Magnetic Interfaces and Nanostructures
Room 316 - Session MI-MoA

Magnetic Recording and Magnetoresistive Structures
Moderator: M.C. Tondra, NVE Corp.

2:00pm **MI-MoA1 Materials/Structures for High Areal Density Write Poles***, **M.K. Minor**, T.J. Klemmer, M.A. Seigler, O. Mryasov,* Seagate Technology*; M. Kim, A.J. Freeman,* Northwestern University **INVITED**

The maximum effective write field of a head is related to head geometry and the saturation magnetization (4@pi@M@sub S@) of the pole material. Typically, head designs require a pole material at the air bearing surface (ABS) which exhibits a large 4@pi@M@sub S@, low coercivity, and a well-defined uniaxial anisotropy. The material with the largest known 4@pi@M@sub S@ at room temperature is exhibited by Fe@sub 65@Co@sub 35@ which has a value of ~2.4T. One of the problems with FeCo that prevents it from being used as a pole material is that the material is not uniaxial, therefore, it has nearly zero permeability which results in an inefficient write head. This lack of uniaxiality or magnetic "softness" is a direct result of the relatively large value of magnetocrystalline anisotropy exhibited by the high moment FeCo alloys. This talk will review some of the methods employed to induce magnetic softness in the high moment FeCo alloys. These methods include the effects of various processing conditions, the use of buffer layers, and laminated structures which are magnetostatically coupled. For each of these methods magnetic properties and film microstructure will be reviewed. A large portion of this talk will focus on FeCo multilayered structures fabricated via dc magnetron sputtering. Some modeling and experimental results will be presented. These results include enhanced moment prediction and effect of multilayering on anisotropy. The modeling results are compared to experimental results where we will show structural and magnetic properties of the FeCo multilayers.

2:40pm **MI-MoA3 Influence of Pd and Pt Buffers on the Soft Magnetic Properties of Fe@sub 70@Co@sub 30@ Thin Films***, **C.L. Platt**, J.K. Howard,* Seagate Technology*; D.J. Smith,* Arizona State University

Writer pole materials with large saturation magnetization are desired to maximize the available writing field for magnetic recording. A 5 nm thick Pd or Pt buffer layer is sufficient to significantly alter the magnetic and structural properties of sputtered high moment (2.4 T) Fe@sub 70@Co@sub 30@ thin films. A 50 nm thick FeCo film with no buffer grown on an amorphous SiO@sub 2@ substrate had a coercivity of 40 Oe and showed no evidence of an induced easy axis, although the film was grown in an applied field of 50 Oe. This is typical of high moment FeCo alloys which usually do not exhibit soft magnetic properties due to large magnetostriction and difficulty controlling magnetic ripple structure. Use of 5 nm Pd or Pt buffer reduced the coercivity of 50 nm FeCo films to about 15 Oe with a definable easy axis. Structurally, the primary influence of the Pd or Pt buffer was a reduction in the average FeCo grain size and more clearly defined columnar grain boundaries. This is similar to what has been observed using other fcc buffers.@footnote 1,2@ Growing thicker FeCo films (200 nm) resulted in a significant increase in average column width and a loss of soft magnetic properties regardless of the buffer. @FootnoteText@ @footnote 1@H. S. Jung, W. D. Doyle, J. E. Wittig, J. F. Al-Sharab, and J. Bentley, Appl. Phys. Lett. 81, 2415 (2002).@footnote 2@C. L. Platt, A. E. Berkowitz, D. J. Smith, and M. R. McCartney, J. Appl. Phys. 88, 2058 (2000).

3:00pm **MI-MoA4 Atomistic Simulations of Metal/Metal Oxide Heterostructures***, **X.W. Zhou**, H.N.G. Wadley,* University of Virginia

A thin aluminum oxide layer sandwiched between a pair of ferromagnetic metal layers forms a spin-dependent tunnel junction that can be used to construct random access memory. Atomistic simulations based upon interatomic potentials provide a way to identify the best conditions to synthesize these structures. However, unlike the approaches that have been successfully used to simulate metal multilayer deposition, atomic simulation methods for metal and metal oxide heterostructures are poorly developed. Metal oxides involve a significant ionic interaction between constituent cations and anions. Traditional fixed charge ionic potentials do not allow the introduction of different oxidation states and cannot ensure charge neutrality during simulation of oxide vapor deposition. They also significantly overestimate the cohesive energy of oxides. Because their charges are designated (for a given bulk oxide), they are not applicable to metal oxide heterostructures and cannot address metal/oxide interfaces. A charge transfer ionic potential (CTIP) model proposed by Streitz and Mintmire has attempted to overcome these deficiencies. However, we found that this charge transfer model is unstable and can only be applied to single metal-oxygen binary systems. By incorporation of the physical principle of elemental valency we have found an expedient solution to the limitations of the original CTIP model. The improved CTIP potential has been combined with an existing embedded atom method (EAM) metal potential to dynamically address both ionic and metallic components of the interatomic interactions in an O-Al-Ni-Co-Fe system during atomistic simulations. Application of this novel approach in the oxidation of aluminum layer in Ni65Co20Fe15/Al2O3/Ni65Co20Fe15 spin-dependent tunnel junction multilayer is reported and the roles of processing conditions used to synthesis the aluminum oxide layer are discussed.

3:20pm **MI-MoA5 Quantum-size Effect of Tunneling Magnetoresistance in Magnetic Tunnel Junctions***, **S. Yuasa**,* AIST and PREST-JST, Japan*; T. Nagahama, Y. Suzuki,* AIST and CREST-JST, Japan **INVITED**

We fabricated magnetic tunnel junctions (MTJs) with single-crystal bottom electrodes and observed new phenomena such as the crystal-orientation dependence of the tunneling magnetoresistance (TMR) effect,@footnote 1@ the quantum-size effect of TMR,@footnote 2@ and the spin-polarized resonant tunneling.@footnote 3@ Here, we report the results on three types of MTJs with a single-crystal bottom electrode; (i) MTJ with an ultrathin ferromagnetic electrode, (ii) MTJ with an ultrathin nonmagnetic electrode grown on a ferromagnetic layer, and (iii) MTJ with an antiferromagnetic electrode grown on a ferromagnetic layer. The results are discussed in terms of spin lifetime of tunneling electrons. @FootnoteText@@footnote 1@S. Yuasa et al.: Europhys. Lett. 52, 344 (2000). @footnote 2@T. Nagahama, S. Yuasa, Y. Suzuki, E. Tamura: Appl. Phys. Lett. 79, 4381 (2001). @footnote 3@S. Yuasa, T. Nagahama, Y. Suzuki: Science 297, 234 (2002).

4:00pm **MI-MoA7 Magnetization Dynamics and Magneto-transport in Epitaxial Nano-structures***, **R.A. Lukaszew**, D. Pearson, Z. Zhang,* University of Toledo*; A. Zambano,* Michigan State University

Abstract: The latest results on ballistic magneto-resistance (BMR) research have shown surprising ballistic magnetoresistance.@footnote 1@ It has been postulated that the BMR effect arises from non-adiabatic spin scattering across very narrow magnetic domain walls trapped at nano-sized constrictions.@footnote 2@ The reported BMR effect has been observed in nano-contacts electrodeposited between Ni wires. Much of the publish data so far, is still poorly understood. In an attempt to clarify some of the possible processes present in the observed phenomena we applied e-beam lithography to epitaxial Ni films to fabricate nano-bridges with more controlled geometry than the ones made with electrochemical deposition. Epitaxial ferromagnetic thin films exhibit narrow domain walls that may favor ballistic regime provided that the nano-contact is small enough. We have modeled the magnetization reversal in epitaxial films and have established that the unusually high coercive field observed along hard axes is due to a second order type transition prior reversal that induces high density of domain walls at the reversal.@footnote 3@ Thus we expect that a patterned nano-structure with segments parallel to magnetization hard axes will be more likely to experience domain-wall related effects in magneto-transport. Therefore we patterned a similar T geometry to that utilized by Chopra and Garcia.@footnote 1,3@ Our preliminary results indicate that magnetic domains do play a role in the magneto-resistance of these nano-bridges but the order of magnitude of the observed effect is considerably smaller than the reported observations for electrochemically prepared nano-contacts. @FootnoteText@@footnote 1@B. D. Chopra and S. Z. Hua, Phys. Rev. B. 66, 020403(R), 2002. @footnote 2@P. Bruno, Phys. Rev. Lett. 83, 2425 (1999). @footnote 3@Lukaszew, R.A. and Clarke R., unpublished. @footnote 4@N. Garcia, M. Munioz, V. V. Osipov, E. V. Ponizovskaya, G. G. Quian, I.G. Saveliev and Y.-W. Zhao, J. Magn. Magn. Mater. 240, 92 (2002).

4:20pm **MI-MoA8 Artifacts in Ballistic Magnetoresistance Measurements***, **W.F. Egelhoff**, M.D. Stiles, T.P. Moffat, J. Mallett, R.D. McMichael, H. Ettedugi, A.J. Shapiro, C.J. Powell,* National Institute of Standards and Technology*; E.B Svedberg,* Seagate

The Ballistic Magnetoresistance (BMR) effect has attracted much attention in the past year with BMR values as large as 100,000% having been reported in Physical Review@footnote 1@ and 1,000,000% reported at Intermag2003.@footnote 2@. Naturally, such impressive results have led many researchers to attempt to reproduce large BMR values. Unfortunately, these attempts have widely failed. This failure has led to much skepticism over whether BMR is a real effect. In our research, we have found several artifacts caused by magnetostriction and magnetostatics that can produce what appear to be huge BMR values. In this talk, we will illustrate these artifacts, provide an assessment of the implications these artifacts have for the field of BMR, and give guidelines for performing BMR measurements in an artifact-free manner. We will also present results of new BMR measurements in which we follow our recommended procedures. @FootnoteText@@footnote 1@S. Z. Hua and H. D. Chopra Phys. Rev. B 67, 060401 (2003). @footnote 2@Nicolas Garcia, invited talk, Intermag2003.

4:40pm **MI-MoA9 Arrays of Magnetoresistive Sensors for Non-destructive Testing**, ***A.V. Nazarov,*** National Institute of Standards and Technology; *F.C.S. da Silva,* National Institute of Standards and Technology, US; *P. Kabos, D.P. Pappas,* National Institute of Standards and Technology

Magnetic field mapping is a powerful tool that can provide high sensitivity and high spatial resolution for current localization.@footnote 1@ In this work, we used magnetic field mapping to non-destructively analyze the current distribution in integrated circuit chips and localize wiring defects. The magnetic field produced by current distributions was simultaneously measured with arrays of magnetoresistive (MR) sensors in order to increase the effective speed of the scan. Arrays of eight permalloy barber-pole type MR sensors were fabricated using a two step lift-off lithography process. The sensors were 40 µm long, 4 µm wide, and separated by 210 µm. The nominal resistance of the sensors was in the 24.9 to 25.2 @ohm@ range and the MR change was 1.8 %. A broadband, simultaneous, 8-channel, computer-based digital lock-in technique was developed for data acquisition and analysis. The measured magnetic field distributions were directly converted to current images using normalized discrete 1-d Fourier transforms. Measurements of test structures show the absence of cross-talk between sensors and that the spatial resolution is approximately z/2 where z is the distance between current plane and the sensor. This work was supported by the National Institute of Standards and Technology Office of Law Enforcement Standards, the Federal Bureau of Investigation, the National Security Agency, the National Institute of Justice, and the Advanced Technology Program. @FootnoteText@ @footnote 1@S. Chatraphorn, E. F. Fleet, F. C. Wellstood, L. A. Knauss, and T. M. Eiles, Appl. Phys. Lett. 76, 2304 (2000).

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+NS-TuM

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

8:20am **MI+NS-TuM1 Characterization of Magnetic Thin Films and Nanostructures using Electron Microscopy**, ***D.J. Smith,*** Arizona State University **INVITED**

The reduced dimensions of magnetic thin films and nanostructures lead to major and often unexpected changes in magnetic properties and behavior. In addition to intrinsic scientific importance, these novel characteristics have obvious relevance to current and projected technological needs. Successful implementation of this technology requires a detailed understanding of materials growth mechanisms. Chemical and crystallographic structure must be correlated with micromagnetic structure and dynamic response before the fundamental limits of device performance can be firmly established. For example, atomic-level imaging and microanalysis of structural and chemical changes induced by changes in growth temperature or by post-deposition annealing are essential for explaining enhanced magnetic properties of antiferromagnetic pinning layers and magnetic tunnel junctions. And electron holography allows direct visualization of magnetization behavior within patterned nanostructures. This talk will provide an overview of electron microscopy and related techniques, with illustrative examples that demonstrate the major contributions being made to ongoing studies of magnetic thin films and nanostructures.

9:00am **MI+NS-TuM3 Imaging of Magnetic Nanoislands at the Thermal Stability Limit**, ***M. Bode,*** *O. Pietzsch, A. Kubetzka, R. Wiesendanger,* University of Hamburg, Germany

Within the past decade spin-polarized scanning tunneling microscopy (SP-STM) became a mature tool for high spatial resolution imaging of the static domain structure of ferro- and antiferromagnetic surfaces.@footnote 1-3@ Recently, we successfully observed the temperature-dependent switching behavior of Fe monolayer islands which were pseudomarphically grown on a Mo(110) substrate and exhibit an perpendicular easy axis. Our SP-STM results show that at temperatures between 15 and 26 K Fe islands consisting of 250-600 atoms (area 20-40 nm@super 2@) are superparamagnetic, i.e., they change their magnetization direction on a time scale of 0.1-1000 s. Small islands were found to switch more often than larger islands as can be expected on the basis of anisotropy barrier considerations. A quantitative analysis reveals, however, that the observed size-dependent variation of the switching rate is much larger than theoretically expected. Possible origins of this behavior are discussed in terms of the island shape and environment. @FootnoteText@@footnote 1@ S. Heinze et al., Science 288, 1805 (2000).@footnote 2@ A. Wachowiak et al., Science 298, 577 (2002).@footnote 3@ M. Bode, Rep. Prog. Phys. 66, 523 (2003).

9:20am **MI+NS-TuM4 Scanning Tunneling Spectroscopy of Magnetic Impurities at Metal Surfaces**, ***M.A. Schneider,*** Max Planck Institute for Solid State Research, Germany **INVITED**

A single magnetic impurity in a metal host is a paradigm of many-body physics in electronic systems. The spin-flip scattering of host electrons at the impurity site leads to the formation of a correlated electron state, the Kondo state. Only recently has it become possible to study this state using Scanning Tunneling Spectroscopy (STS) for magnetic surface impurities.@footnote 1-5@ Through this method, magnetism and properties of the adsorbate-host interaction can be determined in a local, atomic-scale measurement. The Kondo state is characterized by the formation of a resonance at the Fermi energy, which allows to access the characteristic energy scale, the Kondo temperature T@sub K@ of the system. We discuss the properties of the Kondo state created by the interaction of the magnetic atom with surface and bulk electrons, and the role of the tunneling process in the appearance of the resonance in STS spectra. The interaction of the magnetic impurity with two-dimensional surface-state electrons is demonstrated by the measurement of a resonant scattering phase-shift for Co adsorbed on Ag(111).@footnote 4@ However, this interaction with surface-state electrons is only weak, the main properties of the Kondo state are determined by the interaction with bulk electrons. This is corroborated by experiments comparing Co impurities on various Cu surfaces where the decisive role of the number of interaction channels to bulk electrons in the atomic-scale system is shown.@footnote 5@. @FootnoteText@ @footnote 1@ J.-T. Li, W.-D. Schneider, R. Berndt, B. Delley, Phys. Rev. Lett. 80, 2893(1998)@footnote 2@ V. Madhavan, W. Chen, T. Jamneala, M. F. Crommie, N. S. Wingreen, Science 280, 567 (1998) @footnote 3@ H.C. Manoharan, C. Lutz, D. M. Eigler, Nature 403, 512 (2000)@footnote 4@ M. A. Schneider, L. Vitali, N. Knorr, K. Kern, Phys. Rev. B 65, 121406(R) (2002)@footnote 5@ N. Knorr, M. A. Schneider, L. Diekhöner, P. Wahl, K. Kern, Phys. Rev. Lett. 88, 096804 (2002).

