Semiconductors
Room 304B - Session SC+MI-MoM

Dilute Magnetic and Ferromagnetic Semiconductors
Moderator: C.J. Palmström, University of Minnesota

8:20am **SC+MI-MoM1 Heterointerfaces and Magnetism in Ferromagnetic Semiconductor Heterostructures**, ***N. Samarth,*** Pennsylvania State University **INVITED**

We discuss recent experiments that demonstrate how heterointerfaces impact the magnetic properties of heterostructures derived from the "canonical" ferromagnetic semiconductor (Ga,Mn)As. In this material, holes created by the Mn acceptors mediate a ferromagnetic interaction between the Mn ions themselves, and the Curie temperature is determined by a complex interplay between substitutional magnetic ions, interstitial defects and holes. Although as grown epilayers of (Ga,Mn)As typically have Curie temperatures lower than 110 K, post-growth annealing at low temperatures (180 C - 250 C) significantly enhances the ferromagnetic properties, leading to Curie temperatures above 150 K. The first set of experiments examines the effects of capping ferromagnetic Ga1-xMnxAs epilayers with a thin layer of undoped GaAs. We find that the overgrowth of even a few monolayers of GaAs significantly suppresses the enhancement of the ferromagnetism associated with low temperature annealing, suggesting that heterointerfaces have a direct impact on the migration of interstitial defects during post-growth annealing. In the next set of experiments, we demonstrate the first exchange biasing of (Ga,Mn)As by an overgrown antiferromagnet (MnO). Although the exchange bias effect is unambiguous when successful, we also find that the high reactivity between Mn and GaAs affects the ferromagnet/antiferromagnet heterointerface, presenting interesting experimental challenges for the routine achievement of exchange bias in this important spintronic material. This work was carried out in collaboration with K. C. Ku, M. B. Stone, K. F. Eid, P. Schiffer, T. Shih, and C. Palmstrom. Supported by ONR and DARPA.

9:00am **SC+MI-MoM3 Structural and Magnetic Properties of a Magnetic Semiconductor MnGeN@sub2@ Grown by MBE**, *S.H. Cheung, M.L. Harland, V.K. Lazarov,* University of Wisconsin, Milwaukee*; Y. Zhang,* Peking University, China*; M. Weinert, M. Gajdardziska-Josifovska,* University of Wisconsin, Milwaukee*; Z. Gai,* Peking University, China*;* ***L. Li,*** University of Wisconsin, Milwaukee

A novel magnetic semiconductor MnGeN@sub2@ was synthesized on 6H-SiC(0001), Al@sub2@O@sub3@(0001), and MgO(111) substrates by plasma assisted molecular beam epitaxy. In situ reflection high-energy diffraction, ex situ atomic force microscopy and transmission electron microscopy (TEM) investigations indicate that the films grown are epitaxial on all three substrates, with the ones on MgO having the best overall quality. Detailed analysis of high-resolution TEM digital diffractograms and convergent beam electron diffraction patterns of the films show that the MnGeN@sub2@ is orthorhombic, and has the following crystallographic orientation relationships with the substrate: MnGeN@sub2@(001)//MgO(111), MnGeN@sub2@(100)//MgO(11-1), and MnGeN@sub2@(210)//MgO(01-1). Investigations by SQUID magnetometry indicate that the magnetic properties of the films can be controlled by the stoichiometry, i.e. Mn/Ge ratio, varying from paramagnetic to ferromagnetic, with the ferromagnetic samples exhibiting a Curie temperature above 300 K.

9:20am **SC+MI-MoM4 Thermal Stability of GaCrN Epitaxial Layers**, ***G.T. Thaler,*** *R.M. Frazier, C.R. Abernathy, S.J. Pearton,* University of Florida

A number of recent studies have reported the observation of room temperature ferromagnetism in GaMnN. However, this material appears to be thermally unstable during processing at temperatures as low as 500°C unless co-doped with oxygen. For the development of spintronics devices based on GaN, thermal annealing at or above ~700°C is necessary to improve contact resistances and for p-dopant activation. An alternative material that has received some interest of late is GaCrN, which has also been reported to be ferromagnetic at room temperature. However, little is known as yet about the thermal stability of this material and its suitability for integration with GaN device processing technology. In this talk we will discuss the thermal stability of GaCrN and the effect of Cr concentration on both the as-grown magnetic behavior and the magnetic properties as a function of annealing. Epitaxial growth was performed using Gas Source Molecular Beam Epitaxy. Films with magnetic transition temperatures above room temperature were produced for a variety of Cr concentrations, though the signal appeared to maximize around 2-3% Cr, as is the case for GaMnN. Unlike GaMnN, the addition of Cr to GaN produced material that was thermally stable after annealing up to 700°C with little change observed in the magnetic behavior of the GaCrN films. The implications of this stability for device processing and performance will also be discussed. This work was supported by the Army Research office under: ARO-DAAD19-01-1-0701 and by NSF under: ECS-0224203.

9:40am **SC+MI-MoM5 Structural Characterization of GaMnN Thin Films Grown by Chemical Beam Epitaxy (CBE).**, ***L.A. Carreno,*** *C. Boney, A. Bensaoula, Z. Zhang,* University of Houston

Diluted magnetic semiconductors (DMS) based on Mn doped GaN are intensively investigated for their potential spintronics applications. Ferromagnetism has been demonstrated in Mn-doped implanted p-type GaN, Mn-diffused GaN, and n-type films of GaMnN grown by MBE. Two approaches to understanding the magnetic properties of DMS materials are pursued: one considers these materials as more-or-less random alloys; the second one considers the magnetic atoms forming small clusters that produce the observed ferromagnetism. To clarify these issues we have performed structural analysis of GaMnN thin films grown by CBE using two in-situ time of flight (TOF) ion spectroscopy techniques combined with SARIC trajectory simulations. These were complemented with ex-situ XRD, PL, Raman spectroscopy, and Backscattering/ channeling combined with PIXE. GaMnN has been grown using TEG, NH@sub 3@, and solid Mn on sapphire/GaN templates prepared by CBE and MBE. Evolution of the stress for the as grown and annealed thin films has been studied by XRD and Raman. Samples grown on sapphire/GaN templates prepared by CBE show n-type conductivity, those grown on MBE GaN templates are highly resistive. The reactor is fitted with two in-situ TOF techniques, Direct Recoil Spectroscopy (DRS) and Mass Spectroscopy of Recoiled Ions. For structural characterization, azimuthal DRS scans are used to extract the surface periodicity and from that construct models of GaMnN surfaces. Simulations of scattering and recoiling scans for GaMnN surfaces have been performed for different possible lattice locations of Mn in GaN. Similar experiments were performed using Rutherford backscattering/channeling combined with particle induced X-ray emission. DRS confirmed retention of wurtzite crystal structure obtained by RHEED and XRD for Mn concentrations up to 2.5%. Although results have shown mainly substitutional incorporation of Mn atoms at Ga sites, DRS scans also show presence of Mn atoms at interstitial positions.

