inferred from the XPS data and lead to the appearance of a pronounced exchange bias effect at low temperatures. This observation stress the importance of an appropriate capping.

11:20am **MI+TF-FrM10 Growth and Characterization of Ferromagnetic Fe-Doped Rutile TiO_2 Clusters and Thin Films**, ***S. Thevuthasan***, Pacific Northwest National Laboratory, *Y.J. Kim*, Taejon National University of Technology, *T. Droubay, V. Shutthanandan, A.S. Lea, M.H. Engelhard, S.A. Chambers*, Pacific Northwest National Laboratory, *J. Schneider, R. Sears, B. Sinkovic*, University of Connecticut

There is a growing interest in searching for spin injection materials with high injection efficiencies and room temperature operations. Some of the dilute magnetic semiconductors with the potential for room temperature spintronics applications include Co-doped ZnO, Mn-doped GaN and Co-doped anatase TiO_2. Although there are still some issues associated with the growth of single crystal Co-doped anatase TiO_2, recent experiments show that this material is the most promising candidate because of its room temperature ferromagnetism.[1,2] Recently, we have investigated the growth and characterization of $Fe_xTi_{1-x}O_2$ (x ~ 0.02-0.16) on single crystal TiO_2(110) at the Molecular Beam Epitaxy facility of the Environmental Molecular Sciences Laboratory (EMSL). Some of these films exhibit ferromagnetism at room temperature. The morphology of these films consist of the film proper along with Fe rich clusters containing a mixture of Fe^{2+} and Fe^{3+} valence states. These films were characterized using several surface science techniques including x-ray photoelectron spectroscopy (XPS) atomic force microscopy (AFM), scanning Auger microscopy (SAM), x-ray absorption spectroscopy (XAS), and Rutherford backscattering spectrometry (RBS)/channeling. These results with the magneto-optical Kerr effect (MOKE) measurements from these films will be discussed.

[1] M. Matsumoto et al., Science, 291, (2001) 854.

[2] S.A. Chambers et al., Appl. Phys. Lett. 79 (2001) 3467. Work supported by the U.S. Department of Energy, Offices of Basic Energy Sciences and Biological and Environmental Research and the laboratory directed research and development (LDRD) program.

11:40am **MI+TF-FrM11 MOCVD Growth of $Co_xZn_{1-x}O$ on R-plane Sapphire: Structure, Composition, and Magnetic Properties**, ***A.C. Tuan***, University of Washington, *T. Droubay, J.W. Rogers, S.A. Chambers*, Pacific Northwest National Laboratory

We have grown Al-doped $Co_xZn_{1-x}O$ films by MOCVD for application as a spintronic material. Films were grown at substrate temperatures between 750 and 825 K at a growth rate of ~6 nm/min. XRD and RBS show that up to 35% of the Zn cations can be substituted with Co without disrupting the wurtzite crystal structure of ZnO. Furthermore, XRD pole figures indicate that the films are of near-single crystal quality. Comparison of the Co 2p core-level XPS from our $Co_xZn_{1-x}O$ films with reference spectra for Co metal, Co(II), and Co(III) shows that the Co ions are in the +2 oxidation state. XPS also shows that there is no carbon contamination in the bulk of the film, which suggests that the organometallic precursors are completely oxidized/pyrolyzed. Since the Co distribution in the material strongly affects the magnetic properties, we performed SIMS depth profiling, which confirmed that the Co and Al constituents are uniformly distributed throughout the film and show no segregation at either the interface or the surface. In addition, AFM indicates that the surface is very smooth with an RMS roughness of only 3.7 nm over a 5 x 5 micron area. However, in spite of recent theoretical predictions,[1] we have yet to observe room temperature ferromagnetism in this material. These results differ from those recently obtained by Ueda et al. in which they show weak ferromagnetism that persists to ~300 K from similar PLD-grown films of slightly lower crystalline quality.[2] We are currently performing below-room-temperature magnetic measurements to determine the exact value of the Curie temperature in our material. These results, as well as the effects of post-growth annealing will be presented at the conference.

[1]Sato et al., Japanese Journal of Applied Physics 40, L334-L336 (2001)
[2]Ueda et al., Applied Physics Letters 79(7), 988-990 (2001).

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