10:00am **MI+NS-TuM6 A Practical Guide to the Interpretation of Point-contact Andreev Reflection Data**, ***R.J. Soulen,*** *G.W. Woods, I. Mazin, M. Osofsky,* Naval Research Laboratory

Point-contact Andreev reflection (PCAR), has become a useful tool in determining the spin polarization, P, of magnetic materials. It consists of establishing a point contact between a sharpened superconductive point and a magnetic base (or, vice versa), and measuring the conductance G of the junction as a function of the applied voltage, V. The value of P can be extracted from the conductance data through use of a modified Blonder, Tinkham, Klapwijk (BTK) model of the supercurrent conversion at the superconductor-metal interface (Andreev reflection). This algorithm, however, does not take into account several factors which depend on properties of the point contact: whether it is in the ballistic or diffuse regime, ratio of the spreading resistance to the junction resistance, the value of the superconducting energy gap. These properties are often difficult to measure or estimate so that the practitioner is left without a means to assess the error in the value of P. We have systematically examined these effects (by theory and experiment) and can offer some new and practical guidance on how to correct for them and to estimate the error. We use data on several materials (CrO2, SrRuO, and LaSrMnO) taken in our laboratory and in others to illustrate the process.

10:20am **MI+NS-TuM7 Preparation and Magneto-Optical Spectroscopic Studies of Diluted Magnetic Semiconductor Quantum Dots and Related Nanostructures: Potential Building Blocks for Spintronics Applications**, ***D.R. Gamelin,*** *D.A. Schwartz, P.V. Radovanovic, N.S. Norberg, J.D. Bryan,* University of Washington **INVITED**

Diluted magnetic semiconductors (DMSs) are currently the focus of intense applications-oriented research in the emerging area of spin-based electronics, or "spintronics." DMS nanostructures such as quantum dots (DMS-QDs), quantum wells, quantum wires, and epitaxial thin films are pivotal architectural elements in many proposed spintronics devices including spin-dependent LEDs, field-effect transistors, and quantum computers. A central challenge facing the development of this technology is the identificati on of semiconductors that combine the necessary properties of conductivity and ferromagnetic ordering at temperatures above room temperature. This seminar will present our group's recent advances in the development of direct routes for preparation of freestanding high-quality DMS quantum dots. Emphasis will be placed on the application of magneto-optical spectroscopic methods (including magnetic circular dichroism and Zeeman spectroscopies) to study the electronic structural properties of these materials. Spectroscopic identification of ligand field, charge transfer, and excitonic transitions in DMSs will be presented in the context of their functional properties. The use of variable-temperature variable-field magneto-optical methods to define ground state spin-orbit splittings, and the influence of such splittings on the magnitudes of semiconductor band level Zeeman splittings, will also be discussed.

11:00am **MI+NS-TuM9 Magnetic Linear and Circular X-ray Dichroism Studies of the Magnetic Instability of Fe(x)Ni(1-x) Pseudomorphic Thin Films Exhibiting the Invar Effect**, ***S.A. Morton,*** Lawrence Berkeley National Laboratory*; M. Hochstrasser,* Lawrence Livermore National Laboratory*; N.A.R. Gilman, R.F. Willis,* Pennsylvania State University*; G.D. Waddill,* University of Missouri - Rolla*; J.G. Tobin,* Lawrence Livermore National Laboratory

At a composition of 65% Fe, bulk Fe(x)Ni(1-x) alloys exhibit the invar effect: a sudden change in the atomic volume which is associated with a dramatic change in the magnetic ordering from a high-spin high-volume state to a low-spin low-volume state at higher Fe concentrations; this results in a collapse in the magnetic moment and Curie temperature. Magnetic X-ray Linear Dichroism measurements of the Fe and Ni 3p exchange splitting have been used as a probe of the element specific Fe and Ni magnetic moments for ultra thin fcc FeNi/Cu(100) films across the full compositional range. These results have been further complemented by composition dependent Magnetic X-ray Circular Dichroism measurements of the element specific orbital and spin moment contributions. The data shows excellent agreement with published neutron and SQUID magnetometry measurement and with theoretical predictions of the Fe and Ni atomic moments based upon the 2gamma state model and the Slater Pauling Curve. Furthermore, the data demonstrate the potential for the use of magnetic linear dichroism as a quantitative element specific magnetometer in a wide variety of magnetic thin film systems.

11:20am **MI+NS-TuM10 Magnetic Circular X-ray Dichroism of Gd2O3 Nanoparticles***, **K. Uvdal**, R.M. Petoral, Jr., F. Söderlind, P.-O. Käll,* Linköping University, Sweden

In this study we are investigating the possibilities to use magnetic circular X-ray dichroism (MCXD) to probe the magnetic properties of Gd2O3 nanoparticles. The Gd2O3 nano particles were further characterized by means of X-ray Photoelectron Spectroscopy (XPS) to investigate the elemental composition the nanoparticles as well as verifying the oxidation level. The particle size of Gd2O3 nanoparticles is estimated from Atomic Force Microscopy (AFM) and transmission electron microscopy (TEM). The elemental composition shows high carbon content, which is expected due to the synthesis pathway. The relative carbon content could be reduced by Ar sputtering of the Gd2O3 nano particles, in good agreement with earlier studies on CoO. MCXD is used to determine the orbital-to-spin relative magnetic moment. It is shown that the orbital-to-spin relative ratios are greatly enhanced for sputtered sample. Gd2O3 nanoparticles show a superparamagnetic behaviour at room temperature and a large orbital contribution to the magnetic moment at low temperature. MCXD is show to be a powerful tool for investigating magnetic properties of small volume samples.

11:40am **MI+NS-TuM11 Magnetism in Transition-metal Alloy Films: Lineshape Analysis of Magnetic Linear Dichroism Angle-selective Photoemission Spectra***, **R.F. Willis**, N.A.R. Janke-Gilman,* The Pennsylvania State University

MLD photoemission measurements using synchrotron radiation to excite atomic core levels are reported for thin epitaxial films of transition-metal binary alloys.@footnote 1@ Careful background subtraction gives spectral lineshapes which are analyzed to give information on the magnitudes of the elemental magnetic moments and the degree of local magnetic order. The width of the dichroism spectrum is shown to relate to the magnitude of the moment, while the amplitude reflects the local magnetic anisotropy and ordering. Dichroism spectral widths and amplitudes are plotted as a function of alloy composition, reflecting changing magnetic behavior. The elemental spectral widths track the Slater-Pauling curve showing changing moments as a function of changing composition. Changing spectral amplitudes are compared with neutron scattering results which show changing magnetic anisotropy and magnetic order. @FootnoteText@ @footnote 1@ Measurements taken on Beamline 7.0.1 at the Advanced Light Source, Berkeley, CA.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+NS-TuA

Self Assembly and Nanomagnetism

Moderator: S.D. Bader, Argonne National Laboratory

2:00pm **MI+NS-TuA1 Many-spin Hamiltonian for the Single-molecule Magnet Mn12-Ac**, ***K. Park,*** Naval Research Laboratory and Howard University; *M.R. Pederson,* Naval Research Laboratory; *S.L. Richardson,* Howard University and Naval Research Laboratory

Nanoscale single-molecule magnets recently received great attention due to scientific and practical reasons: macroscopic quantum phenomena and possible utilization as magnetic storage devices or quantum computing. A single-molecule magnet (SMM) is a three-dimensional array of identical molecules, each of which consists of several transition metal ions surrounded by organic ligands and is independent of neighboring molecules. Among many kinds of SMMs, Mn12-Ac has been the most extensively studied for the past decade. Although the low-energy features of Mn12-Ac have been well understood by considering each molecule as an effective ground-state spin of S=10, there is still a big controversy over the energy gap between the first excited-state manifold and the ground-state manifold as well as the internal structure of the single molecule. To provide a guide to understanding the controversial many-spin features, we investigate the intramolecular exchange couplings and the projected single-ion anisotropies using density-functional theory (DFT). We use all-electron Gaussian-orbital-based Naval Research Laboratory Molecular Orbital Library (NRLMOL) within Perdew-Burke-Ernzerhof (PBE) generalized-gradient approximation (GGA). Based on the calculated exchange couplings and anisotropy parameters, we construct a model many-spin Hamiltonian which reproduces calculated single-spin results and allows for the extraction of many-spin features.

2:20pm **MI+NS-TuA2 Magnetic Interaction in Assemblies of Nanometer-sized Fe Dots on Cu (111)**, ***M.A. Torija,*** *J. Pierce,* University of Tennessee, Knoxville; *J.F. Wendelken,* Oak Ridge National Laboratory; *E.W. Plummer,* University of Tennessee, Knoxville; *J. Shen,* Oak Ridge National Laboratory

Assemblies of separated iron quantum dots can be prepared on the Cu(111) surface via a buffer-layer-assisted growth process. First, an inert Xe layer is frozen onto a Cu(111) substrate that is held below 30 K. Then, Fe atoms are dosed from a typical evaporation source and form clusters on the Xe layer. Finally, the sample is warmed above 90 K, allowing the buffer layer to evaporate and the formed quantum dots to land on the surface. Scanning tunneling microscopy has shown us that we can control the average spacing and size of the dots by changing the Xe layer thickness and/or the amount of Fe deposited. Surprisingly, the dot arrays show non-zero remanent magnetization that is stable with the passage of time. To distinguish the roles of the magnetic interactions vs. the magnetic anisotropy in stabling the remanent magnetization, measured by SMOKE, we compare the ordering temperature of dot assemblies that have equal size distribution but different density. At fixed dot size distribution, varying the density of the Fe dots from 0.003 to 0.015 leads to an enhancement of ordering temperature from 153 K to 363K. This clearly indicates that magnetic interactions play an important role in stabling the remanent magnetization. Another interesting phenomena that we observed is a spin reorientation induced by the dot size. that for a fixed nominal thickness, the easy axis of magnetization is perpendicular for lower Xe thickness (small dots), and becomes in-plane for higher Xe thickness (big dots). It may be explained by the interplay between surface and bulk anisotropies.

2:40pm **MI+NS-TuA3 Contribution of Orbital Magnetism to the Magnetism of Monodisperse Nanoparticles**, ***M. Farle,*** Universitaet Duisburg-Essen, Germany **INVITED**

Self-organized magnetic nanoparticles with diameters of less than 10 nm are interesting for technological applications and for the investigation of interface properties due to their high surface-to-volume atom ratio. One of the most important magnetic properties, the magnetic anisotropy energy (MAE) is strongly influenced by the local structure and size of the particles, since on the atomic level MAE is related to the anisotropy of the orbital magnetic moment. Well-known techniques to measure the orbital contribution to the total magnetic moment are ferro-/paramagnetic resonance (FMR/EPR) and x-ray magnetic circular dichroism. Two examples will be discussed: a)disordered 3 nm FePt with different Fe contents, b)11.4 nm CoO@Co (a 2nm CoO shell surrounding a 8 nm Co core). For the FePt particles with different Fe concentration we find a linear increase of the g-factor measured by FMR/EPR , i.e. of the ratio of orbital-to-spin magnetic moment for larger Pt contents. This indicates that the presence of Pt induces an enhanced orbital magnetic moment in the nanoparticle. In the case of CoO@Co we find by FMR a bulk- like g factor g = 2.15 of fcc Co, while XMCD yields a 300 % enhanced ratio of orbital-to-spin moment. A quantitative comparison taking the different sampling depths of both techniques into account reveals the presence of uncompensated large magnetic Co moments at the interface of the antiferromagnetic CoO shell to the ferromagnetic Co core . Supported by EC contract no. HPRN-CT-1999-00150 and Deutsche Forschungsgemeinschaft.

3:20pm **MI+NS-TuA5 Self-assembly of FePt Nanoparticles on Si(100) Surface**, ***N. Shukla,*** *J. Ahner, D. Weller,* Seagate Research

Chemically synthesized monodispersed FePt nanoparticles are of great interest due their high magnetic anisotropy. The self-assembly and uniform coating of these nanoparticles on substrates is crucial for enabling high-density magnetic recording media. We have studied various parameters, potentially influencing the uniformity of FePt nanoparticle coatings. In particular, we report on the effects of excess surfactant concentration, type of surfactant, solvents and substrates. Films are fabricated using dip-coating and spin-coating methods. A narrow range of surfactant concentration is identified that leads to long range (~ 1x 1 mm@super2@) uniformity. Outside this concentration range the nanoparticle coatings form clusters with local self-assembly. In addition, the type of solvent and type of surfactant has a profound impact on the self-assembly of FePt. Decreasing the size of surfactant chain length changes the self-assembly from uniform to ring structures. Polarity and viscosity of the solvents also impact the self-assembly. Polar solvents give poor uniformity. Low viscous solvents have a similar impact.

3:40pm **MI+NS-TuA6 Submicron Cobalt Particle Fabrication by Ion Beam Induced Chemical Vapor Deposition (IBICVD)**, ***Y. Kageyama,*** *T. Suzuki,* Toyota Technological Institute, Japan

Nanometer-sized patterned structures for high density data storage have recently become of great interest. It has been demonstrated that the ion-beam induced chemical vapor deposition (IBICVD) technique has a potential benefit for fabrication of nano-dots.@footnote 1,2@ Characterization of IBICVD-synthesized Co particles was performed, and the result is presented in this paper. The submicron Co particles were deposited on Si@sub 3@N@sub 4@ substrates by a focused Ga@super +@ ion beam (FIB) system equipped with a source reservoir filled with precursor of octacarbonyl dicobalt [Co@sub 2@(CO)@sub 8@] powders. Vapor of the precursor was introduced though a feeding nozzle (0.5mm diameter) above the substrate separated by 0.5 mm. The base pressure of the deposition chamber was about 10@super -5@ Pa. The ion current and the pressure during deposition were 14 pA and 0.7 - 1.4 x 10@super -4@ Pa, respectively. The in-situ image of Co particles was taken by SEM of the FIB system. Under the condition of irradiation of ion beams, the particle formation process is rather complicated due to concurrence of competitive processes (etching and deposition), therefore the morphology of Co particles strongly depends on the ion beam dwell time (5 to 120 µms) and the partial pressure of Co@sub 2@(CO)@sub 8@ precursor, as revealed by AFM analysis. The smallest size of Co particle obtained is about 150 nm so far. They exhibit ferromagnetic behaviors. Further studies on modification of properties by heating substrates, and on formation of alloys by introducing a second deposition source, are in progress. @FootnoteText@@footnote 1@ A. Lapicki, E. Ahmad, and T. Suzuki, J. Magn. Magn. Mat. 240 (2002) 47@footnote 2@ A. Lapicki, K. Kang, and T. Suzuki, IEEE Trans. Magns. 38 (2002) 2589.

4:00pm **MI+NS-TuA7 Magnetic Nanostructures Made by Self-assembled Block Copolymer Lithography**, ***C.A. Ross,*** *J.Y. Cheng, H.I. Smith, E.L. Thomas,* Massachusetts Institute of Technology; *G. Vancso,* University of Twente, The Netherlands **INVITED**

The fabrication and magnetic properties of thin-film particles with diameters of 35 nm and periodicity of 50 nm made using block copolymer nanolithography will be described. Such particle arrays may be used in magnetoelectronic and magnetic storage devices, where it is important to control the magnetization state, switching field, and uniformity of the particles and to understand their size-dependent magnetic behavior. Arrays of single-layer Co and NiFe particles with thicknesses of 5, 10, 15 and 20 nm, and Co/Cu/NiFe multilayer particles have been made. The Co and NiFe particles show an increase in coercivity and a decrease in switching field distribution with thickness. The particles exhibit thermally-assisted reversal, with switching volumes larger than the physical particle volume due to strong magnetostatic coupling between the particles. The multilayer particles show hysteresis behavior consistent with interlayer magnetostatic coupling, and measurable giant magnetoresistance despite the small dimensions of the particles. These arrays have short-range close-packing, but no long-range order. To impose long-range order the substrates have been patterned with shallow grooves, which induce alignment of the rows of polymer features parallel to the steps creating an ordered array. The polymer domain spacing conforms to the dimensions of the templating features leading to a quantized number of rows of domains within each groove. It is also possible to confine the polymer to certain regions of the substrate using soft printing methods, which also leads to a limited degree of ordering. Results from these templated self-assembly processes will be discussed. This work was supported by NSF. Refs: Cheng et al, Adv. Mater. 13 1174 (2001); Appl. Phys. Letts. 81 3657 (2002); IEEE Trans. Magn. 38 2541 (2002).