10:00am **SC+MI-MoM6 Induced Host Moments and Mn Electronic Structure in Mn-Doped Iii-V Ferromagnetic Semiconductors**, ***D.J. Keavney,*** Argonne National Laboratory*; D. Wu, J. Shi,* University of Utah*; E. Johnston-Halperin, D.D. Awschalom,* University of California, Santa Barbara*; Y. Cui, L. Li,* University of Wisconsin-Milwaukee **INVITED**

We have used soft x-ray magnetic circular dichroism (XMCD) and absorption spectroscopy (XAS) to examine induced host magnetic moments and the local Mn environment in Mn-doped GaAs and GaN. X-ray absorption probes unoccupied states via transitions from deep core levels, thus providing electronic structure information with element specificity. With circularly polarized radiation at the L edges, element specific moments can be detected via their projection onto the Mn 3d and host 4s states, providing a test of predictions made by the carrier-mediated model of ordering. In (Ga,Mn)As, we find small XMCD signals at the onset of the absorption edge for both Ga and As, which we attribute to induced 4s moments. The relative orientations of all three elements are as expected for carrier-mediated coupling, and we estimate that the As moment is larger than the Ga moment. In (Ga,Mn)N, we detect a weak Ga XMCD signal 2-3 eV above the absorption edge of opposite sign to that in (Ga,Mn)As, which may be attributable to Mn 3d tails at the Ga sites. The absence of a Ga 4s moment would suggest a weaker p-d hybridization consistent with the deeper position of the Mn acceptor level. In both systems, XAS shows that Mn is divalent, although with differing amounts of line broadening, suggesting that the Mn 3d localization varies significantly depending on the host. (Ga,Mn)N has a lineshape closer to atomic Mn 2+ than (Ga,Mn)As. These results show that the Mn 3d and valence band electronic structure in doped III-V systems is strongly dependent on the host, and have implications for the degree of p-d hybridization and the coupling mechanism responsible for ferromagnetism. Use of the Advanced Photon Source was supported by the U.S. DOE, Office of Science, Contract No. W-31-109-Eng-38. Work at the Univ. of Utah was supported by ONR/DARPA grant No. N00014-02-10595, at UCSB by ONR/DARPA grant No. N00014-99-1-1096 and AFOSR F49620-02-10036, and at Univ. of Wisconsin by NSF DMR-0094105.

10:40am **SC+MI-MoM8 Intrinsic Versus Extrinsic Nature of Co Doped TiO@sub 2@ Diluted Magnetic Semiconductor Thin Films**, ***S.R. Shinde***, *S.B. Ogale, J. Higgins, T. Zhao,* University of Maryland*; S.E. Lofland,* Rowan University*; V.N. Kulkarni,* University of Maryland*; A.J. Millis,* Columbia University*; S. Das Sarma, R.L. Greene, R. Ramesh, T. Venkatesan,* University of Maryland

The issue of Co distribution in TiO@sub 2@ (in anatase and rutile forms), a widely studied oxide based diluted magnetic semiconductor (DMS) system, is still controversial. Although all the reported studies have discovered room temperature ferromagnetism in this system, some of the researchers claim that the material is intrinsic, whereas others have found that cobalt forms small clusters and therefore the material has extrinsic origin of ferromagnetism. In our work we have grown (by pulsed laser deposition) and characterized epitaxial thin films of Co:TiO@sub 2@ at different growth conditions and Co doping concentrations. We noticed that Co distribution strongly depends on the growth parameters. At lower growth temperature (~700C) there is a limited solubility of Co (up to ~2%) above which nanometer sized Co clusters are formed. When the films are grown in ultrahigh vacuum (10-8 Torr), the films have low resistivity and show the anomalous Hall effect. Although this could be interpreted as a signature of carrier induced DMS nature of these particular films, our detailed magnetic and structural analysis shows the presence of Co nanoclusters in these films. In the magnetization data of these films we observe superparamagnetism with a blocking temperature of 250K. This temperature corresponds to Co particles of 7nm diameter, the presence of which was further confirmed by transmission electron microscopy (TEM). On the other hand, when the films grown at lower temperature are annealed at high temperature (~900C) the clusters dissolve in titanium dioxide matrix leading to an intrinsic DMS with a Curie temperature ~650C. Similar properties are observed for films directly grown at high temperature and no indication of any clustering of Co is observed in TEM. We have also observed electric field induced reversible modulations, in the magnetization of these films in PbZr@sub 0.2@Ti@sub 0.8@O@sub 3@/Co:TiO@sub 2@/SrRuO@sub 3@ field effect transistor structure.

11:00am **SC+MI-MoM9 Ferroelectric Field Effect on Ferromagnetism in Diluted Magnetic Insulator Anatase Co:TiO@sub2@**, ***T. Zhao***, *S.R. Shinde, S.B. Ogale, H. Zheng, T. Venkatesan,* University of Maryland*; R. Ramesh,* University of California, Berkeley*; S. Das Sarma,* University of Maryland*; J. Misewich,* Brookhaven National Laboratory

Recently considerable success is reported in making a non-magnetic semiconductor ferromagnetic by dilute doping of magnetic impurities. However, the possibilities of extrinsic effects such as dopant clustering, impurity magnetic phases etc., have not been completely ruled out in many systems. In this work we report the first successful implementation of an external electric field modulation of ferromagnetism in an oxide-based DMS anatase Co:TiO@sub2@. An anatase TiO2 layer with 7% Co doping and a ferroelectric PbZr@sub0.2@Ti@sub0.8@O@sub3@ layer were epitaxially grown on a conducting SrRuO@sub3@ buffered LaAlO@sub3@ substrate by pulsed laser deposition. The high-quality of epitaxy and uniform distribution of Co were confirmed by X-Ray diffraction and transmission electron microcopy. The Co:TiO@sub2@ channel grown in this case at a high temperature of 875°C is insulating in nature. The magnetic hysteresis loops of the Co:TiO@sub2@ were measured by superconducting quantum interference device after positive or negative electric poling on PZT. The room temperature saturated magnetic moment clearly shows two stable states which are reversible by switching the ferroelectric polarization. The observed effect, which is about 15% in strength can be modulated over several cycles. This first demonstration of electric field effect in an oxide based diluted ferromagnetic insulator system provides evidence of its intrinsic nature. Furthermore, the ability of electric field modulation of ferromagnetism is very promising for next-generation multi-functional electronic devices. Possible mechanisms for electric field induced modulation of insulating ferromagnetism are discussed. This work was supported by DARPA SpinS program (through US-ONR) and the NSF-MRSEC (DMR 00-80008) at Maryland. The PLD and RBS facilities used in this work are shared experimental facilities (SEF) supported in part under NSF-MRSEC.

11:20am **SC+MI-MoM10 Applications of a Dilute Magnetic Semiconductor Based on AlN**, ***R.M. Frazier***, *G.T. Thaler, J.Y. Leifer, C.R. Abernathy, S.J. Pearton,* University of Florida

With the increasing interest in spintronics, many attempts have been made at incorporating spin-based functionality into existing semiconductor technology. One approach, utilizing dilute magnetic semiconductors (DMS) formed via introduction of transition metal ions into III-Nitride hosts, would allow for integration of spin based phenomena into current wide bandgap technology. Further, the use of AlN broadens III-V DMS applications to tunneling devices and UV light emitters. The most evident application of ferromagnetic AlN is as a ferromagnetic tunnel barrier, similar to EuS, but unlike EuS should allow for operation at room temperature. Ion implantation has been shown to be an effective survey method for introduction of various transition metals into AlN. However, it is not a technique which will allow for the development of advanced spin based devices. Such devices will require epitaxial methods of the sort currently used for synthesis of III-Nitride optoelectronics. In this study, one such technique, Gas Source Molecular Beam Epitaxy (GSMBE) has been used to synthesize AlN films doped with Cr and Mn. In the Mn doped films, increasing the V/III ratio corresponded to an increased magnetic signal, indicating an increase in active Mn sites. In the case of both Mn and Cr doped AlN, the magnetic signal was found to depend on the flux of the dopant, and the optimal growth conditions were found. Growth of tunnel devices using AlTMN as a barrier will also be discussed. This work is supported by the Army Research Office under ARO-DAAD19-01-0-0701 and NSF under ECS-0224203.

11:40am **SC+MI-MoM11 Ferromagnetism and Polaron Percolation in Mn@sub x@Ge@sub 1-x@ Dilute Magnetic Semiconductor**, ***A.P. Li***, *J.F. Wendelken, J. Shen,* Oak Ridge National Laboratory*; J.R. Thompson, H.H. Weitering,* Oak Ridge National Laboratory, University of Tennessee

In dilute magnetic semiconductors (DMS), ferromagnetic ordering is carrier mediated. This picture seems to be accepted more or less universally, but the detailed nature of the ferromagnetism varies greatly from system to system. We have studied ferromagnetism and the correlation between transport and ferromagnetism in Mn@sub x@Ge@sub 1-x@ DMS for Mn concentrations up to 9%. By carefully controlling the growth conditions, we obtained precipitate-free Mn@sub x@Ge@sub 1-x@ that exhibits magnetic phase transitions at Tc = 20 K and Tc* = 112 K. The magnetic response to temperature and doping concentration is indicative of a magnetic-polaron percolation transition at Tc [1], which coincides with a metal-insulator transition and Hall-effect sign anomaly. Tc* is the ferromagnetic ordering temperature within isolated polarons which can be determined from a Curie-Weiss plot of the high-temperature magnetic susceptibility. Ferromagnetism in Mn@sub x@Ge@sub 1-x@ DMS reveals a striking analogy with the magnetism of so-called "clustered states" in manganite compounds [2]. [1] A. Kaminski and S. Das Sarma, Phys. Rev. B 68, 235210 (2003) [2] G. Alvarez and E. Dagotto, Phys. Rev. B 68, 045202 (2003).

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-TuM

Spintronics
Moderator: C.J. Palmstrøm, University of Minnesota

8:20am **MI-TuM1 Semiconductor Spintronics: From Basic Physics towards Spin Devices*, M. Oestreich,*** *D. Hägele, J. Rudolph, S. Döhrmann, R. Winkler,* Universität Hannover, Germany*; H.M. Gibbs, G. Khitrova,* University of Arizona*; D. Schuh, M. Bichler,* Technische Universität München, Germany*; W. Stolz,* Universität Marburg, Germany **INVITED**

The electron spin in semiconductors has become a focus of intense research in the context of spintronic devices. A prime condition for the development of potential applications is the understanding of the spin decoherence, i.e. the loss of spin memory. In the first part of this talk we present the spin dynamics in (110) GaAs quantum wells at high temperatures and put forward a new spin dephasing mechanism that ultimately limits the high temperature spin dephasing times in GaAs quantum wells.@footnote 1@ In the second part of the talk we demonstrate the reduction of the threshold of semiconductor lasers by injection of spin polarized electrons, compare high and low temperature operation, and discuss problems and prospects of these spintronic devices.@footnote 2@. @FootnoteText@ @footnote 1@ S. Döhrmann et al., "Anomalous spin dephasing in (110) GaAs quantum wells: anisotropy and intersubband effects", cond-mat 0403052.@footnote 2@ J. Rudolph et al., "Laser threshold reduction in a spintronic device", Appl. Phys. Lett. 82, 4516 (2003).