4:40pm **MI+NS-TuA9 Magnetic Properties of Low-dimensional Nanostructures on an Insulator***, **Z. Gai**, J.R. Thompson, J. Pierce, J. Shen,* Oak Ridge National Laboratory

Magnetic nanostructured materials are attracting much attention because of the dramatic changes in their magnetic, electronic and transport properties compared with conventional bulk materials. In previous work, iron zero-dimensional dots, one-dimensional nanowires and two-dimensional films have been successfully prepared on top of a commonly used insulating NaCl (001) single crystal surface. In-situ atomic force microscopy images show that the sizes of the dots and the widths of the wires are very uniform; the films are atomically flat and are formed due to a high nucleation density. In the present work, the magnetic properties of the dots, wires and films are measured by Superconducting Quantum Interference Device (SQUID) magnetometer X-ray magnetic circular dichroism (XMCD). The wires have an out-of-plane easy magnetization axis, and surprisingly show ferromagnetic stability even at room temperature. The magnetic behaviors of the dots and films are very different from the wires. The detailed comparison will be discussed in the talk. Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

5:00pm **MI+NS-TuA10 Magnetic Reversal of Co/Pd Multilayer Films and Sub-100nm Islands***, **G. Hu**, T. Thomson, M.E. Best, B.D. Terris,* Hitachi San Jose Research Center*; C.T. Rettner, S. Raoux, G.M. McClelland, M.W. Hart,* IBM Almaden Research Center

Patterned arrays of Co/Pd multilayer islands with perpendicular anisotropy are one approach to increasing magnetic recording density towards 1Tbit/in@super 2@. To realize this technology arrays consisting of single domain islands with sufficient anisotropy for thermal stability and a narrow switching field distribution will be required. In order to understand the reversal properties of islands we have compared the reversal mechanism and anisotropy of patterned arrays to nominally identical unpatterned, continuous films. The island arrays were fabricated by creating an etch mask using electron beam lithography and nano-imprinting followed by etching of a SiO@sub 2@ substrate. Multilayer films of Co/Pd were then sputter deposited onto the topographically patterned substrates. We found that for the continuous films, the magnetic anisotropy is only sensitive to the Co and Pd layer thicknesses while coercivity and magnetization reversal mechanism can be easily tuned by varying the deposition conditions. However, for small, single domain islands, the coercivity is much less sensitive to deposition conditions and more sensitive to composition than for the continuous films. The coercivity of these islands is generally significantly greater than that of the continuous films. Moreover, the switching behavior of the islands does not exhibit any correlation with the film reversal mechanism, but rather follows the film magnetic anisotropy closely. Systematic studies have been carried out to adjust the magnetic anisotropy of the multilayer films by varying the cobalt and palladium layer thicknesses. Unlike the continuous films, the measured coercivity of the islands agrees well with the reversal field calculated based on the measured anisotropy of the film and the Sharrock equation.

Processing at the Nanoscale
Room 308 - Session NS+MI-TuA

Nanoscale Patterning and Lithography
Moderator: B.D. Terris, IBM Almaden Research Center

2:00pm **NS+MI-TuA1 Patterning Magnetic Recording Media by Imprinting***, **G.M. McClelland**, M.W. Hart,* IBM Almaden Research Center*; M.E. Best,* Hitachi San Jose Research Center*; C.T. Rettner, K.R. Carter,* IBM Almaden Research Center*; G. Hu, B.D. Terris, M. Albrecht,* Hitachi San Jose Research Center **INVITED**

Patterning magnetic media is a promising strategy for increasing magnetic recording density beyond the current value of 15 Gbit/sq. cm. As proposed by Chou, imprinting is an attractive means for generating the small structures required. This application is not affected by some difficult aspects of imprinting: overlay is not required, long range distortion is accommodated by positioning of the recording head, and defects can be corrected by error correction during read out. We have developed a complete, cost effective process for patterning of 30-nm-dia. single-domain magnetic islands over a 65 mm disk. The process steps are: forming a flexible stamp from a master, imprinting a replica in resist, reactive ion etching SiO2 pillars into the substrate, and depositing a magnetic film by evaporation. To accommodate the roughness and curvature of the substrate, a 10-micon-thick polymer stamp on an acrylic backing plate is used. The stamp is formed by photocuring an acrylate mixture in contact with an SiO2 master made by e-beam lithography. The resist is formed from a 15-nm-thick prepolymer liquid acrylate film spun onto the glass substrate. The film is viscous, so that non-flatness in the substrate is accommodate by stamp deformation, rather than by flow of the resist. After UV exposure, the stamp is removed to leave 30-nm-high resist pillars on a 10-nm-thick base layer. A dozen repeated imprints show a defect rate of about 1 in 10,000 pillars. A CF4/CH4 etch transfers the resist pattern into 30-nm-high, 30-nm-dia. SiO2 pillars with a period of 60 nm. To form a magnetic film, a 10-nm CoPt multilayer is deposited by e-beam evaporation at 300 K. This method shows promise for large-scale manufacturing, because the stamp-making process can be repeated indefinitely from a single master, and many replicas can be formed from each stamp.

2:40pm **NS+MI-TuA3 Buffer Layer Assisted Laser Patterning of Metals at the Nanometer Scale***, **G. Kerner**, M. Asscher,* The Hebrew University of Jerusalem, Israel

Spatial patterning of thin films on surfaces is of great importance for basic physical sciences and technology. An innovative method is presented for a single pulse, macroscopic scale laser patterning of metallic thin film to form nanometer range variable width conducting wires. Employing laser induced thermal desorption (LITD) via interfering split low power beams- metallic gold and potassium coverage grating on top of multilayer Xe is formed over Ru and Si at 20K as a demonstration. Upon annealing to 80K, the Xe layer desorbs and the metallic pattern softly lands and strongly attaches to the substrate. This is a highly versatile patterning technique that can be employed with practically any element and chemical species. It may readily be utilized to prepare millimeters long, 30nm wide conducting wires using current laser technology. The structure and thermal stability of the metallic pattern has been studied by means of AFM, STM, optical second harmonic and linear diffraction. The metallic structures are composed of nanometer size clusters, their size and distribution depend on the buffer layer thickness. The technique presented here is potentially an attractive alternative method for the deposition of periodic and more complex spatial patterns of conducting wires at widths well below the current limits.

3:00pm **NS+MI-TuA4 Low-Temperature Nanolithography using Energetic Neutral Atoms***, **E.A. Akhadov**, A.H. Mueller, M.A. Hoffbauer,* Los Alamos National Laboratory

Neutral atomic beams with kinetic energies of a few eV are exploited for etching of nanoscale features in polymeric materials and for epitaxial thin film growth on substrates held near ambient temperature. A unique low temperature etching and thin film growth technique, called Energetic Neutral Atom Beam Lithography (ENABL), has been recently developed at LANL. Using a collimated atomic beam with a small de Broglie wavelength permits the fabrication of high-aspect-ratio (>25:1) nanoscale features in polymeric substrates without undesirable defects (undercutting, tapering etc.) common to conventional etching. The high flux (~10@super17@ atoms/cm@super2@sec) and high kinetic energies (1 to 5 eV) of reactive atomic species (O and N) allow etching of sub-100nm features at high rates and the growth of high-quality oxide films at ambient temperatures. The use of ENABL for etching and film growth opens new frontiers for materials synthesis and processing at the nanoscale at ambient temperatures. Future prospects and challenges for low-temperature ENABL-based nanoscale fabrication will also be addressed.

3:20pm **NS+MI-TuA5 Self-Assembling Circuits?***, **K.W. Guarini**, C.T. Black,* IBM **INVITED**

The aggressive dimensional and performance targets for future technology generations place severe demands on lithography, not only for feature size scaling but also pattern integrity, density, line edge roughness, and process control. Already today many process "tricks" are routinely employed to shrink the dimensions of lithographically-defined features, such as resist trim and sidewall image transfer, but there are limitations on the extendibility of such approaches. While the great potential of various so-called "next generation" lithography techniques has been well touted, these solutions are inherently complex, require new tooling infrastructure, and present throughput challenges. Self organizing materials offer an exciting prospect for overcoming many of these hurdles. The simplicity, reproducibility, and dimensional control inherent in self-assembling materials make them attractive for silicon nanofabrication. In the grandest vision, we might imagine integrated circuits that one day "organize themselves"-yielding the ultimate sizing and positional control, but this vision is still in the realm of science fiction. However, already today we can implement self-organizing materials for selective unit processes to complement or enhance conventional semiconductor processing. For instance, self-assembling polymer films provide an appealing alternative to photoresists for certain types of patterning at nanometer-scale dimensions. In particular, diblock copolymer thin films self assemble into uniform, densely-spaced nanometer-scale features over wafer-scale areas. These films are compatible with standard semiconductor fabrication processes, enabling their integration into device and circuit fabrication. Such self-organizing materials provide novel nanofabrication capabilities and may enable solutions to some challenges confronting integrated circuit fabrication.

4:00pm **NS+MI-TuA7 Fabrication and Electrical Characterization of 2D Dopant Nanostructures in Si***, **J.S. Kline**, J.C. Kim, S.J. Robinson, K.-F. Chen, R. Chan, M. Feng, J.R. Tucker,* University of Illinois at Urbana-Champaign*; J.-Y. Ji, T.-C. Shen,* Utah State University*; C. Yang, R.-R. Du,* University of Utah

Lithography and contact with external leads are the two major challenges in nanoscale electronic device fabrication. We attempt to address both of these issues by using an integrated approach. STM lithography on H-terminated Si surfaces routinely achieves 1nm resolution. P donors can be selectively deposited onto the H-desorption area by dosing phosphine gas onto the STM patterned device template. Subsequent Si low-temperature deposition and annealing allows epitaxial overgrowth and the dopant atoms are completely activated. The sheet resistance of the P-delta layer is in the range of 1-4k@Omega@/square and can be controlled by phosphine surface coverage. External contacts to the device are fabricated by As ion implantation. We present a method whereby differences in surface features and tunneling spectroscopy between the contact and device region allow the registration of the STM. Low temperature electrical measurements of nanowires and other more complex structures are currently in progress and will also be reported. This work is supported by NSF, ARO, and DARPA.

4:20pm **NS+MI-TuA8 Polymer Patterning using a Soft Inkpad***, **Y.P. Kong**,* Institute of Materials Research and Engineering, Singapore*; L. Tan, L.-R. Bao,* University of Michigan, Ann Arbor*; X.D. Huang,* Institute of Materials Research and Engineering, Singapore*; S.W. Pang,* University of Michigan, Ann Arbor*; A.F. Yee,* Institute of Materials Research and Engineering, Singapore

We present a method of producing micrometer and submicrometer patterns of polymer on substrates. A patterned hard mold is pressed onto an 'inkpad' coated by a polymer. The inkpad consists of a polydimethylsiloxane (PDMS) layer backed by a hard substrate. The function of the PDMS layer is twofold. Oxygen plasma treatment of the PDMS layer allows a polar polymer solution to be spun coated on it. The hydrophobic recovery of the PDMS layer then lowers its surface energy and this allows the transfer of the polymer to the hard mold that has a higher surface energy. Secondly, the deformation of the PDMS layer during the pressing induces a large stress field gradient at the edges of the mold protrusions. It is this stress that leads to a localized rupture of the polymer layer. The pressing is carried out at temperatures close to the glass transition temperature of the polymer and under relatively low pressures to transfer the polymer onto the protrusions of the hard mold. After the hard mold is separated from the inkpad, it is brought into contact with a substrate under a suitable temperature and pressure to produce a positive replica of the mold. At the same time, a negative image of the mold is left on the inkpad and this negative pattern can be transferred to a substrate. With a 700 nm period silicon grating mold, we are able to produce both positive and negative polymeric gratings. We also demonstrate the transfer of multiple layers of polymer onto the protrusions of the mold thereby increasing the aspect ratio of the patterns. Transferring of different polymer layers leads to the possibility of making high-resolution polymer light emitting displays and organic circuits. The advantages of our patterning method over nanoimprint lithography are: lower process temperatures and pressures, no material transport related problems, absence of a residual layer that needs removal, and the possibility to create both negative and positive replicas of the mold.

4:40pm **NS+MI-TuA9 Influence of Stoichiometry and Structure on the Local Oxidation of Metal Films***, **N. Farkas**, G. Zhang, K.M. Donnelly, E.A. Evans, R.D. Ramsier,* The University of Akron*; J.A. Dagata,* National Institute of Standards and Technology

Oxidation growth kinetics of sputter-deposited Zr and ZrN thin-films are studied on the local scale by atomic force microscope (AFM) -assisted lithography. The growth kinetics are found to depend strongly upon the nitrogen content of the deposition plasma. Mass transport of subsurface O, H, and N species also plays an important role in the growth of nanometer-scale oxide structures, producing feature heights up to an order of magnitude greater than those observed in other material systems such as silicon and titanium. The stoichiometric and structural differences in the films are investigated by X-ray photoelectron spectroscopy (XPS), secondary ion mass spectrometry (SIMS) and X-ray diffraction (XRD) techniques to account for solid-state reaction and transport mechanisms involved in oxidation driven by a highly localized electric field. These results demonstrate the potential of AFM lithographic techniques for characterizing oxidation kinetics in the presence of the rich chemical behavior exhibited by reactive metal films.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI-WeM
Current-Induced Magnetic Switching and Excitations

Moderator: S.E. Russek, National Institute of Standards and Technology

8:20am **MI-WeM1 Direct Measurements of Spin Momentum Transfer Induced Dynamics**, ***W.H. Rippard***, *M.R. Pufall, S. Kaka, S.E. Russek, T.J. Silva,* National Institute of Standards and Technology

Slonczewski and Berger first predicted that the angular momentum from a spin-polarized current can be transferred to a ferromagnetic film creating a torque on the film magnetization, the so-called spin momentum transfer (SMT) effect. Previous work has shown that for sufficiently high current densities and applied magnetic fields, there occurs an abrupt increase in the dc resistance of point contact junctions or nanopillar devices. In accordance with theoretical predictions, these steps have been attributed to the onset of coherent magnetization dynamics. We will discuss our recent results from studying these excitations directly in a number of different materials, sample geometries, and applied field geometries. In general we find that the excitations can be well described with the Kittel equation for magnetization dynamics. We commonly observe these excitations from frequencies below 5 GHz to greater the 25 GHz. We have found that these linewidths are often as narrow as 20 MHz and persist for fields from H = 200 Oe to ~1 T, although the specifics depend on the particular geometry and material of the device under study. We also compare these results to single-domain model simulations of SMT induced dynamics and find good agreement between the simulated and measured behavior.

8:40am **MI-WeM2 Dynamical Modes of Nanomagnets Driven by a Spin-Polarized Current**, *S.I. Kiselev,* ***J.C. Sankey***, *I.N. Krivorotov, N.C. Emley,* Cornell University; *S.E. Russek,* National Institute of Standards and Technology; *R.J. Schoelkopf,* Yale University; *R.A. Buhrman, D.C. Ralph,* Cornell University

A spin-polarized current can apply a torque directly to a ferromagnet through transfer of angular momentum. Here we report direct electrical measurements of microwave-frequency magnetic dynamics driven by DC spin-transfer currents in Co/Cu/Co nanopillar structures. We demonstrate that spin-transfer can produce several types of excitations, including small angle elliptical precession, more complicated large angle motions and high current static state. Microwave power emitted by magnetic multilayer devices may enable nanoscale oscillators and microwave sources generated by DC current.

9:00am **MI-WeM3 Current-Induced Precession at Ferromagnetic Interfaces**, ***A. Zangwill***, Georgia Institute of Technology **INVITED**

It is well established experimentally that the relative orientation of two ferromagnetic layers in a multilayer film can be switched by passing a sufficiently large current through the film. Often, this "converse GMR" effect is preceded by a precession-type instability of one or both ferromagnetic layers. The signature of this instabilty has also been seen during point contact current injection into a single ferromagnetic film. In this talk, I discuss the precessional phenomenon theoretically using a combination of phenomenological modelling, Boltzmann transport theory, and first-principles quantum mechanical calculations. The key ingredient is a "spin-transfer" torque associated with spin polarization of the electric current. Special emphasis is placed on the possibility of quantitative comparison with experiment.