9:00am **MI-TuM3 Characterization of Thin Film MnGa/GaAs(001) Heterostructures*, J.L. Hilton,*** *B.D. Schultz, S. McKernan, C.J. Palmstrøm,* University of Minnesota

MnGa thin films are desirable for use as ferromagnetic contacts in spintronic devices because they can be grown epitaxially on GaAs with perpendicular magnetization@footnote 1@. The interface between the ferromagnetic contact and the semiconductor has a significant influence on the spin injection efficiency of spintronic devices. It has been shown previously that elemental Mn is not stable on GaAs and that it reacts to form an interfacial region composed of Mn@sub 2@As and MnGa@footnote 2@, suggesting that MnGa may be stable in contact with GaAs. However, bulk material studies suggest that Mn@sub 2@As and elemental Ga are the two stable phases in contact with GaAs@footnote 3@. To address this discrepancy, a number of MnGa/GaAs heterostructures were grown by MBE and subsequently annealed either in-situ or ex-situ for different times and temperatures. X-ray diffraction of MnGa/GaAs samples following growth shows peaks corresponding to both MnGa(001) planes and the GaAs substrate. Following post-growth anneals at 400°C for 1 hr, peaks corresponding to (001) planes of the Mn@sub 2@As-like crystal structure are observed. Rutherford backscattering spectrometry shows only minor compositional changes upon annealing, indicating that any reactions are confined to the interfacial region. These results will be combined with results from in-situ RHEED, LEED, STM, and XPS, and ex-situ RBS channeling and TEM to characterize the growth and interfacial properties of epitaxial MnGa/GaAs heterostructures. Supported by ONR, DARPA, NSF, and AFOSR. @FootnoteText@ @footnote 1@M. Tanaka et al., Appl. Phys. Lett. 62, 1565 (1993).@footnote 2@J. L. Hilton et al., Appl. Phys. Lett. 84, 3145 (2004).@footnote 3@P. Kordos et al., Solid State Electron 18, 223 (1975).

9:20am **MI-TuM4 Co@sub 2@MnGe/Ga@sub 1-x@Al@sub x@As Heterostructures: Growth, Characterization and Spin Injection*, X.Y. Dong,*** *C. Adelmann, J. Strand, X. Lou, S. McKernan, J.Q. Xie, B.D. Schultz,* University of Minnesota*; A.K. Petford-Long,* University of Oxford*; P.A. Crowell, C.J. Palmström,* University of Minnesota

A number of ferromagnetic Heusler alloys of the type MMnX ("half" Heusler) and M@sub 2@MnX ("full" Heusler) have been predicted to be half-metallic @super 1@. The ability to grow Co@sub 2@MnGe epitaxially on GaAs, the predicted half-metallicity and the high Curie temperature, make it an ideal candidate for a spin injecting contact. Co@sub 2@MnGe epitaxial films were grown by molecular beam epitaxy (MBE) on Ga@sub 1-x@Al@sub x@As (001) surfaces prepared in a separate MBE-growth chamber and transferred in ultra high vacuum (<10@super -10@ torr) to the Heusler alloy growth MBE chamber. In-situ RHEED, ex-situ XRD and TEM demonstrate the epitaxial single crystallinity of the films. In-plane VSM measurements showed that the Co@sub 2@MnGe films have a 1000 emu/cm@super 3@ saturation magnetization at room temperature and a 8 Oe coercivity. A SQUID magnetometer was used to measure the out of plane magnetization, which was found to saturate around 1 Tesla. In order to measure the spin injection, tunneling Schottky barrier contact spin-LED structures were fabricated from MBE-grown p-Ga@sub 0.9@Al@sub 0.1@As/GaAs(100Å)/n-Ga@sub 0.9@Al@sub 0.1@As/Co@sub 2@MnGe/Al heterostructures. The 70Å thick Co@sub 2@MnGe Schottky barrier injector was grown at 175°C and the 25Å thick Al capping layer used to prevent oxidation during exposure to air was grown at 0°C. The epitaxial heterostructures were processed into LED devices and the devices were operated with the Schottky contact under reverse bias and the p-i-n LED under forward bias. Electroluminescence was collected along the sample normal. The circular polarization of the observed electroluminescence was 14% indicating a spin injection efficiency of 14% at 2K. To our knowledge, this is the first time demonstration of spin-injection from a Heusler alloy into a semiconductor. @FootnoteText@ @footnote 1@ S. Fujii, S. Sugimura, S. Ishida, and S. Asano., J. Phys.:Condens. Matter 2, 8583 (1990).

9:40am **MI-TuM5 Determination of the Influence of the Interfacial Formation and the Semiconductor Doping Profiles on the Spin Injection from Fe@sub x@Co@sub 1-x@ Contacts into Ga@sub x@Al@sub 1-x@As*, C. Adelmann,*** *X.Y. Dong, B.D. Schultz, C.J. Palmstrøm, J. Strand, X. Lou, P.A. Crowell,* University of Minnesota*; S. Park, M.R. Fitzsimmons,* Los Alamos National Laboratory

Spin injection from ferromagnetic contacts into semiconductor structures is a crucial part in spintronic devices operating at room temperature. Recently, it has been shown that spin injection is possible from Fe into GaAs by tunneling through a reverse-biased Schottky contact into an light emitting diode@footnote 1@. The dependence of spin injection on the inter-face doping level and drift layer doping was studied. Efficient spin injection was only obtained in a narrow interface doping window between 3E18 and 5E18 cm@super -3@. The optimum drift layer doping was found to be about 1E16 cm@super -3@. The spin detection efficiency was also found to depend on the p-layer. The carrier transport as a function of doping level will be discussed. The effect of growth temperature and annealing on the spin injection was also investigated. Low temperature annealing was found to increase the electroluminescence polarization. However, at high annealing temperatures, no spin injection was observed suggesting reactions between GaAs and the metal contact. The observed changes in electroluminescence polarization were found to correlate with the changes in the interfacial magnetic properties for Fe@sub 0.5@Co@sub 0.5@/GaAs heterostructures determined from polarized neutron reflectivity. Optimized devices were found to lead to >10% spin injection at room temperature. This work was supported by the DARPA SPINS program, ONR, and the University of Minnesota NSF-MRSEC program. @FootnoteText@ @footnote 1@ A.T. Hanbicki et al., Appl. Phys. Lett. 80, 1240 (2002).

10:00am **MI-TuM6 Growth and Magnetic Properties of Group-IV Dilute Magnetic Semiconductors*, Y.F. Chiang,*** *R.K. Kawakami,* University of California, Riverside

The synthesis of magnetically-doped semiconductors is important for electronics based on spin. We utilize molecular beam epitaxy (MBE) to incorporate magnetic dopants such as Mn and Co into Ge and Si semiconductor thin films. The structural properties of the samples are characterized by in situ reflection high energy electron diffraction (RHEED), x-ray diffraction, and transmission electron microscopy (TEM). Substrate temperatures during growth are monitored by a transferable thermocouple to ensure accurate thermometry for low-temperature growth (0-250Â° C). Magnetic hysteresis loops are measured by superconducting quantum interference device magnetometry (SQUID) and magneto-optic Kerr effect (MOKE) over a large temperature range (5K â?" 300K) in order to determine the Curie temperature, magnetic anisotropy, and remanence. The dependence of magnetic properties on the magnetic dopant concentration and the growth temperature will be discussed.

10:20am **MI-TuM7 Universal Scaling of Magnetoconductance in Magnetic Nanoconstrictions@footnote *@*, S.-H. Chung,*** University of Maryland, College Park, Argonne National Laboratory **INVITED**

Large magnetoresistance in ferromagnetic transition metals, half-metallic oxides and magnetic semiconductors connected by nanoconstrictions has recently been observed by several research groups. In this work, we present new results that magnetoconductance in nanometer size constrictions has a universal scaling behavior [1]. The results were obtained for half-metallic ferromagnets formed by nanoconstrictions of CrO@sub 2@-CrO@sub 2@ and CrO@sub 2@-Ni. Analysis of the

magnetoconductance versus scaled conductance data for all materials known to exhibits so-called ballistic magnetoresistance suggests that the magnetoconductance of nanoconstrictions follows universal scaling. If the maximum magnetoconductance is normalized to unity and the conductance is scaled to the resistivity of the material, then all data points from the current experiment and others in the literature fall into a universal curve that is independent of the constriction material and the transport mechanism. The results agree with a theory that takes into account the enhancement of spin scattering within a magnetic domain wall in nanoconstriction. The adiabatic spin transport increases as the width of the domain wall increases with the size of nanoconstrictions. This analysis suggests that the large magnetoresistance in the nanoconstrictions of materials even in different conductance regimes may have the same mechanism of spin-ballistic transport through magnetic nanoconstrictions. [1] S.-H. Chung, M. Munoz, N. Garcia, W. F. Egelhoff, and R. D. Gomez, Physical Review Letters vol. 89, 287203 (2002). @FootnoteText@ @footnote *@ Supported by the University of Maryland, College Park, NSF and MRSEC, by the Spanish DGICyT, and by the DOE, BES under contract W-31-109-ENG-38.@footnote **@ In collaboration with N. Garcia, M. Munoz, W. F. Egelhoff, H. Pandana, and R. D. Gomez .

11:00am **MI-TuM9 Spin-Transfer Torque in a Single Ferromagnetic Layer**, ***Y. Ji***, Argonne National Lab*; T.Y. Chen, C.L. Chien,* Johns Hopkins University*; M.D. Stiles,* National Institute of Standards and Technology **INVITED**

When a spin polarized current passes through a ferromagnet, spin angular momentum can be transferred between the conduction electrons and the magnetization of the ferromagnet. As a result, a torque is imparted on the magnetization, which will be realigned toward the polarization direction of the conduction electrons, an effect called â?ospin-transfer torqueâ?. Previously most theories and experiments explore F/N/F trilayer or F/N multilayer structures, where F denotes a ferromagnet and N denotes a nonmagnetic metal. In low magnetic fields, the trilayers hysteretically switch between parallel and anti-parallel states, as the current is swept between polarities with a current perpendicular to plane (CPP) geometry. In high magnetic fields, reversible dV/dI peaks are observed for only one polarity of the current, and previously interpreted as the onset of spin-wave excitations. The multilayer or trilayer structures have been generally presumed indispensable, since non-collinear magnetizations between a polarizing layer and a receiving layer are required to generate spin torques, and the GMR effect is essential in detecting magnetization reversals. In this work, spin-transfer torque effects in a single ferromagnetic layer are demonstrated, using current injection through a point-contact. Differential resistance peaks are observed in high magnetic fields. The current values corresponding to the peak positions linearly depend on the external field. Hysteretic current-induced switching is observed in low magnetic fields. Systematic variations between low field and high field regions have been investigated and the implications will be discussed. The first author's work was done as a Ph.D. student in Johns Hopkins, supported by NSF DMR00-80031 and DMR97-32763. His current work at Argonne is supported by U.S. DOE BES-MS W-31-109-ENG-38.

11:40am **MI-TuM11 Magneto-Resistance in Epitaxial Nano-Contacts for Spintronic Device Applications**, ***D. Pearson***, University of Toledo*; R.A. Lukaszew,* University of Toledo, US

Ballistic magnetoresistance (BMR) research has shown surprising MR effects in electrodeposited Ni nano-contacts at room temperature and low magnetic field@footnote 1@. A large BMR effect may arise from non-adiabatic spin scattering across very narrow (atomic scale) magnetic domain walls (DW) trapped at nano-contacts@footnote 2@. Kent el al@footnote 3@ have studied MR in epitaxial microstructures and found small intrinisc DW related effects only on highly anisotropic films. We have studied nano-contacts in various other epitaxial films. The idea behind our scheme is that epitaxial ferromagnetic thin films may favor non adiabatic spin transport provided that the nano-contact is small enough as predicted by Bruno. We used a similar geometry to that utilized by Chopra and Garcia@footnote 1@,@footnote 4@. The combined shape and magnetocrystalline anisotropies provide the required two states for the magnetization at each side of the constriction. Our results indicate that domain walls do play a role in the magnetoresistance of these nano-bridges. Micromagnetic simulations where carried out on the Ni nanocontacts using OOMMF. We will present our work on epitaxial Ni, FeN and CrO@sub 2@ nano-contacts. FeN exhibits enhanced magnetic moment and is an attractive candidate for write-heads. CrO@sub 2@ is a half metal with 100 percent polarization and therefore of fundamental interest in these studies. @FootnoteText@ @footnote 1@ S. Z. Hua and B. D. Chopra, Phys. Rev. B. 67, 060401(R), 2003.@footnote 2@ P. Bruno, Phys. Rev. Lett. 83, 2425 (1999).@footnote 3@ Kent, et al., J. Phys: Condens. Matter 13 (2001) R461.@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).