9:40am **MI-WeM5 Spin-transfer Induced Magnetic Switching in Batch-fabricated sub-100 nm Spin-valves**, ***J.Z. Sun***, IBM T.J. Watson Research Center; *T.S. Kuan,* SUNY at Albany; *M.J. Rooks,* IBM T.J. Watson Research Center; *J.M.E. Harper,* IBM T.J. Watson Research Center and University of New Hampshire; *R.A. Carruthers, S.M. Rossnagel, R.H. Koch,* IBM T.J. Watson Research Center **INVITED**

A hard-mask stencil method is developed for the efficient fabrication of sub-100nm current-perpendicular spin-valve junctions with low contact resistance. The approach uses a trilayer template. The templated substrate is batch fabricated first with the junction features defined by a top stencil layer and an undercut in the insulator. The spin-valve thin film stack is deposited afterwards into the stencil, with the insulator undercut providing the necessary isolation of magnetic exchange coupling. By placing electron-beam lithography at the very beginning of the process before the deposition of the magnetic thin films, this approach improves the turnaround time for materials optimization in nanostructures. Using this approach, spin-transfer induced magnetic switching and magnetic excitation are observed for junctions down to 50nm x 100nm in size.

10:20am **MI-WeM7 Current-Driven Magnetization Reversal at High Magnetic Fields in Co/Cu/Co Nanopillars**, ***B. Oezyilmaz***[1], *A.D. Kent,* New York University; *D. Monsma,* Harvard University; *J.Z. Sun, M.J. Rooks, R.H. Koch,* IBM T.J. Watson Research Center

Recently there has been great interest in current induced angular momentum transfer in magnetic nanostructures. Its observation in point contact experiments on magnetic multilayers in the field perpendicular geometry has boosted efforts to understand the underlying mechanism.@footnote 1@ We have studied spin transfer torques in the same field perpendicular configuration in sub-micron size (~100 nm) Co/Cu/Co pillar devices at 4.2 K and 293 K. Pillars have been fabricated by means of a new nano-stencil mask process, which enables the production of large arrays of templates ideal for systematic variations of layer thicknesses and compositions. I(V) measurements in large magnetic fields (>1.5T) show an abrupt increase in device resistance at high current densities for one current polarity. The onset of this transition is marked by both a hysteretic step in the DC voltage and a hysteretic peak in dV/dI. The magnitude of the step in resistance is similar to the device in-plane GMR (~5 %) and is thus consistent with current-induced switching into a high resistance state of anti-parallel magnetization in large applied perpendicular magnetic fields. In contrast to experiments with point-contacts, our results suggest that the peak in dV/dI marks the end and not the onset of magnetization dynamics.@footnote 2@ High field hysteresis in MR measurements at fixed (positive) bias current is also observed which is consistent with this interpretation. Micromagnetic modeling that includes a spin-transfer torque is in qualitative agreement with these observations and provides an explanation for the basic features observed in the device I-V characteristics as a function of magnetic field. Further, to study the importance of the longitudinal spin-accumulation, pillars with only a single Co layer have been fabricated. Initial experiments with these Cu/Co/Cu sub-micron size pillar devices will be discussed. @FootnoteText@@footnote 1@M. Tsoi et al, Nature 406, 46 (2000). @footnote 2@B. Oezyilmaz et al., arXiv:cond-mat/0301324.

10:40am **MI-WeM8 Current-Triggered Domain Wall Motion in Focused Ion Beam Fabricated Magnetic Nanowires**, ***C.T. Rettner***, *M. Tsoi, L. Thomas, S. Parkin,* IBM Almaden Research Center

Focused ion beam techniques have been used to pattern NiFe and CoFe thin films into nano-wires to study magnetic domain wall motion triggered by an electric current. We have investigated a variety of shapes, including simple and notched straight lines as well as zigzags and semi-circular shapes. Our scheme begins with a large structure created by deposition of the magnetic material onto SiO2 through a shadow mask. This structure consists of 1 mm pads connected by a 0.1 mm line. The focused ion beam is first used to cut this line with a 11 nA beam leaving just 6 microns of film on the centerline. Next an 11 pA beam is used to roughly form the desired shape in this region, and a 4 pA with ~25 nm resolution is used to add details such as notches and to form the final dimensions. We will discuss our observations of current-triggered domain-wall motion in these structures, including results for motion in zero fields. These results include magneto-resistive measurements and MFM imaging. Finally, we will briefly discuss the results in terms of micro-magnetic simulations for these structures.

[1] **Falicov Student Award Finalist**

Magnetic Interfaces and Nanostructures
Room Hall A-C - Session MI-WeP
Poster Session

MI-WeP4 Magnetic and Structural Properties of Fe@sub 3@Pt/Fe Thin Films*, **M.A.I. Nahid**, T. Suzuki,* Toyota Technological Institute, Japan

Recently hcp phase of Fe@sub 3@Pt is stabilized by e-beam evaporation which shows 6-fold in-plane magnetic anisotropy (K@sub in@) of the order of 2x10@super 5@erg/cc.@footnote 1@ However it does not show significant perpendicular magnetic anisotropy (K@sub per@).Theoretical calculation by A. Sakuma predicts that uniaxial anisotropy is expected in a Fe@sub 3@Pt/Fe system.@footnote 2@ Therefore it is investigated the magnetic properties of Fe@sub 3@Pt/Fe system in conjunction with structure. The thickness of Fe underlayer(d) was varied from 0-300Å. The hcp phase of Fe@sub 3@Pt thin films has been synthesized onto Al@sub 2@O@sub 3@(00.1) substrate using Fe underlayer by e-beam evaporation at deposition temperature 400°C. The epitaxial relationship is found as Al@sub 2@O@sub 3@(00.1)[10.0]||Fe(110)[1-10]||Fe@sub 3@Pt(00.1)[11.0]. The superlattice peak (00.1) intensity of Fe@sub 3@Pt changes with Fe underlayer thickness and becomes maximum at the 100Å. The 6-fold symmetry of Fe@sub 3@Pt was observed in the so called @PHI@-scan measurement when the X-ray is irradiated at the grazing angle. From the perpendicular hysteresis loop of Fe@sub 3@Pt measured by MO polar kerr instrument, the coercivity and remanence is found to increase with Fe thickness and becomes constant after d=200Å. This suggests that a perpendicular magnetic anisotropy (K@sub per@) exists in the Fe@sub 3@Pt thin films by using Fe underlayer. The maximum K@sub per@ is about 3x10@super 6@erg/cc at d=100-150Å. Besides the K@sub per@, the Fe@sub 3@Pt films possess the 6-fold in-plane magnetic anisotropy (K@sub in@) which increase with increasing d and become constant after 200Å. The maximum K@sub in@ of Fe@sub 3@Pt is obtained about 3.2x10@super 5@erg/cc which is much larger than that of Co.@footnote 3@ @FootnoteText@ @footnote 1@M.A.I. Nahid and T.Suzuki: Accepted for publication in the IEEE trans. on Magn. Sep,2003. @footnote 2@A.Sakuma: J. Phy. Soc. Japan. 64,4317(1995). @footnote 3@Y. Kadena: J.Sci. Hiroshima Univ.31,21(1967). .

MI-WeP5 Ultrafast Laser Measurements of Electron and Spin Dynamics in Half-metallic CrO@sub 2@ Thin Films*, **H. Huang**, K. Seu, A.C. Reilly,* College of William and Mary*; W.F. Egelhoff, Y. Kadmon,* National Institute of Standards and Technology

Half-metallic ferromagnets are an important class of materials in which one spin state is conducting while the other has a semiconductor-like gap. While evidence of half-metallic behavior has been found, there are still many questions regarding the bandstructure and dynamics in these materials. Ultrafast laser pump-probe techniques have shown great promise for elucidating such information in a variety of materials. Recently, such pump-probe techniques have been applied to study spin dynamics@footnote 1@ in Sr@sub 2@FeMoO@sub 6@ and coherent magnetization rotation@footnote 2@ in CrO@sub 2@. We will present measurements of charge and spin dynamics in half-metallic CrO@sub 2@ thin films by ultrafast laser pump-probe reflection, transmission and MOKE experiments as a function of temperature and energy (wavelength). We find that the pump-probe reflection and transmission consist of components simlar to those seen in the other half-metallic systems such as LCMO and Sr@sub 2@FeMoO@sub 6@: An initial fast peak which decays within ~ 1 ps, and a longer component with a rise of ~ 10 ps and a decay time of ~ 500 ps. This may indicate similar mechanisms for these systems. We attempt to correlate the temperature dependence with the two-order-of-magnitude increase in resistivity with temperature that is taken as a signature of the half-metallic behavior. The wavelength dependence is used to explore the bandstructure. For example, we observe different electron and spin dynamics for excitation energies of 1.5 eV and 3 eV, corresponding to the energies of excitation within the conducting spin-up band and across the gap for the spin-down state. @FootnoteText@ @footnote 1@T. Kise et al., Phys. Rev. Lett., 85, 1986 (2000). @footnote 2@Qiang Zhang et al., Phys. Rev. Lett., 89, 177402 (2002).

MI-WeP7 Spin-polarized Scanning Tunneling Microscopy Study of Ferromagnetic Arrays Fabricated by In-situ Alumina Shadow Mask*, **J.H. Choi**, T.-H. Kim, S.H. Kim, Y. Kuk,* CSNS and Seoul National University, Korea

Spin-polarized scanning tunneling microscopy(SPSTM) can detect the local electron spin density of the sample surface in atomic resolution, so it has been used to study magnetic properties of ferromagnetic materials. However, SPSTM study of patterned nanomagnetic arrays has not been done because all the fabrication process of nanomagnetic arrays must be done in-situ in UHV chamber to avoid contamination problems. We fabricated a shadow mask for in-situ SPSTM study of nanomagnetic arrays on Si wafer. 500nm thick aluminum was thermally evaporated on Si wafer and indented by SiC mold to produce an ordered pore of porous alumina. The sample was electrochemically anodized in oxalic acid. After pore widening and removing barrier layer, we opened 5x5mm@super 2@ window on backside Si substrate by photolithography and etched Si wafer completely using deep silicon etch process until the aluminum layer was appeared. Fabricated shadow mask was mounted in front of Si substrate in UHV chamber. Fe was evaporated on a Si wafer through shadow mask, forming nanomagnetic arrays of 30-80nm dia. The magnetic properties of ferromagnetic arrays studied by SPSTM will be discussed.

MI-WeP8 Properties of Self-assembled Nanowires Fabricated using Glancing Angle Deposition*, **H. Alouach**, G.J. Mankey,* University of Alabama

The spin-dependent transport in nanoscale spin electronic devices, such as Current Perpendicular to the Plane Giant Magnetoresistive (CPP-GMR) devices, is closely dependent on the spin arrangement and physical properties of single wires. Self-assembled Cu and permalloy nanowires were deposited using glancing angle electron beam evaporation technique with and without substrate rotation. Wire texture and crystallographic orientation of such features are known to be strongly dependent on the deposition parameters. We report an unprecedented and efficient method allowing determination of the crystal orientation independent of the geometrical wire and grain orientation. For Cu wires deposited without substrate rotation, the (111) crystal orientation, which corresponds to the close packed low energy surface of Cu, coincides with the geometrical wire orientation. Whereas, for Cu wires deposited with azimuthal rotation of the substrate, the (111)-crystal direction and the wire orientation are different depending on the rotation speed. We compared the validity of the empirical tangent rule@footnote 1@ and the geometrical Tait rule@footnote 2@ which are different equations which describe the relationship between the incident flux angle and the resulting wire orientation. Applications in nanowire circuits will also be discussed. @FootnoteText@ @footnote 1@ J.M. Nieuwenhuizen and H.B Hannstra., Philips Tech. Rev. 27, 87 (1966)@footnote 2@ R.N. Tait, T. Smy and M.J. Brett, Thin Solid Films 226, 196 (1993) .

MI-WeP9 Characterization and Room-temperature Ferromagnetic Properties Of Ti@sub 1-x@Co@sub x@O@sub 2@ Films Prepared by Cobalt Implantation*, K.H. Cheng, K.W. Lo, C.F. Chow, Y.W. LAI, W.M. Tsang, N. Ke, W.Y. Cheung,* Chinese University of Hong Kong*; **S.P. Wong**,* Chinese University of Hong Kong, Hong Kong

In this work, TiO@sub 2@ thin films were prepared by RF sputtering onto thermally grown oxide layers on Si substrates. Cobalt implantation was performed using a metal vapor vacuum arc (MEVVA) ion source at an extraction voltage of 65 kV to doses ranging from 1.4x10@super 16@ cm@super -2@ to 1.4x10@super 17@ cm@super -2@. Annealing was performed in vacuum at 600@super o@C for 2h. The cobalt composition and distribution in these implanted Ti@sub 1-x@Co@sub x@O@sub 2@ films was studied using Rutherford backscattering spectrometry. The crystal structures were studied using x-ray diffraction. The optical properties were studied using spectroscopic ellipsometry in the wavelength range from 350 to 700 nm. The magnetic properties were measured by vibrating sample magnetometry. We observed clear room-temperature ferromagnetic properties for all the as-implanted and annealed samples prepared under the above conditions. The measured M@sub S@ values ranged from 0.5 µ@sub B@/Co atom to 2.1 µ@sub B@/Co atom and the coercivity values ranged from 200 Oe to 500 Oe, depending on the Co dose and annealing conditions. The correlation between the optical properties, the magnetic properties and their structures will be discussed. This work is supported in part by the Research Grants Council of Hong Kong SAR (Ref. number: CUHK4216/00E and CUHK4221/00E).

MI-WeP10 Characterization of Transition Metal Doped CVD-grown ZnO Films*, D. Hill, J. Quinn, L. Wielunski, **R.A. Bartynski**, P. Wu, Y. Lu, G. Popov, M. Greenblatt,* Rutgers University

A crucial element for the success of spintronics is finding a material that combines the desirable properties of ferromagnets and semiconductors. Diluted magnetic semiconductors (DMS) are intriguing materials that offer the possibility of studying magnetic phenomena in crystals with a simple band structure and excellent magneto-optical and transport properties. ZnO, a wide bandgap (~3.3 eV) semiconductor that has received increasing attention due to its broad applications and its many desirable material properties, has recently has been identified as a promising DMS candidate for room temperature spintronics. We have characterized the chemical, compositional, and magnetic properties of TM-doped ZnO films grown by MOCVD. Doping using V, Mn, Fe, Co, and Ni has been investigated. X-ray photoelectron spectroscopy indicates that the TM dopant is in the 2+ oxidation state and thus may be substitutional for Zn. Squid magnetometry measurement show that the Mn- and Fe-doped films exhibit ferromagnetic behavior, with Mn-doped films having a Curie temperature of ~ 45K. For Fe-doped films, the Curie temperature is above room temperature. Both Rutherford backscattering spectrometry and XPS depth profiling indicate that Mn and Ni show extensive diffusion while Fe and Co exhibit more penetration into the ZnO film.

MI-WeP11 Epitaxial Growth, Structural, and Magnetic Properties of a Chalcopyrite Magnetic Semiconductor: MnGeN2*, S. Hardcastle,* ***L. Li****,* University of Wisconsin, Milwaukee

Epitaxial thin films of MnGeN2 were grown on Al2O3(0001), 6H-SiC(0001), and MgO(111) substrates using ECR plasma assisted MBE at 500 C. In situ RHEED studies indicated that the growth was 3D, consistent with ex situ AFM investigations. X-ray diffraction studies revealed that the films are single-phased material. Hysteresis loop with a coercive field of 100 Oe was observed at 300 K using a SQUID magnetometer, indicating ferromagnetic ordering at room temperature.