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-TuA

BioMagnetism

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

1:20pm **MI-TuA1 Synthesis and Surface Modification of Monodisperse Magnetic Nanoparticles for Biological Applications**, ***S. Sun***, *H. Zeng, H. Yu, D. Robinson,* IBM T.J. Watson Research Center*; G. Li, S. Wang, R. White,* Stanford University **INVITED**

We present our chemical synthesis and surface modification of monodisperse magnetic nanoparticles for potential applications in bio-recognition. Biocompatible dispersions of magnetic nanoparticles have been used widely in bimolecular labeling and biological imaging, sensing and separation in recent years. These applications require that the particles be superparamagnetic at room temperature, and monodisperse for uniform biodistribution, bioelimination and contrast effects. The Co and Fe based magnetic nanoparticles, including metallic Co, Fe, CoFe and oxide MFe2O4 nanoparticles, have high magnetic moment, and thus sufficient sensitivity for magnetic detection. With proper functionalization, they can be useful candidates as magnetic probes for biomolecule identification. We have developed various synthetic procedures for making monodisperse magnetic nanoparticles. Using a combination of surfactants, such as oleic acid/oleyl amine, to control nanoparticle growth and stabilization, we can tune the size of the nanoparticles to obtain an optimum magnetic signal for sensor detection. By controlling particle surface chemistry and synthetic conditions, we can also produce multi-functional nanoparticles with either core/shell-structured particles, such as Fe3O4/AgSe or Fe3O4/FePt, or dumbbell-structured particles, such as Fe3O4-Ag. We can further transform the oleic acid/oleylamine capped, hydrophobic nanoparticles into hydrophilic ones by using tetramethylammonium hydroxide, bi-functional thiol molecules, or multi-functional polymeric molecules. These hydrophilic nanoparticles are both chemically and magnetically stable in phosphate buffer solution at neutral pH, and can withstand DNA denaturing and hybridization conditions. They are suitable as magnetic probes for highly sensitive bio-detection. Acknowledgement: The work is supported in part by DARPA under grant No. N00014-01-1-0885.

2:00pm **MI-TuA3 Progress in Non-Invasive Biomagnetic Liver Iron Store Measurements**, ***D.N. Paulson,*** Tristan Technologies **INVITED**

Biomagnetic liver susceptometry is a non-invasive measurement of liver (and spleen) iron stores. Proposed by Bauman in 1967, it was demonstrated on animals@footnote 1@ shortly thereafter. With the development of the Superconducting quantum interference device (SQUID) magnetic field sensor, a prototype system was developed for measurement of human liver iron stores. Measurements on normal and iron overloaded subjects showed this technique to be an accurate quantitative measurement of human iron stores@footnote 2@. The basic system is comprised of a superconducting magnet, a highly sensitive SQUID magnetic field sensor, a water bag (placed between the sensor and patient) that simulates the natural magnetism of the body, a non-magnetic bed and data acquisition system. Since the installation of the first clinical systems at Cleveland and Hamburg, over 6,000 clinical measurements have been made on over 4,000 patients. We describe the measurement technique and present summaries of a number of clinical studies comparing biomagnetic liver susceptometry to needle biopsies. We describe the current status of both the original systems@footnote 3@ and improved systems now being produced and comment on future directions in the non-invasive measurement of liver-iron stores including the possibility of assessment of cardiac iron. @FootnoteText@ @footnote 1@ Bauman JH, Harris JW, "Estimation of hepatic iron stores by in-vivo measurement of magnetic susceptibility", J Lab Clin Med 1967; 70: 246-257.@footnote 2@ Brittenham GM, Farrell DE, Harris JW, Feldman ES, Danish EH, Muir WA, Tripp JH, Bellon EM."Magnetic-susceptibility measurement of human iron stores", N Engl J Med 1982; 307: 1671-1675.@footnote 3@ Paulson DN, Fagaly RL, Toussaint RM, Fischer R, "Biomagnetic Susceptometer with SQUID Instrumentation", IEEE Transactions on Magnetics, vol 27, no. 2, March 1991.

2:40pm **MI-TuA5 Design Considerations for High Sensitivity Biosensing with Magnetic Labeling and Detection**, ***J.C. Rife,*** Naval Research Laboratory **INVITED**

We are developing the BARC (Bead ARray Counter) sensor chip for the detection of biomolecules labeled with magnetic microbeads.@footnote 1@ Presently, 2.8 µm-diameter commercial magnetic beads are detected by an array of 64 GMR sensors on the chip, with each sensor spanning a 200 µm diameter spot. Arrays of single-stranded DNA or antibody probes are immobilized onto the sensor spots, and biomolecular targets (e.g. DNA or proteins) that are captured by the probes are then labeled with magnetic microbeads. Although at the limits of detection each bead labels a single captured molecule, non-specifically bound beads and sensor noise currently set the limit of detection to about 10 beads (potentially 10 molecules) per sensor. Although the sensor signal to noise can be improved, ultimately the sensitivity will be limited by delivery of molecules to the sensor surface as governed by diffusion, sensor geometry, and fluidics. The current BARC sensor array has an advantage because of its relatively large sensors, and can presently detect DNA concentrations as low as 1 fM (10@super 5@ molecules/cm@super 3@). Further improvement in the sensitivity will require coupling the design of the fluidics with the sensor array. I will discuss the BARC sensor response, along with finite element calculations of the delivery of molecules to the surface under various conditions. I will also discuss how these issues affect various alternative magnetic labeling and detection approaches, such as those based on spin valves and SQUIDs. This work done in collaboration with M. M. Miller, P. E. Sheehan, C. R. Tamanaha, M. Tondra, and L. J. Whitman. @FootnoteText@ @footnote 1@J. C. Rife et al., Sensors and Actuators A 107, 209-218 (2003).

3:20pm **MI-TuA7 Advances in MR Elastic Displacement Imaging and Non-invasive Measurements of Myocardial Compliance**, ***H. Wen,*** NHLBI/NIH **INVITED**

The vector nature of the NMR signal gives rise to a group of displacement imaging methods in magnetic resonance imaging that are based on spin phase-shifts. They are suited for studying physiological motions such as the heartbeat and elastic reponses of arterial walls to the blood pressure. Elevated myocardial stiffness is a cause of high diastolic blood pressure and congestive heart failure. The traditional measure of heart chamber stiffness uses diagnostic catheterization, an invasive procedure not acceptable for many patients. MR elastic displacement imaging is a new way to estimate material viscoelastic parameters non-invasively. It has been validated in animal models and shown feasible in humans. Clinical trials to detect heart and artery stiffening in patients with congenital heart disease are being prepared.

Magnetic Interfaces and Nanostructures
Room Exhibit Hall B - Session MI-TuP

Poster Session

MI-TuP1 Comparative Studies of Magnetic Phases of the Interfacial Layers for Co/Ge(100) and Co/Ge(111) Films, ***J.S. Tsay,*** National Chung Cheng University, Taiwan; *C.W. Su,* Academia Sinica, Taiwan; *C.H. Hwang,* Tunghai University, Taiwan; *Y.D. Yao,* Academia Sinica, Taiwan

Magnetic phases of the interfacial layers were comparatively investigated for Co/Ge(100) and Co/Ge(111) films thinner than 13 monolayers using surface magneto-optic Kerr effect technique. Co/Ge(100) films show nonferromagnetic behavior up to 12 monolayers at 300 K. After systematic investigations of the magnetic properties upon cryogenic treatments, magnetic phase diagram of the Co/Ge(100) films was established. The boundary between nonferromagnetic and ferromagnetic phases was experimentally determined to be from below 150 K to above 300 K as the cobalt thickness increases from 9 to 14 monolayers. This behavior is consistent with the thickness-dependent scaling law of Curie temperature for a thin film system. As comparing to Co/Ge(111) system, this boundary shifts to higher Co thickness side. Due to the difference of the electronegativities for Co and Ge atoms, Co LMM Auger line shifts to a higher kinetic energy as the Co thickness increases. This gives the spectroscopic evidence of the formation of interfacial compounds. Co/Ge(100) exhibit a diffused 2x1 diffraction pattern within the first monolayer thickness followed by a diffused background for thicker films as observed using low-energy electron diffraction technique. Ordered structure up to several monolayers were observed for Co/Ge(111) films as deposited at 300 K. In additional, the critical exponent @beta@ï? in the power law relationship of magnetization for Co/Ge(100) films is about 0.38 that lies close to the value expected by three-dimensional Heisenberg model, while the critical exponent of Co/Ge(111) is close to the value of two-dimensional XY model. These experimental evidences show that the structure of Co/Ge(100) interfacial layers is in a much disordered state. This causes a three-dimensional stacking of subsequently deposited Co atoms and furthermore the different magnetic transition behavior of Co/Ge(100) and Co/Ge(111) films.

MI-TuP2 Fabrication and Magnetic Property of Co Platelets On Si (111) Surfaces, *M.H. Pan, H. Liu, J.Z. Wang, J.F. Jia, Q.-K. Xue,* The Chinese Academy of Science, China; ***J.L. Li***, *S.Y. Qin, C.-K. Shih,* University of Texas at Austin

Self-organized Co platelets with uniform size and shape were fabricated on Si(111)-7x7 surfaces covered with identical Al nanocluster arrays. The Al nanocluster array not only suppresses reaction between Si and Co, but also enables formation of well-defined Co nano-platelets. These platelets appear as equilateral triangles with fixed orientation and two-monolayer "magic" thickness, and the area of individual plates is quantized in N square units of halves of the 7x7 unit cells. Despite their small volume (a few nm3), these magnetic nanoplateles exhibit unusually high blocking temperature (>100 K).

MI-TuP3 Surfactant Effects on the Growth of FePt Nanoparticles: Toward Core-Shell Nanomagnets, ***A.C.S. Samia***, *X.-M. Lin, J.A. Schlueter, J.S. Jiang, S.D. Bader,* Argonne National Laboratory

Nanosized magnetic materials offer interesting possibilities to investigate fundamental physics and create new technologies in sensors, biomedicine and data storage applications. Particularly, magnetic alloy nanoparticles have attracted great interest due to their potential in ultra high-density recording media applications. Among the different nanomaterials being developed for this application is the FePt system. The high magnetic anisotropy, good chemical stability and resistance to corrosion of this material make it an ideal candidate for permanent magnet applications. Furthermore, monodispersed FePt nanoparticles can be readily obtained from the simultaneous reduction of platinum acetylacetonate and decomposition of iron pentacarbonyl in the presence of organic ligand stabilizers. To date most synthetic work has focused on the use of oleic acid and oleyl amine as passivating surfactants. Using this surfactant combination, spherical FePt nanoparticles in the size range of 3-10 nm have been reported. As prepared, the magnetic nanoparticles are superparamagnetic and requires an annealing step to transform them to a more stable magnetic state. Here we report the effects of other surfactant systems on the particle size and growth of FePt nanoparticles. We will present the effects of oleic acid and trioctylphosphine oxide (TOPO) surfactants on the particle size, size distribution and shape of FePt nanoparticles. By gaining insights on the role of these surfactants in regulating the growth of FePt nanoparticles we are able to synthesize larger FePt nanoparticles. To overcome the superparamagnetic limitation in ferromagnetic nanoparticles we are also developing novel core-shell exchange-spring nanomagnets, which consist of hard magnetic (CoPt, FePt) and soft magnetic components (Co). Such combination results to the interaction of the two phases by exchange coupling that leads to a high magnetic energy product.