MI-WeP12 Ferromagnetism in Epitaxial Mn:Ge Films*,* ***A.P. Li,*** Oak Ridge National Laboratory*; C. Zeng,* The University of Tennessee*; Z. Gai, J.F. Wendelken,* Oak Ridge National Laboratory*; H.H. Weitering,* The University of Tennessee and Oak Ridge National Laboratory*; J. Shen,* Oak Ridge National Laboratory

We report on the magnetic properties of Mn-doped homo-epitaxial Ge films. Two different approaches are used to fabricate ferromagnetic Ge films. In the first approach, Mn-doped Ge films were grown on (2x1) reconstructed Ge(100) using molecular beam epitaxy (MBE) as was reported by Y.D. Park et al (Science 295, 651 (2002)). The Mn-concentration was varied between 1% and 5%. The Ge films show ferromagnetic ordering with Curie temperatures ranging from 25 K to 295 K, which have been determined from the remnant magnetization measured with a SQUID magnetometer. The magnetic response appears to consist of two different contributions, namely the ferromagnetic response from the dilute magnetic semiconductor (DMS) and the response from ferromagnetic alloy precipitates. X-ray diffraction (XRD), Rutherford Backscattering, and ion-channeling experiments were used to characterize the stoichiometry, homogeneity, and epitaxial quality of the films. In the second approach, a 40 nm Mn film is deposited onto Ge(111) and annealed to 150 °C for several minutes. Scanning Tunneling Microscope and XRD measurements show a high-quality epitaxial Mn@sub 5@Ge@sub 3@ alloy film with Mn@sub 5@Ge@sub 3@(001)//Ge(111). The Curie temperature of this ferromagnetic alloy film is 295 K, which is similar to that of bulk Mn@sub 5@Ge@sub 3@. The identical Tc of the epitaxial alloy film and Mn-doped Ge(100) films strongly suggests that the DMS film contains bulk Mn@sub 5@Ge@sub 3@ precipitates. These precipitates are below the detection limit of XRD. This thin film ferromagnetic system has good potential for spin-injection studies in silicon-compatible semiconductors. This research was sponsored by the LDRD Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

MI-WeP13 Increase of Conductance and Magnetoconductance with Oxygen Exposure During Deposition of Spinvalves*,* ***A.T. McCallum****, S.E. Russek,* National Institute of Standards and Technology

It has been found that the magnetoconductance and conductance of spinvalves increase when a small partial pressure of oxygen(1 x 10@super -9@ - 5 x 10@super -9@ torr)is present during deposition. Conductance measurements made during the sputter deposition of spin valves show directly that the conductance increases are occurring in the active layers of the spin valve flims. The Ne`el coupling between the free layer and the pinned layer is also reduced suggesting that the oxygen is leading to smoother growth. Eventually a high enough partial pressure of oxygen will lead to oxidation of the deposited metal and a drop in giant magnetoresistance. A series of conductance measurements at different gas flows show the onset of oxidation beginning with the NiFe and Cu layers. Relatively thick layers of material also have a higher conductance when grown in the presence of oxygen. The in-situ conductance measurement for NiFe layers reveal that the increase in conductance is starts at 1 nm and ends at 5 nm. After this the differential conductivity is the same for samples grown with and without oxygen. This is consistent with the samples grown in oxygen having a smoother surface but essentially the same microstructure.

MI-WeP14 Exploring Spintronic Materials and Structures with Interatomic Potentials*,* ***D.A. Murdick****, X.W. Zhou, H.N.G. Wadley,* University of Virginia*; D.G. Pettifor, D. Nguyen-Manh,* University of Oxford

The use of interatomic potentials in atomistic simulations has become a powerful approach for studying the atomic structures of materials. Molecular dynamic atomic simulations allow assembly phenomena encountered during the synthesis of spintronic devices to be analyzed in detail and allow the optimization of process conditions for desired spintronic structures and compounds. This approach has been successfully applied in metal/metal oxide multilayer systems to identify the deposition conditions for creating atomically smooth interfaces with minimized interlayer mixing. The extension of such an approach into semiconductors is very promising. The key to this is the availability of a high fidelity interatomic potential that can accurately describe covalent bonding in doped compound semiconductors and can be used for simulation of vapor deposition to reveal the time-dependent atomic structure as a function of processing conditions. We demonstrate that the existing literature multi-component interatomic potentials are too limited for spintronic applications. We describe a new class of bond-order potentials that overcome these limitations. The bond order potential has been successfully applied for GaAs systems and is being extended to (Ga,Mn)As/GaAs heterostructures and other doped semiconductors of group IV and III-V semiconductors.

MI-WeP15 The Isomer Dependent Semiconductors of Boroncarbide*,* ***A.N. Caruso,*** University of Nebraska*; L. Bernard,* Ecole Polytechnique Federale de Lausanne*; B. Doudin, P.A. Dowben,* University of Nebraska

We demonstrate that boroncarbide, grown by chemical vapor deposition, is an effective dielectric barrier layer for magnetic tunnel junctions. Decomposition of the insulator closo-1,2 dicarbadodecaborane or orthocarborane (C@sub 2@B@sub 10@H@sub 12@) has been shown to form p-type semiconducting boron carbide (C@sub 2@B@sub 10@).@footnote 1-4@ We present recent photoemission results which indicate that closo-1,7 dicarbadodecaborane or metacarborane (C@sub 2@B@sub 10@H@sub 12@) forms an n-type semiconducting boroncarbide (C@sub 2@B@sub 10@) upon decomposition. Bonding, orientation, and electronic structure of the two materials in both associative and decomposed configurations are compared as adsorbates. The electronic structure of orthocarborane and metacarborane are calculated to be very similar, but there are significant differences in the experimental binding energies for each isomer as an adsorbed species. Metacarborane adsorbs on both Co and Au with the Fermi Level (chemical potential) placed closer to the lowest unoccupied molecular orbital than is observed with orthocarborane adsorbed on Co and Cu. @FootnoteText@@footnote 1@ S. Lee and P.A. Dowben, Appl. Phys. A 58 (1994) 223. @footnote 2@ Dongjin Byun, Seong-don Hwang, Jiandi Zhang, Hong Zeng, F. Keith Perkins, G. Vidali and P.A. Dowben, Jap. Journ. Appl. Phys. Lett. 34 (1995) L941-L944@footnote 3@ D.N. McIlroy, C. Waldfried, T. McAvoy, Jaewu Choi, P.A. Dowben and D. Heskett, Chem. Phys. Lett. 264 (1997) 168-173@footnote 4@ Seong-Don Hwang, Ken Yang, P.A. Dowben, Ahmad A. Ahmad, N.J. Ianno, J.Z. Li, J.Y. Lin, H.X. Jiang and D.N. McIlroy, Appl. Phys. Lett. 70 (1997) 1028-1030 .

MI-WeP16 Extraordinary Hall Effect in Mn Ion-implanted p@super +@GaAs:C*, ***J.D. Lim****, S.B. Shim, K.S. Suh, Y.D. Park,* Seoul National University, Korea*; C.R. Abernathy, S.J. Pearton,* University of Florida*; R.G. Wilson,* Consultant

Gas source molecular beam epitaxy (GSMBE) prepared p@super +@GaAs:C (p = 3 x 10@super 20@cm@super -3@) on SI GaAs substrate was ion-implanted with Mn at 250 keV (at 350° C) with dose ranging from 1 - 5 x 10@super 16@ cm@super -2@. AC-magnetotransport measurements were conducted in Van der Pauw geometry using indium soldered contacts on as-implanted samples (I@sub ac@ = 100@mu@A @@ 17.1 Hz). Resistivity as function of temperature (@rho@ vs. T) for various applied fields showed anomalies consistent with magnetic properties. For various applied fields (up to 9 Tesla) for the temperature range considered (5 K - 400 K), the magnetoresistance (MR) was found to be positive, as oppose to nanometer-sized ferromagnetic clusters embedded in semiconductor matrix systems, which generally show a cross-over in sign of MR.@footnote 1@ Hall Effect measurement show a positive response consistent with overall p-character of the implanted samples. Sheet resistance increased with dose due to the expected implantation damage, and sheet carrier concentration as measured at 300 K increased with dose. Determination of the exact carrier concentration was made difficult with the onset of extraordinary Hall Effect (EHE) below 280 K (where @rho@@sub H@=R@sub o@B + R@sub S@H), again consistent with magnetic properties. For specific temperature range, the dominant EHE mechanism was found to be skew scattering (R@sub s@ ~ c@rho@). An apparent mobility enhancement was not observed as reported in inhomogeneous systems.@footnote 2@ Along with detailed magnetotransport measurements, effects of temperature of sample during implantation process and post-implantation anneal processes will be discussed. @FootnoteText@@footnote *@ partially supported by Samsung Electronics Endowment and KOSEF through CSCMR.@footnote 1@ H. Akinaga et al., Appl. Phys. Lett. 72, 3368 (1998); D.R. Schmidt et al., Phys. Rev. Lett. 82, 823 (1999).@footnote 2@ Sh.U. Yuldashev et al., J. Appl. Phys. 90, 3004 (2001).

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+TF-WeA

Magnetic Thin Films

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

2:00pm **MI+TF-WeA1 Electrodeposition of Epitaxially Grown Fe Films on n-type GaAs***, C. Scheck,* ***Y.-K. Liu,*** The University of Alabama*; G. Zangari,* University of Virginia*; R. Schad,* The University of Alabama

Epitaxial growth of Fe thin films on both n-type GaAs(001) and n-type GaAs(011) substrates have been demonstrated using Molecular Beam Epitaxy (MBE) in the past. Indeed, Fe and GaAs lattice constants match very well leading to easy epitaxial growth. However, special surface preparation or growth at elevated temperature were needed to obtain good quality films. Also diffusion and segregation of substrate material (As) at the surface, characteristic of intermixing at the interface, were observed on MBE grown films. Electrodeposition (ECD) technique on the contrary is an equilibrium process which thus releases much less energy per absorbed atom than other deposition techniques (MBE). This allows preparation of chemically sharp interfaces (i.e. no intermixing) which otherwise show a high degree of reactivity and interdiffusion. We reported for the first time the epitaxial growth of high quality Fe thin films on both n-type GaAs(001) and n-type GaAs(011) substrates using ECD. Two different electrolytes FeSO4 and FeC§¤2 solutions 0.1M were used at pH 2.5. Results from X-Ray Diffraction (XRD) show Fe(001)[110]//GaAs(001)[110] and Fe(011)[100]//GaAs(011)[100] as the primary epitaxial relations similarly to Fe films grown by MBE. These films' in-plane magnetic anisotropy is related to the crystalline structure. Their coercivity Hc is around 30-100 Oe.

2:20pm **MI+TF-WeA2 Epitaxial Growth of Ferromagnetic Fe Overlayers on CH@sub 3@CSNH@sub 2@ - Passivated GaAs(100)-S(2x1) Reconstruction***,* ***E.D. Lu****, H.T. Johnson-Steigelman, P.F. Lyman,* University of Wisconsin, Milwaukee

Epitaxial growth of ferromagnetic metallic Fe overlayers on thioacetamide (CH@sub 3@CSNH@sub 2@)-passivated GaAs(100)-S(2x1) reconstructed surfaces at room temperature (RT) has been investigated by low energy electron diffraction (LEED), x-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES). Prior to Fe deposition, GaAs(100) wafers were passivated by CH@sub 3@CSNH@sub 2@ solution then annealed between 320°C and 450°C under UHV. A clear (2x1) reconstructed LEED pattern with around 1 monolayer (ML) sulfur coverage resulted. Upon deposition of Fe at RT, epitaxial bcc(100) Fe overlayers could be grown from 3 to 40 ML. XPS and AES have revealed that only an initial interface reaction (<4ML) takes place between the evaporated Fe overlayer and GaS sulfide passivation layers. Upon annealing, the Fe/S-GaAs(100) heterostructure appears stable up to 320°C; solid state reaction and/or interdiffusion of the layers starts at higher annealing temperatures, becoming severe by 450°C. Nonetheless, a LEED pattern is observed even after intermixing. These results indicate that the S passivation layer may inhibit Ga and As outdiffusion at modest substrate temperatures, and may thus suppress or reduce the formation of an anti-ferromagnetic Fe@sub 2@As dead layer or other unfavorable Fe@sub 3@Ga@Sub 2-x@As@sub x@ phases.

2:40pm **MI+TF-WeA3 On the Magnetic Properties of Ultra Thin Epitaxial Fe Films on GaAs(001)***, S.A. Morton,* Lawrence Livermore National Laboratory*; J.R. Neal, M. Spangenberg, T.-H. Shen,* University of Salford, UK*; A.E.R. Malins, E.A. Seddon,* CLRC Daresbury Laboratory, UK*; D. Greig,* University of Leeds, UK*; J.A.D. Matthew,* University of York, UK*;* ***G.D. Waddill,*** University of Missouri, Rolla*; J.G. Tobin,* Lawrence Livermore National Laboratory

The magnetic properties of epitaxial Fe films on GaAs have attracted considerable interest in recent years because of their potential for use as spin injection sources for spintronic devices; however, previous studies have been unable to demonstrate a magnetic signature in films with thicknesses below approximately 5 ML. A number of possible explanations for this observation have been proposed such as the presence of a magnetically dead interfacial layer of Fe2As. However, by measuring the thickness and temperature dependence of the Fe 3p core level magnetic linear dichroism signal we have shown that such films are indeed ferromagnetic but that their Curie temperature is substantially below room temperature. For instance a Tc of approximately 240K was measured for thin films with a nominal thickness of 0.9 nm. Furthermore the values of the Curie temperature in this thickness regime have been shown to be extremely sensitive both to initial substrate conditions and to the overall film thickness; an increase in the thickness of 0.35nm results in a Curie temperature above room temperature. These measurements have been complemented with spin resolved and angle resolved measurements of the Fe/GaAs valence band and core levels; together with ex-situ XRD and SPM studies of sample growth. The origins of the evolving magnetic behavior of Fe films on GaAs(001) from 1-50ML is discussed in terms of the spin dependent electronic band structure and the stoichiometry and growth morphology.

3:00pm **MI+TF-WeA4 Correlated Structural and Magnetization Reversal Studies on Epitaxial Ni Films Grown with MBE and with Sputtering***,* ***Z. Zhang***[1]*, R.A. Lukaszew,* University of Toledo*; A. Zambano,* Michigan State University*; C. Cionca,* University of Michigan, Ann Arbor*; D. Walko,* Argonne National Laboratory*; E. Dufresne,* University of Michigan, Ann Arbor*; M. Yeadon,* National University of Singapore, Singapore*; R. Clarke,* University of Michigan, Ann Arbor

The study of epitaxial magnetic thin films is important to understand structure-property correlations. We have studied the correlation between film structure and azimuthal dependence of the magnetization reversal on (001) epitaxial Ni films grown on MgO substrates with two different deposition techniques: molecular beam epitaxy (MBE) and DC magnetron sputtering . The films were grown and annealed in-situ under identical conditions. The magnetization reversal was investigated using MOKE. The coercive field in the sputtered films exhibits 4-fold symmetry as expected for a crystal of good epitaxial quality. The MBE grown films exhibit an additional uniaxial symmetry superimposed to the four-fold symmetry. We note that films of the same thickness made with these two deposition techniques, exhibited the same average coercivity. We performed high-resolution XRD at the Advanced Photon Source (ANL) in order to establish similarities and differences in the structure of the films. Both types of films exhibit epitaxial growth and very good crystalline quality with no indication of strain, and don't exhibit fundamental structural differences. The main difference between the films was the surface morphology. STM images of the surface of the MBE grown films indicated self-assembled periodic stripe nano-patterning, while STM images of the sputtered films didn't exhibit any regular patterning of the surface. Cross sectional TEM studies performed on the films will be correlated with the surface morphology and with the magnetic anisotropy.

3:20pm **MI+TF-WeA5 Adsorption-induced Giant Stress and Surface Relaxation in Ni/W(110)***,* ***H.L. Meyerheim****, D. Sander, R. Popescu,* Max-Planck-Institut f. Mikrostrukturphysik, Germany*; O. Robach, S. Ferrer,* ESRF, France*; J. Kirschner,* Max-Planck-Institut f. Mikrostrukturphysik, Germany

Surface stress has been recognized as a decisive factor, which determines a variety of phenomena like self-assembled pattern formation on the nano-scale, shape evolution of nano-objects and surface reconstruction. Our work reveals an important aspect of adsorbate-induced stress which might be of key importance for the general understanding of stress-strain relations in the monolayer range. We identify an intimate correlation between structure and stress from an in-situ combination of surface x-ray diffraction and stress measurements. We show that one atomic layer of Ni induces substantial lateral shifts of the top W-atoms of up to 0.5 Å. At this coverage we measure an anisotropic change of the surface stress induced by Ni. The experiments were carried out at the ESRF in Grenoble (France). Surface stress was measured by the crystal curvature technique.@footnote 1@ From earlier experiments@footnote 2@ it is known that Ni forms a c(1x7) superstructure on W(110) at a coverage above 0.8 monolayers (ML, 1ML=1.41x10@super15@ atoms/cm@super2@). Up to 0.8 ML the stress measurements indicate compressive stress along [001] and tensile stress along [1-10]. The emergence of the c(1x7)-structure coincides with the formation of compressive stress along [1-10]. The x-ray analysis shows that the Ni-atoms form a distorted densely packed hexagonal adlayer. However, the most important and astonishing aspect is the pronounced shifts (up to 0.5 Å) of the first layer W-atoms out of their bulk positions along [1-10]. The structure consists of alternating Ni-W-Ni-chains running along [1-11]. In conclusion we have measured a substantial adsorbate-induced relaxation in a system, which is generally considered to be structurally inert upon adsorbate deposition. There is a striking correlation between the onset of lateral shifts of atomic positions and compressive surface stress. @FootnoteText@@footnote 1@D. Sander et al. Rev. Sci. Instr. 66, 4734 (1995); @footnote 2@D. Sander et al. Phys. Rev. B57, 1406 (1998).

[1] **Falicov Student Award Finalist**

3:40pm **MI+TF-WeA6 Ion Deposited Co and DLC Films Generated from Laser Excitation*, F.J. Cadieu,* *L. Chen,* Queens College of CUNY

A modified pulsed laser deposition system has been used to deposit films from ions generated due to the impact of 248 nm excimer laser pulses. A synchronously pulsed magnetic field coil with a wide entrance throat and a tapered bore in conjunction with a set of permanent magnets has been used to capture and concentrate the ion and electron beam flux under vacuum conditions onto the substrates. Co and other films such as diamond like carbon, DLC, are strongly adherent when deposited onto even room temperature substrates. The ion collection and concentration factor is such that Co films deposited on glass to an optical density of 3.0, approximately 7 nm thickness, with coil pulsing and magnets only exhibited an optical density of 0.10 without coil pulsing and magnets for the same number of laser pulses. Films have been characterized by x-ray reflectivity, x-ray diffraction, scanning electron microscopy, SEM, and magnetoresistivity measurements when combined with other magnetic layers. Over an order of magnitude intensity modulation has been observed in x-ray reflectivity measurements for Co films, 7-15 nm thickness, deposited onto R-plane sapphire substrates and onto Si (111) substrates. In contrast to this Co films simultaneously deposited onto A-plane sapphire substrates hardly exhibited x-ray reflectivity fringes indicating a large surface roughness. Similarly DLC films deposited onto (111) Si substrates exhibited order of magnitude intensity modulations indicating a very small surface roughness. X-ray reflectivity measurements of DLC, Co layers on (111) Si are used to show the conditions necessary to make smooth and hence insulating DLC films onto the metallic layer. SEM measurements indicated smooth films were obtained with no discernible particulates. X-ray pole figures are used to characterize single crystal films versus polycrystalline growth modes.

4:00pm **MI+TF-WeA7 Ultrathin Magnetic Layers Electrodeposited on Au(111)and Related Technological Substrates*, P. Allongue,*** *F. Maroun,* CNRS, France*; J.E. Schmidt, A. Gundel,* UFRGS*; M.L. Munford,* UFSC*; T. Devolder,* IEF, France **INVITED**

Magnetic properties such as interface perpendicular anisotropy (PMA) is strongly depending on the coupling between the substrate, generally a noble metal, and the ultrathin ferromagnetic layer. Both the film and interface structures are also critically influencing the strength of PMA. We recently showed that electrodeposited Cu/Co/Au(111) structures exhibit strong PMA due to an excellent 2D epitaxial growth of cobalt and some residual elastic stress at the interface. This talk will be divided into two parts. In the first one, I will present in situ structural and magnetic characterizations of M / Au(111) ultrathin layers, with M = Co, Ni and Fe using STM, EXAFS and real time in situ magnetic characterizations (AGFM and PMOKE) with sub-monolayer sensitivity. It will be shown that the latter measurements, performed in the electrolytic environment, yield new information regarding the relationship between the deposition conditions (potential, pH etc.) and the magnetic state of layers. While Co and Fe layers are ferromagnetic at submonolayer coverages, results show that Ni layers become ferromagnetic only after the deposition of 5-6 monolayers. By proper adjustment of the deposition condition, so as to avoid dramatic H-incorporation, ultrathin ferromagnetic Ni layers may however be prepared. The strength of PMA at Co/Au(111) layers will be discussed in details. The second part of the talk will address the deposition of cobalt on epitaxial Au(111) layers on vicinal H-Si(111) surfaces. We are able to prepare ultraflat Au films or Au films consisting in nm-sized dots aligned along the step edges. As a consequence, we may prepare Co/Au/Si films with quite different magnetic properties. For instance, in the case of Au dots in plane anisotropy is obtained and it is possible to vary the coupling between lines of Co dots by changing the Si miscut. These results will be discussed in details at the conference.

4:40pm **MI+TF-WeA9 The Effect of Interlayer Coupling to the Magnetic Phase Transition of Thin Films*, C. Won,*** *Y.Z. Wu,* University of California at Berkeley*; A. Scholl, A. Doran,* Lawrence Berkeley National Laboratory*; N. Kurahashi, H.W. Zhao, Z.Q. Qiu,* University of California at Berkeley

Magnetic phase transition of two-dimensional systems is one of the intensively studied topic in condensed matter physics. One of the basic questions on this subject is how the addition of the interlayer coupling changes the magnetic phase transition. The coupled magnetic sandwiches of Co/Fe/Ni/Cu(100) and Co/Cu/Ni/Cu(100) were investigated by photoemission electron microscopy(PEEM). Element-specific magnetic domain images were taken at room temperature to reveal the critical thickness at which the magnetic phase transition occurs. The phase diagrams with thickness of each magnetic film were constructed under a few selected coupling conditions. The results shows three different types of magnetic phase transitions depending on the relative ferromagnetic film thickness. If the magnetic orders of two magnetic films are similar, both films undergo magnetic phase transition simultaneously. This means the lost of magnetic order of one film can be compensated by the interlayer coupling with the other magnetic film and two magnetic films are highly correlated each other in the interlayer coupling strength. Other two phase-transitions happened when one film is coupled with the other film that is too thin to have magnetism even with the help of coupling or that is ferromagnetic already by its own magnetic order. The difference of the critical thickness for these two cases shows that interlayer coupling increases Curie temperature. The strength and sign of coupling was changed to see how the coupling strength changes this behavior and we found that not the sign but the coupling strength has main role in the phase transition. And Monte-Carlo simulations based on 2 dimensional Ising model were performed to explain this experimental results.

5:00pm **MI+TF-WeA10 Biased Target Ion Beam Deposition of GMR Multilayers***, H.N.G. Wadley,* ***X.W. Zhou****, J.J. Quan, S. Subha,* University of Virginia*; T. Hylton, D. Baldwin,* 4Wave, Inc.

Detailed atomistic simulations have identified the preferred deposition conditions for growing the ideal atomic structures that maximize the performance of giant magneto resistive (GMR) multilayers. They reveal that increasing the velocity (energy) of condensing atoms or assisting ion fluxes flattens interfaces, but promotes atomic interlayer mixing. The maximum magneto resistance is believed to occur for the lowest combination of interfacial roughness and interlayer mixing. Low values of this metric have been predicted to occur using a constant intermediate energy of a few electron volts throughout the growth process. However, the lowest values of the metric have been predicted to occur when a modulation of the energy during deposition of each material layer is used. It is difficult to implement such processes in a conventional PVD or ion beam system. We have developed a biased target ion beam deposition system to overcome these difficulties and report its design and the characteristics of the spintronic devices grown with it.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+SC-ThM

New Spintronic Materials

Moderator: B.T. Jonker, Naval Research Laboratory

8:20am **MI+SC-ThM1 Materials for Spin Injection Into GaN-Based Devices**, ***C.R. Abernathy****, G.T. Thaler, R.M. Frazier, A. Stewart, S.J. Pearton, F. Ren,* University of Florida*; Y.D. Park,* Seoul National University, Korea*; R. Rairigh, J. Kelly,* University of Florida*; J. Lee,* Seoul National University, Korea*; A.F. Hebard,* University of Florida **INVITED**

Future spintronic devices will likely require injection of polarized currents into semiconductor devices. Though significant work has been carried out in GaAs-based materials, the rapid advancement of GaN-based devices for visible light emission and high power electronics makes this an attractive system for investigation. Two types of spin injection layers appear most promising. One approach is to incorporate magnetic ions into the semiconductor. The introduction of Mn into GaN has been shown to produce ferromagnetism at 300K, making it one of the few DMS materials which may be technologically useful. This method may be limited by the relatively low degree of ordering and the possibility of scattering at the DMS/semiconductor interface. An alternative approach is the use of ferromagnetic layers with metallic conduction, such as MnAs. This material has been used to produce polarized injection into GaAs-based structures, though only at low temperature. Though the lattice mismatch to GaN is greater than for GaAs, the MnAs crystal structure possesses the same Group V symmetry as GaN. This may make growth of a good quality MnAs/GaN interface more achievable than for the MnAs/GaAs heterostructure. This talk will discuss the growth and characterization of both of these types of spin injection layers on GaN. Gas-source molecular beam epitaxy using either an RF nitrogen plasma source, for GaMnN, or AsH3, for MnAs, along with elemental sources for Ga and Mn have been used to deposit thin films on MOCVD GaN buffer layers. Conditions for depositing single phase material with optimum magnetic ordering will be described. The processing challenges associated with integrating these materials into standard GaN/AlGaN light emitting diodes (LEDs) will be discussed along with preliminary electroluminescence results from SpinLEDs fabricated using only low temperature processing. This work was supported by the U. S. Army Research Office (ARO-DAAD19-01-1-0701) and NSF (ECS-0224203).

9:00am **MI+SC-ThM3 Characterization of AlGaN and AlN Based Dilute Magnetic Semiconductors**, ***R.M. Frazier***[1]*, G.T. Thaler, J. Stapleton, C.R. Abernathy, S.J. Pearton,* University of Florida*; M.L. Nakarmi, J.Y. Lin, H.X. Jiang,* Kansas State University*; R. Rairigh, J. Kelly, A.F. Hebard,* University of Florida*; J.M. Zavada,* U. S. Army Research Office*; R.G. Wilson,* Consultant

The realization of room temperature ferromagnetism in GaN@footnote 1@ has ignited interest in the development of magnetic devices based on existing wide bandgap technology. However, in order to integrate magnetic semiconductors into the existing technology, it may be necessary to tailor the bandgap through addition of Al. Thus, AlGaN and AlN are two promising candidates for investigation, but optimization of the material in terms of choice of dopant, magnetic characteristics and crystalline quality is necessary before device fabrication can be undertaken. Ion implantation has been shown to be an effective survey method for optimization of dopant type and concentration. In this study, AlGaN and AlN grown on sapphire substrates by Metal Organic Chemical Vapor Deposition have been implanted with Mn, Cr, and Co at high doses (3x10@super 16@ cm@super -2@, 250 keV). After implantation the samples were annealed at 900°C for activation. Photoluminescence of the AlGaN-based alloys showed no band-edge luminescence before or after ion implantation, but the implantation process did introduce deep emission lines. In AlN, the Co and Cr doped films showed hysteresis at 300K while the Mn doped material did not. Epitaxial AlMnN by contrast does show hysteresis at room temperature suggesting that defects may be deleterious to magnetic ordering. The effects of dopant type and host conductivity type on the magnetic and electrical properties after implantation into AlGaMnN will also be presented. The work was supported by the Army Research Office under ARO-DADD19-01-0-0701, ARO-DAAF190110701 and DAAF 19021420 and by NSF under ECS-0224203, DMR 0101856, and DMR 0101438. @FootnoteText@ @footnote 1@ G. T. Thaler, M. E. Overberg, B. Gila, R. Frazier, C.R. Abernathy, S. J. Pearton, J. S. Lee, Y. D. Park, Z. G. Khim, J. Kim, F. Ren, Appl. Phys. Lett. 80, 3964 (2002).

9:20am **MI+SC-ThM4 Growth and Characterization of GaMnN/AlN Multiple Quantum Wells**, ***G.T. Thaler****, R.M. Frazier, J. Stapleton, C.R. Abernathy, S.J. Pearton, R.P. Rairagh, J. Kelly, A.F. Hebard,* University of Florida

Though a number of recent studies have reported room temperature ferromagnetism in GaMnN, some important questions remain including determining the minimum layer thickness needed for ferromagnetic ordering.@footnote 1,2,3@ In this paper, we report on the growth and characterization of a variety of multiple quantum well structures comprised of layers of GaMnN and AlN. XRD analysis of the layers showed sharp satellite peaks indicative of good interfacial quality. By contrast to the GaMnAs system, magnetic ordering was maintained even for structures with 5nm GaMnN layer thicknesses. The magnetic moment of the GaMnN/AlN layers was determined to be ~1.7 Bohr magnetons per Mn, much higher than the 1.1 Bohr magnetons per Mn obtained in 200nm GaMnN films grown under the same conditions. This increase is believed to be due in part to improved crystallinity brought about by the presence of the AlN and also due to strain induced by the smaller lattice constant of the AlN. The use of strained superlattices has been shown to increase the activation of the deep acceptor Mg in p-GaN and p-AlGaN.@footnote 4,5@ It is likely that a similar effect is increasing the concentration of Mn+2 relative to Mn+3, resulting in a higher moment than in the thicker films. Attempts to tailor the strain, and the magnetic properties, by varying the Al content in the buffer and barrier layers will be discussed, as will the potential for using these phenomena to make magnetic strain sensors. This work was supported by the Army Research Office under: ARO-DAAD19-01-1-0701 and by NSF under: ECS-0224203 and DMR 0101856. @FootnoteText@ @footnote 1@ G.T. Thaler, et al. Appl. Phys. Lett. 80, 3964 (2002). @footnote 2@ S. Sonada, et al. J. Cryst. Growth 237-239, 1358 (2002). @footnote 3@M.L. Reed, et al. Appl. Phys. Lett. 79, 3473 (2001). @footnote 4@ Y.-L. Li, et al. Appl. Phys. Lett. 76, 2728 (2000). @footnote 5@P. Kozodoy, et al. Appl. Phys. Lett. 74, 3681 (1999). .

9:40am **MI+SC-ThM5 Theory of Dilute Magnetic Semiconductors**, ***P. Bruno****,* Max Planck Institute of Microstructure Physics, Germany **INVITED**

10:20am **MI+SC-ThM7 Materials Characterization and Magnetic Studies of Epitaxial Co@sub x@Ti@sub 1-x@O@sub 2-x@ Deposited on Si(001) by Molecular Beam Epitaxy**, ***T.C. Kaspar***[2]*,* University of Washington*; T. Droubay,* Pacific Northwest National Laboratory*; A.C. Tuan,* University of Washington*; C.M. Wang, S.A. Chambers, J.W. Rogers, Jr.,* Pacific Northwest National Laboratory

For spintronic devices such as spin-FETs, efficient injection of spin-polarized electrons into a semiconductor material is necessary. Progress has been made using ferromagnetic metals to tunnel spin-polarized electrons into AlGaAs/GaAs quantum well structures. However, for devices compatible with current semiconductor technology, efficient spin injection into Si is desired. Diluted magnetic semiconductors (DMSs) that can be grown epitaxially on Si are prime candidates. The epitaxial growth will result in a high-quality interface, reducing depolarization caused by scattering at interfacial defects. Further, the conductivity of the DMS can be tuned by doping to match that of Si, greatly increasing the spin injection efficiency. While most known DMS materials have Curie points well below room temperature, anatase Co@sub x@Ti@sub 1-x@O@sub 2-x@ has been shown to have a Curie temperature of at least 700K when deposited on LaAlO@sub 3@(001). In addition, anatase is well lattice-matched to Si. To prevent interfacial reactions between the film and substrate resulting in SiO@sub 2@ and/or silicide formation, a buffer layer of epitaxial SrTiO@sub 3@ (STO) is first deposited. In this study, a STO buffer layer and Co@sub x@Ti@sub 1-x@O@sub 2-x@ film on Si(001) are deposited by molecular beam epitaxy (MBE), which has been shown previously to result in higher quality Co@sub x@Ti@sub 1-x@O@sub 2-x@ films than pulsed laser deposition (PLD). Magnetic films have been successfully deposited with Co in the +2 charge state. The growth mode of Co@sub x@Ti@sub 1-x@O@sub 2-x@ has been investigated to minimize the formation of Co-rich anatase particles on the film surface. Thorough materials characterization of the Si interface, the STO buffer layer, and the Co@sub x@Ti@sub 1-x@O@sub 2-x@ film will be presented, paying particular attention to the possibility of metallic Co atoms in the film. In addition, the electronic and magnetic properties of the structure will be presented.

[1] **Falicov Student Award Finalist**

[2] **Falicov Student Award Finalist**

10:40am **MI+SC-ThM8 Ferromagnetic Co-doped Anatase TiO@sub 2@: Are All Growth Methods Created Equal?**, ***T. Droubay***, *S.M. Heald,* Pacific Northwest National Laboratory*; T.C. Kaspar,* University of Washington*; C.M. Wang, S.A. Chambers,* Pacific Northwest National Laboratory

With both theoretical and experimental underpinnings, a flurry of activity has centered around new candidate diluted magnetic semiconductors (DMS) based on doping semiconducting oxides with magnetic impurities. With a Curie point of ~700K, high remanence, and high saturation, Co-doped TiO@sub 2@ in the Anatase form stands out as the most magnetically robust oxide DMS. Following the initial discovery in 2001, several groups have explored the synthesis and properties of Co-doped anatase using an array of different growth methods. While most of these techniques produced materials exhibiting room temperature ferromagnetic behavior, the resounding message learned has been to accurately determine if minority phases are present. Thin film growth of this novel oxide material has been dominated by pulsed laser deposition (PLD) and oxygen plasma-assisted molecular beam epitaxy (OPA-MBE) on SrTiO@sub 3@(001) and LaAlO@sub 3@(001). We have consistently produced epitaxial materials by OPAMBE in which the saturation moment is consistently found to be ~1.1 - 1.3 µ@sub B@/Co at room temperature. In contrast, Co@sub x@Ti@sub 1-x@O@sub 2@ grown by PLD typically has a saturation magnetization at room temperature of 0.3 µ@sub B@/Co. We will discuss the similarities and differences between materials produced by these two techniques highlighting morphological, electrical and magnetic properties. We will also discuss our recent post-growth annealing study of MBE grown specimens in which the magnetic properties do not change when the films are annealed in vacuum at 825K. This is particularly interesting in light of recent seemingly contradictory results of annealed PLD grown films. Shinde et al. report that Co metal inclusions in an Anatase film can be dissolved within the matrix and substituted for Ti as a result of a 1200K anneal in 1atm. argon. In contrast, Kim et al. found that Co came out of solution and formed Co metal as a result of a 700K anneal in 10@sup -6@ torr O@sub 2@.

11:00am **MI+SC-ThM9 Ferromagnetism in Optically Transparent Semiconducting Co Doped SnO@sub 2-d@ Films**, ***R.J. Choudhary***[1], *S.B. Ogale, S.R. Shinde,* Univ. of Maryland*; J.P. Buban,* Univ. of Illinois at Chicago*; S.E. Lofland,* Rowan Univ.*; S.N. Kale, V.N. Kulkarni, J. Higgins,* Univ. of Maryland*; C. Lanci,* Rowan Univ.*; J.R. Simpson,* Univ. of Maryland*; N.D. Browning,* Univ. of Illinois at Chicago*; S. Das Sarma, D. Drew, R.L. Greene, T. Venkatesan,* Univ. of Maryland

Thin films of Co doped SnO@sub 2-d@ grown by pulsed laser deposition on single crystal sapphire substrates are examined for their magnetic, structural, electrical, magnetotransport and optical properties. The films exhibit room temperature ferromagnetism with a Curie temperature close to 650 K. In addition, the films with 5 % of Co doping exhibit a giant magnetic moment of 7.5 ± 0.5 µ@sub B@/Co. The films are highly transparent even at 27 % of Co doping. The optical bandgap shows a redshift with Co doping. Ion channeling data show a fair degree of channeling for Sn but no channeling for Co, implying Co atoms to be structurally incoherent. However, no clustering of Co can be observed in high-resolution transmission electron microscopy even up to 27 % of Co doping. The electrical resistivity shows a rapid increase with Co doping. Possible scenarios about the microscopic state of this system and the origin of ferromagnetism will be discussed.

11:20am **MI+SC-ThM10 Elaboration and Characterisation of Cobalt Doped ZnO Thin Films for Spintronic Applications**, ***A. Anane***, *K. Rode, J.L. Maurice, J.P. Contour,* UMP CNRS-Thales and Paris XI University, France

ZnO is a large gap II-VI semiconductor potentially interesting for UV opto-electronic applications. We have investigated the structural and the magnetic properties of cobalt substituted ZnO thin films deposited on sapphire (0001) substrates by pulsed laser deposition. The films show clear ferromagnetic behavior up to 400K, the saturation moment does not exceed 1.3 ÂµB / Co atom which far away from is expected for the ionic Co2+ (3d7). We have ruled out parasitic phases as the origin of the measured magnetism by many experimental techniques, including High resolution transmission electron microscopy, X-ray edge spectroscopy and X-ray magnetic-circular-dichroism. Preliminary transport measurements on magnetic tunnel junctions based on Zn0.75Co0.25O will be presented.

11:40am **MI+SC-ThM11 Ferromagnetism in Cobalt Doped La@sub 0.5@Sr@sub 0.5@TiO@sub 3-d@ Films**, ***S.R. Shinde***, *S.B. Ogale, Y.G. Zhao, J. Higgins, R.J. Choudhary,* University of Maryland*; S.E. Lofland, C. Lanci,* Rowan University*; J.P. Buban, N.D. Browning,* University of Illinois at Chicago*; S. Das Sarma,* University of Maryland*; A.J. Millis,* Columbia University*; V.N. Kulkarni, R.L. Greene, T. Venkatesan,* University of Maryland

Epitaxial films of lightly cobalt doped La@sub 0.5@Sr@sub 0.5@TiO@sub 3-d@ are shown to exhibit ferromagnetism at room temperature. A clear hysteresis loop with coercevity ~150 Oe and the Curie temperature around 450 K are observed for these (001) oriented films grown by pulsed laser deposition at oxygen pressure of 10@super -4@ Torr on LaAlO@sub 3@ substrates. For cobalt doping up to ~2%, no inhomogeneity is observed by scanning transmission electron microscopy (S-TEM). The magnetization is found to change non-monotonically (in the range 1-3 µ@sub B@/Co) as a function of conductivity in films deposited at different partial pressures. The films range from being opaque metallic to transparent semiconducting depending on the oxygen pressure during growth and are yet ferromagnetic at and above room temperature.

[1] **Falicov Student Award Finalist**

Magnetic Interfaces and Nanostructures
Room 316 - Session MI-ThA

Magnetization Dynamics

Moderator: W.H. Rippard, National Institute of Standards and Technology

2:00pm **MI-ThA1 Ultrafast MOKE Study of Magnetization Dynamics in Exchange-Biased FeMn/Co and IrMn/Co Thin Films*, K. Seu*,** *H. Huang, A.C. Reilly,* College of William and Mary*; W.F. Egelhoff, L Gan,* National Institute of Standards and Technology

We have observed coherent magnetization rotation in exchange-biased Co systems by ultrafast laser pump-probe magnetooptical Kerr effect (MOKE). This technique, first introduced by Ju et al. in the study of NiO/NiFe, uses ultrafast photoexcitation to spontaneously decouple the antiferromagnetic/ferromagnetic system.@footnote 1@ The magnetization undergoes coherent precession as described by the Landau-Lifshitz-Gilbert equations of motion.@footnote 1@ Such ultrafast measurements provide opportunity to study the ultimate time scale for these processes as well as determination of fundamental parameters such as anisotropy and damping.@footnote 2@ This is in analogy with FMR, but with the benefit of direct access to the time domain, sub-micron spatial resolution and straightforward in-situ application. Co exchange-biased systems such as FeMn/Co and IrMn/Co, besides being technologically important, offer an interesting comparison to the NiFe systems. It has been observed that magnetization reversal takes place via more complicated processes in Co, involving nucleation of many small domains.@footnote 3@ Also, recent FMR experiments suggest that the damping in IrMn/Co films is not strongly dependent on exchange bias field strength, unlike the NiO/NiFe system.@footnote 4@ We will present measurements of anisotropy and damping parameters in FeMn/Co and IrMn/Co as a function of Co thickness and exchange bias field strength. These will be used to further explore the nature of exchange biasing in these systems as well as investigate the wider applicability of ultrafast optical techniques. @FootnoteText@ @footnote 1@Ganping Ju et al., Phys Rev Lett 82, 3705 (1999), Phys Rev. B., 62, 1171 (2000)@footnote 2@ M. van Kampen et al., Phys. Rev. Lett. 88, 227201 (2002)@footnote 3@ Chan-Gyu Lee et al., J. Appl. Phys. 91, 8566 (2002)@footnote 4@ R.D. McMichael et al., J. Appl. Phys. 83, 7037 (1998).

2:40pm **MI-ThA3 Spatial and Temporal Control of Magnetization Dynamics in Lithographic Elements and Nanocrystalline Composites*, M.R. Freeman*,** *M. Belov, K. Buchanan, A. Krichevsky, A. Meldrum,* University of Alberta, Canada **INVITED**

Time-resolved optical microscopy is a versatile tool for investigations of dynamic phenomena in magnetic thin films, including resonance, reversal, and relaxation.@footnote 1@ Broadband pulsed ferromagnetic resonance studies of square NiFe elements were performed to investigate the control of modal oscillations in inhomogeneously magnetized structures. The spatiotemporal evolution of the magnetization, as excited by a small out-of-plane transient magnetic field, was imaged in the presence of a weak in-plane static bias. In a uniform platelet the spatial response is governed by the nonuniform static magnetization distribution associated with closure domains across the bias field direction. A circular pinhole was patterned in the center of a square platelet to show that the spatial pattern of FMR response also sensitively depends on weak variations of the static magnetization. Comparison to numerical modeling confirms that the experimental observation of spatially-nonuniform damping is a result of the evolution of energy into shorter wavelength modes. The magnetic switching behavior of mesoscopic structures continues to arouse interest for technological applications. Magnetization reversal of mesoscopic structures driven in a crossed-excitation wire (prototype MRAM) geometry will be described. The magnetic and magneto-optical properties of nanocomposite materials created using ion implantation and subsequent thermal processing are also being investigated. Implanting iron ions into a SiO2 host results in a collection of randomly oriented crystalline Fe nanoparticles, the magnetic and microstructual properties of which depend on both the implantation and annealing conditions. Iron implanted SiO2 samples subject to a particular treatment exhibit large Faraday rotation and an extremely fast and tunable response to out-of-plane excitation. @FootnoteText@ @footnote 1@ B.C. Choi, A. Krichevsky, and M.R. Freeman, to be published in Proceedings of the IEEE, June 2003.

3:20pm **MI-ThA5 Real-Time Imaging of Spin Dynamics in Magnetic Vortex Structures*, J.P. Park*,** *P. Eames, D.M. Engebretson, P.A. Crowell,* University of Minnesota **INVITED**

Patterned nanometer-scale magnetic structures have been proposed as media for high-density data storage. A prerequisite for implementing such a technology will be an understanding of the fundamental characteristics of magnetic nanostructures, including switching times, damping constants, and the spatial distribution of collective modes. We use time-resolved Kerr microscopy to study the spin dynamics of individual ferromagnetic disks with thicknesses of 50 nm and aspect ratios @beta@= L/R ~ 0.1 - 0.5, where L is the thickness and R the radius.@footnote 1@ The equilibrium state of each disk in zero field is a vortex with a singularity at the center. As the field is reduced from saturation, the vortex nucleates at one edge of the disk, and it moves across the diameter until it is annihilated at the opposite edge in negative fields. We observe three distinct excitations of this vortex state, in contrast to the simple uniform precession observed in the saturated state. The lowest mode corresponds to the gyrotropic motion of the entire vortex around its equilibrium position.@footnote 2@ The exact nature of the higher modes is being explored through a combination of spatially-resolved spectroscopy and micromagnetic simulations. The frequencies of all three vortex modes are nearly independent of the value of the applied field and hence the position of the vortex inside the disk. This work was supported by NSF DMR 99-83777, the Research Corporation, the Alfred P. Sloan Foundation, the University of Minnesota MRSEC (DMR 02-12032), and the Minnesota Supercomputing Institute. @FootnoteText@ @footnote 1@J. P. Park, P. Eames, D. M. Engebretson, J. Berezovsky, and P. A. Crowell, Phys. Rev. B 67, 020403R (2003). @footnote 2@K. Yu. Guslienko et. al., J. Appl. Phys. 91, 8037 (2002). .

4:00pm **MI-ThA7 High-Frequency Noise and Thermal Fluctuations in GMR Devices*, S.E. Russek*,** National Institute of Standards and Technology

High-frequency (1 GHz to 8 GHz) magnetic noise has been measured in giant magnetoresistive (GMR) devices with dimensions down to 100 nm. Both commercial recording heads and GMR devices fabricated within microwave circuit structures were measured. The uniform ferromagnetic resonance mode has been measured as a function of applied field, bias current, and temperature. In addition to the uniform mode, other modes have been observed that are due to micromagnetic structure in the devices. The presence of these modes can be correlated with Barkhausen noise in the magnetoresistance data. The data have been fit with simple models based on the fluctuation-dissipation theorem and with numerical models that incorporate more complex dissipation processes.

4:20pm **MI-ThA8 Weak Spin Pumping and Inhomogeneity in Cr/NiFe/Cr Trilayers*, R.D. McMichael*,** *A.J. Shapiro, A.P. Chen, W.F. Egelhoff,* National Institute of Standards and Technology

Ferromagnetic resonance linewidth measurements on 10 nm Cr/5 nm Ni@sub 80@Fe@sub 20@/10 nm Cr trilayers show that Cr does not contribute significantly to the damping properties of NiFe. In contrast, measurements in Pt/NiFe/Pt and Pd/NiFe/Pd trilayers have demonstrated strong "spin pumping" enhancements due to the normal metal layers.@footnote 1@ The experiments described here were designed to determine whether similar spin-pump damping effects were likely in CoCr recording media due to the presence of Cr in grain boundaries. We found that the linewidth in Cr/NiFe/Cr trilayers was large relative to Cu/NiFe/Cu trilayers. To discern the origins of the enhanced line width, Cu spacer layers were included between the NiFe layer and either the bottom or top Cr layer and an analysis of the angular dependence of the line width was performed. The results show that the linewidth increase is associated with inhomogeneity at the bottom Cr/NiFe interface. The inhomogenitey at this interface may be a reflection of the growth beginning as bcc-NiFe on bcc-Cr and converting to fcc-NiFe. Growth of Cr on NiFe had an insignificant effect on the linewidth of the NiFe. These conclusions were confirmed by MOIF imaging of the magnetization reversal, which showed nucleation and growth of reversed domains in NiFe on Cr, but which showed low coercivity motion of a single domain wall sweeping out the entire area when the NiFe was deposited on Cu, whether the cap layer was Cu or Cr. @FootnoteText@ @footnote 1@ S. Mizukami, Y. Ando and T. Miyazaki, Jpn. J. Appl. Phys., v. 40, pp. 580-585 (2001).

4:40pm **MI-ThA9 Tunnel Barrier Materials Development for Magnetometer based Josephson Qubits***, **D.P. Pappas**, R. McDermott, D.A. Hte, R.W. Simmonds, K.M. Lang, J.M. Martinis,* National Institute of Standards and Technology

Although Josephson-junction qubits show great promise for quantum computing, the origin of dominant decoherence mechanisms remains unknown. We report Rabi oscillations for a phase qubit, and show that their "coherence amplitude" is significantly degraded by spurious microwave resonances. These resonances appear to arise from changes in the junction critical current, produced by fluctuations in the position of electrons or atoms within the tunnel barrier. We argue this mechanism is a dominant source of decoherence in all present Josephson qubits, and improvements will require materials research directed at the tunnel barriers to remove these spurious resonances. In order to test the influence of the junctions on the cohereance amplitude we have developed tunnel junctions fabricated from both Al/AlO/AL and Al/AlN/Al trilayer structures.

Magnetic Interfaces and Nanostructures
Room 316 - Session MI+SC-FrM

Semiconductor Spin Injection

Moderator: S.A. Chambers, Pacific Northwest National Laboratory

8:20am **MI+SC-FrM1 Ferromagnetic Nano Fe-Germenide Particles in MBE-grown Ge-Fe***, **R. Goswami**,* Geo-Centers Inc.*; G. Kioseoglou, A.T. Hanbicki, B.T. Jonker, G. Spanos,* Naval Research Laboratory

Ferromagnetic-semiconductors (FMSs) have attracted considerable attention due to the coexistence of semiconductor properties and long-range ferromagnetic (FM) order in these materials. Recently, ferromagnetic order was reported in alloy thin films based on Ge, which provides a simple host lattice to explore the fundamental origins of FM order. A relatively high Curie temperature,120 K, has been experimentally observed in a Ge-3.3at.% Mn film grown epitaxially on GaAs. It has been theoretically predicted very recently that Ge with Fe atoms in the lattice will be ferromagnetic semiconductors and the Curie temperature will increase as a function of Fe concentration. To date, relatively little attention has been paid to understanding the fine scale microstructural evolution within Ge-Fe thin films. It is well known that the microstructure plays a vital role in dictating the ferromagnetic properties. Fe-Ge contains different phases with magnetic properties ranging from ferromagnetic Fe to antiferromagnetic FeGe@sub2@. The purpose of the present investigation is to elucidate the phase transformations and overall microstructural evolution in epitaxial Ge- 4at.% Fe thin films deposited on (100) GaAs substrates at three different temperatures, 150°, 250° 400 ° C, in order to better understand magnetic properties in these materials. The equilibrium phases at this composition (4%Fe) are Ge with negligible amount of Fe and antiferromagnetic FeGe@sub2@. We have observed for all cases that nano-particles of ferromagnetic- Fe@sub3@ Ge@sub2@ form uniformly in a crystalline Ge-matrix. The particle size was observed to decrease with the substrate temperature. We demonstrate that a supersaturated Ge-Fe solid-solution forms initially from the vapor phase resulting in the solid state precipitation of this metastable ferromagnetic- germanide. This work was supported by the Office of Naval Research and DARPA.

8:40am **MI+SC-FrM2 Epitaxial Ferromagnet on Ge(111)***, **C. Zeng**,* The University of Tennessee*; J.R. Thompson,* The University of Tennessee and Oak Ridge National Laboratory*; L.C. Feldman,* Vanderbilt University and Oak Ridge National Laboratory*; S.C. Erwin,* Naval Research Laboratory*; H.H. Weitering,* The University of Tennessee and Oak Ridge National Laboratory

The difficulty of injecting spin-polarized electrons into a semiconductor is a major bottleneck in spintronics research. There are two ways to realize spin injection. One of these is to fabricate a ferromagnetic-metal/semiconductor heterostructure; the other is to use a dilute magnetic semiconductor (DMS) as the spin aligner. The former method does not work well, mainly because of the large conductivity mismatch between the ferromagnetic metal and semiconductor. The latter method is limited by the low Curie temperature, T@sub c@ of DMS. We have developed a novel interface with good potential for spin injection, namely an epitaxial ferromagnetic Mn@sub 5@Ge@sub 3@ film on Ge(111). The Mn@sub 5@Ge@sub 3@ films are fabricated by depositing Mn and subsequent annealing, or by codeposition of Mn and Ge. Mn@sub 5@Ge@sub 3@(001)//Ge(111) epitaxy relationship is verified by X-ray diffraction results, due to the small lattice mismatch. STM images display (@sr@3x@sr@3)R30° honeycomb structure, which perfectly agrees with the theoretical image of the Mn terminated Mn@sub 5@Ge@sub 3@ (001) surface. RBS and ion-channeling experiments confirmed the stoichiometry and epitaxy of the film. Magnetic measurements reveal a T@sub c@ of about 295 K. The easy axis is in-plane which is most likely due to the shape anisotropy. The multiplet splitting of the Mn 3s core level in XPS indicates an average magnetic moment of 2.6 µ@sub B@ per Mn atom, which is in almost perfect agreement with the spin-resolved band structure calculations and SQUID measurements. This research was sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

9:00am **MI+SC-FrM3 Tunnel Spin Injection from a Ferromagnetic Metal into a Semiconductor Heterostructure***, **A.T. Hanbicki**, O.M.J. van 't Erve, R. Magno, G. Kioseoglou, C.H. Li, R.M. Stroud, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY at Buffalo **INVITED**

Significant effort has been made to incorporate ferromagnetic metals into semiconductor spintronic devices because they offer high Curie temperatures, low coercive fields, and a ready source of spin polarized electrons. Recently it has been shown that the key to efficient spin injection from a metal into a semiconductor heterostructure is a sufficient interface resistance.@footnote 1@ Tunnel barriers have been a common way of satisfying this criterion, and there are a number of recent experimental successes with Schottky contacts, thin metal oxides, and AlAs. We will review the state of the art of spin injection from an Fe Schottky contact into an AlGaAs/GaAs spin-LED. A Schottky barrier at the Fe/AlGaAs interface can serve as an effective tunnel contact if the doping profile of the semiconductor near the interface is engineered to produce a narrow depletion width. In this system, we have successfully injected polarized electrons and obtained electron spin polarizations ranging from 13% to 32% in the GaAs QW,@footnote 2@ where quantum selection rules directly link the measured circular polarization and the electron spin population. We report here recent efforts to characterize transport properties and the physical structure of this interface, and correlate them with the measured spin polarizations. To determine the dominant transport mechanism, we have analyzed the transport process using the Rowell criteria. The parabolic G-V curves and the temperature dependence of the zero-bias resistance demonstrate that single step tunneling is the dominant transport mechanism. The I-V data show a clear zero-bias anomaly and phonon signatures providing further evidence for tunneling. Preliminary data suggest that roughness and Fe segregation at the spin injecting interface suppresses spin injection. @FootnoteText@ This work was supported by the DARPA SpinS program and ONR@footnote 1@E.I. Rashba, PRB 62 (2000)@footnote 2@A.T. Hanbicki, et al., APL 80 (2002); APL 82 (2003).

9:40am **MI+SC-FrM5 Spin Injection Across (110) Interfaces: Fe/GaAs(110) Quantum Well Spin-LEDs***, **C.H. Li**, A.T. Hanbicki, G. Kioseoglou, O.M.J. van 't Erve, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Spin-LEDs can be used to reliably measure spin injection efficiency via the quantum selection rules subject to the limits imposed by the ratio of spin to radiative lifetimes. However, to date they have been implemented only in (001) oriented GaAs or InGaAs quantum wells (QWs), where the spin lifetime is shorter, resulting in an underestimate of spin injection efficiency. Recent work has shown that the spin lifetime is longer in (110) GaAs QWs, and increases with temperature.@footnote 1@ In this study we investigate spin injection in (110) oriented spin-LED QW structures to take advantage of this, and to explore the effects of band structure and the non-polar interface on spin injection. AlGaAs/GaAs LEDs have been grown on (110) substrates by molecular beam epitaxy at 450 oC and an As/Ga flux ratio of 20. Atomic force microscopy shows excellent surface morphology with a RMS roughness less than 0.5 nm. Photoluminescence is dominated by the QW excitonic emission with a linewidth of 8 meV. Initial electroluminescence results using a tailored Fe Schottky tunnel barrier injector show that a 10% spin polarization in the GaAs QW has been achieved due to injection across the Fe/AlGaAs(110) interface. The temperature dependence of the polarization, as well as comparison with (001) oriented samples and first principles theory will be presented. @FootnoteText@ Supported by DARPA, ONR, and NSF. @FootnoteText@@footnote 1@Y. Ohno et. al., PRL 83, 4196 (1999).

10:00am **MI+SC-FrM6 Electrical Spin Injection from Ferromagnetic Metal/Tunnel Barrier Injectors into AlGaAs/GaAs Quantum Well Structures***, **X. Jiang**,* Stanford University*; R. Shelby,* IBM Almaden Research Center*; R. Wang,* Stanford University*; R. Macfarlane,* IBM Almaden Research Center*; G. Solomon, J. Harris,* Stanford University*; S. Parkin,* IBM Almaden Research Center

Electrical injection of highly spin-polarized electrons into semiconductors is an essential component for the operation of spintronic devices. In this talk, we present a study of electrical spin injection into semiconductors from injectors comprised of ferromagnetic metals and tunnel barriers. An AlGaAs/GaAs quantum well structure is used to optically detect the spin-polarization of the injected electrons in the semiconductor. Large polarization of the electroluminescence from the quantum well is observed. The bias dependence and temperature dependence of the electroluminescence polarization will be discussed. This work is supported by DARPA.

10:20am **MI+SC-FrM7 Efficient Electrical Spin Injection in GaAs: A Comparison Between Different Spin Sources*, P. Van Dorpe*, *V.F. Motsnyi, Z. Liu, W. Van Roy, G. Borghs, J. De Boeck,* IMEC, Belgium **INVITED**

Electrical spin injection in semiconductors remained elusive for a long time. Recently however, break-throughs have been accomplished in the field. It appeared that tunnel injection of spin polarized electrons from ferromagnetic metals provides an efficient way for spin injection, even at room temperature. We will quantitatively compare different spin sources for spin injection in GaAs, based on tunnel injection from ferromagnetic materials. The injected spin polarization is assessed in a (Al,Ga)As-based spin-LED, using the Oblique Hanle Effect@footnote 1@ as the analysis technique. The first material combination that we successfully applied for spin injection is a CoFe/AlOx based tunnel injector where the AlOx provides a stable tunnel barrier between the ferromagnetic material and the GaAs. We have shown injected spin polarizations which exceed 24% at 80K and 12% at room temperature.@footnote 2@ A second spin source we examined uses the native Schottky barrier between GaAs and an epitaxially grown ferromagnetic metal as tunnel barrier. NiMnSb, MnAs and MnSb have been used and will be compared for their spin injection properties. Finally the results of electron spin injection from a (Ga,Mn)As-based Zener diode will be discussed. The spin polarized holes in (Ga,Mn)As are transferred to electrons in GaAs by Zener tunnelling and create a spin polarization in GaAs of at least 50% at LHe temperature. The results on electrical spin injection regularly show an interesting dependence on the applied bias. This dependence will be shown and discussed in terms of doping and band structure. @FootnoteText@@footnote 1@V.F. Motsnyi et al, Appl. Phys. Lett. 81, 265 (2002) @footnote 2@P. Van Dorpe et al, Jpn. J. Appl. Phys., Part 2 42, L502 (2003) Acknowledgements : SPINOSA (IST-2001-33334), FENIKS(GR5D-CT-2001-00535).

11:00am **MI+SC-FrM9 Electrical Spin Injection from a Ferromagnetic Metal Into a Semiconductor: Schottky vs Al@sub 2@O@sub 3@ Tunnel Barriers*, O.M.J. van 't Erve*, *A.T. Hanbicki, C.H. Li, G. Kioseoglou, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Efficient injection of spin-polarized electrons from a metal into a semiconductor requires a high resistance interface contact such as a tunnel barrier.@footnote 1@ The natural Schottky tunnel barrier which forms at the Fe/AlGaAs interface provides highly efficient spin injection, and a polarization of more than 32% has been measured in a GaAs quantum well detector.@footnote 2@ The pseudo-triangular shape and high interface doping level of the Schottky tunnel contact are factors which are quite different from those encountered for the canonical rectangular barrier typically formed from Al@sub 2@O@sub 3@. It is therefore of interest to compare the characteristics and performance of an Al@sub 2@O@sub 3@ tunnel barrier with the Fe/AlGaAs Schottky barrier in essentially identical MBE-grown device structures. The Al@sub 2@O@sub 3@ barrier is formed on top of an AlGaAs/GaAs spin-polarized light-emitting diode (spin-LED) by multi-step in situ natural oxidation of thin evaporated Al layers. A ferromagnetic metal layer is evaporated on top of this tunnel barrier and provides the spin-polarization of the injected electrons. We measure the spectral features, intensities and polarization of the electroluminescence from the surface emitting spin-LEDs, and compare these directly with similar data for the Fe Schottky contact and with literature to obtain insight into various aspects of the spin injection process. @FootnoteText@ This work was supported by the DARPA SpinS program, ONR, and NSF. @footnote 1@ E. I. Rashba, Phys. Rev. B 62, R16267 (2000).@footnote 2@ A.T. Hanbicki et al, Appl. Phys. Lett. 82 (9 June 2003).

11:20am **MI+SC-FrM10 Electrical Spin Injection from CdCr@sub 2@Se@sub 4@ into AlGaAs/GaAs Spin-LED*, G. Kioseoglou*, *A.T. Hanbicki, C.H. Li, O.M.J. van 't Erve, R. Goswami, G. Spanos, B.T. Jonker,* Naval Research Laboratory*; R. Mallory, M. Yasar, G. Itskos, A. Petrou,* SUNY at Buffalo

Ferromagnetic semiconductors (FMS) provide an opportunity to control spin dependent behavior and study spin injection and transport in semiconductor heterostructures. Much of the effort has focused on III-Mn-V p-type FMS, where the ferromagnetism is mediated by holes. Since electron transport is the basis for high frequency and low power operation, an n-type FMS grown epitaxially on a device quality substrate is especially attractive. Recent work demonstrated epitaxial growth of n-type CdCr@sub 2@Se@sub 4@, a chalcogenide spinel FMS, on GaAs(001) and GaP(001).@footnote 1@ The measured conduction band offsets indicate a staggered band alignment conducive to electron transport from the CdCr@sub 2@Se@sub 4@ into the AlGaAs.@footnote 2@ We present here spin polarized electron injection from CdCr@sub 2@Se@sub 4@ into an AlGaAs/GaAs LED structure. The circular polarization due to spin injection from the CdCr@sub 2@Se@sub 4@ reaches a maximum value of 6% at B = 0.5T, and mimics the hard axis magnetization determined by SQUID magnetometry measurements. In contrast to previously studied ZnMnSe and Fe contacts in which injection of predominantly m@sub j@ = -1/2 electrons was observed, for CdCr@sub 2@Se@sub 4@ the majority of the injected electrons are in the m@sub j@ = +1/2 state. TEM reveals that the existing interfaces are highly defected, a factor known to limit spin injection.@footnote 3@ Efforts to increase the spin injection efficiency are focused on improving the interface, the contact resistance and electrical properties of CdCr@sub 2@Se@sub 4@. Ga, an n-type dopant in CdCr@sub 2@Se@sub 4@, was introduced in a @delta@-doping configuration, and results on new LED structures with improved electrical characteristics and interface morphology will be presented. @FootnoteText@ This work was supported by DARPA SpinS program, ONR, and NSF. @footnote 1@Y.D. Park et al., Appl. Phys. Lett. 81, 1471 (2002). @footnote 2@H.B. Zhao et al, Appl. Phys. Lett. 82, 1422 (2003). @footnote 3@R. Stroud et al, Phys. Rev. Lett. 89, 166602 (2002).

11:40am **MI+SC-FrM11 Chemical Intermixing and Spin Injection in Fe/AlGaAs Schottky Barrier SpinLEDs*, R.M. Stroud*, *A.T. Hanbicki, G. Kioseoglou, O.M.J. van Erve, C.H. Li, B.T. Jonker,* Naval Research Laboratory*; G. Itskos, R. Mallory, M. Yasar, A. Petrou,* SUNY Buffalo

Injected spin polarizations ranging from 13% to 32% have been measured for Fe/AlGaAs Schottky barrier spin-polarized light emitting diodes spinLEDs.@footnote 1@ Transmission electron microscopy studies of these devices show evidence for diffusion of the Fe into the underlying AlGaAs. High-resolution images indicate an expansion of the AlGaAs (100) plane spacing near the interface by up to 15% and a change in contrast. The Fe diffusion is confirmed by energy-dispersive x-ray spectroscopy and Z-contrast imaging. The thickness of the intermixing region estimated from lattice images inversely correlates with the injected spin polarization, ranging from 0.8 nm +/- 0.3 nm for the 32% spin polarization sample up to 1.6 nm +/- 0.3 nm for the 13% spin polarization sample. Spin scattering in this intermixing region may explain the reduction in the injected spin polarization. This work was supported by ONR and the DARPA SpinS program. @FootnoteText@ @footnote 1@Hanbicki, et al., APL 80 (7): 1240-1242 (2002).

Author Index

Bold page numbers indicate presenter

Author Index