MI-TuP5 Rotational Loss in Exchange Bias Systems and their Modeling, ***K. Steenbeck,*** *R. Mattheis, M. Diegel,* IPHT Jena, Germany

The rotational loss E in sputtered AF/F systems (AF: IrMn, thickness t = 0 to 13 nm, F: NiFe, CoFe, CoFe/Cu, thickness about 18 nm) is determined in dependence on AF thickness t by torquemetry at high field and at 10 and 300 K. After onset of E at low thickness a huge loss peak occurs at that thickness where exchange bias starts to develop and goes down to a lower and constant value above a critical thickness t@sub c@. Our simulations are based on a statistical distribution of coupling energies and include new aspects not considered up to now. For the first time rotational loss can be calculated in (111) textured films and the complete thickness dependence of E(t) can be described. Below t@sub c@ we consider crystallites with homogeneous AF magnetization, a 3-axial AF anisotropy K and an AF interface net moment which undergoes irreversible switching for critical values j/Kt. This loss disappears for large t. For t above t@sub c@ we include domain walls parallel to the F/AF interface. Our calculations display that the main loss contribution at that thickness is caused by complete AF 60 ° domain walls created in crystallites with 3-axial anisotropy and strong enough coupling (j above 1.5 @sigma@, @sigma@ domain wall energy). Switching processes of partial domain walls in crystallites having their j/@sigma@ in a critical interval contribute only at low level. The modelling allows to derive numerical values for the coupling energy per spin, the AF anisotropy constant K and the AF domain wall energy @sigma@.

MI-TuP6 Nanostructured Zigzag Shaped Magnetic Devices, ***D.P. Pappas,*** *F.C.S.S. da Silva, W.C. Uhlig, J. Unguris,* NIST

Magnetism in zigzag shaped thin film elements is investigated using scanning electron microscopy with polarization analysis, magneto-transport measurements, and micromagnetic simulations. We find that the angle of magnetization alternates along the length of the element, and is strongly correlated to the corrugated edges. We show that this simple and unique geometry can be used as a natural means of biasing the magnetization relative to the current to form a magnetic field sensor. In this configuration the sensors are primarily sensitive to fields parallel to the applied current. These results can be interpreted in terms of a coherent rotation model of the magnetization. These devices are scalable to nanometer dimensions.

MI-TuP7 Spin Momentum Transfer Induced Dynamics in Magnetic Nanostructures, ***W.H. Rippard,*** *M.R. Pufall, S. Kaka, T.J. Silva, S.E. Russek,* NIST; *J.A. Katine, M. Carey,* Hitachi Global Storage Technologies

We have directly measured high-frequency precessional dynamics induced by a dc current I injected into patterned nanopillar devices and continuous spin-valve structures through a lithographically defined nanocontact. The induced magnetization dynamics have been studied as a function of current, material, as well as applied field strength H and direction. For in plane applied fields, the excitation frequency is found to linearly decrease with applied current, in qualitative agreement with single domain modeling. The excited frequencies vary between 5 GHz and 40 GHz as a function of applied field and frequencies of excitation can be well-described by the Kittel equation, indicating that the excitations are ones with wavelengths much larger than the contact size. As the angle of the field is varied with respect to the film plane, the dynamics become more complicated. Abrupt shifts in the frequency occur with applied current applied and df/dI can vary strongly with I at a given field. These shifts can be either to an increased or decreased frequency, depending on the field strength and angle. Moreover, the frequency of precession can be multivalued several different, non-harmonically related frequencies being measured at a given field and current with each mode having a linewidth 18,000. Single domain modeling based on an LLG equation modified to contain a spin-torque term captures a number, but not all, of the behaviors we observe.

MI-TuP9 Undercut Nano Contact-hole Fabrication for a Ferromagnetic Vertical Single Electon Transistor and TMR Enhancement in the Coulomb Blockade Regime, ***S. Haraichi***, *T. Wada,* National Institute of Advanced Industrial Science and Technology, Japan

Recently, we have fabricated ferromagnetic single electron transistor s (FSET) with nanometer sized vertical magnetic tunnel junctions and observe d a strong TMR enhancement in the Coulomb blockade regime at relatively high temperature. The FSET consists of under layer drain electrodes, interlayer insulating layer with nano contact-holes, and over layer source electrodes, which is fabricated on an SOI substrate whose cap silicon layer acts as the gate electrode. The key issue of the process is the fabrication of undercut nano contact-holes. We use the bilayer SiO@sub 2@ of high-temperature sputte r layer and low-temperature sputter layer as an interlayer insulating layer. By using the etching rate dependence on sputtering temperature of SiO@sub 2@ in the electron beam direct lithography process, undercut nano contact-hol es have been successfully fabricated with a minimum diameter of 17 nm. Final ly, we have fabricated a vertical crossbar type FSET and obtained over 100% TMR enhancement at 15 K. This TMR enhancement can be modulated by the gate voltage.

MI-TuP10 Giant Magneto Resistance (GMR) Effect in Nanoscale Alternating Magnetic/ Non-Magnetic Metallic Multilayer, ***K.B. Ravi,*** Birla Institute of Technology, India

Giant magneto resistance (GMR) effect in nanoscale alternating magnetic/ non-magnetic metallic multilayers has evinced tremendous interest worldwide. Cu/Co Multilayers have been electrolytically deposited directly on to n-Si substrate from single bath, there by eliminating the need of a conducting seed layer. Magneto resistance is very sensitive to the growth conditions and can be destroyed by intermixing magnetic and non-magnetic interfaces and also by poor crystalline quality of the layers. Co and Cu are weakly miscible elements and for the reason they are most likely to yield chemically sharp interfaces. The observed MR value is Â»1%. Interface characteristics are analyzed using TEM, AFM and EPMA. Aim of the present work is to improve the magneto resistance value in these films by optimizing the deposition conditions and the layer thickness. The studies are going on to find out the effect of Cu layer thickness [by fixing Co layer to 2 nm thick] on MR and also to correlate the interface structure with giant magneto resistance.

MI-TuP11 Interface Chemistry and Structural Properties of Expitaxial Ultrathin Fe Films on MgO(100), ***E.D. Lu***, *V.K. Lazarov, H.T. Johnson-Steigelman, M. Gajdardziska-Josifovska, P.F. Lyman,* University of Wisconsin at Milwaukee

Epitaxial ultra thin Fe films have been grown successfully on MgO(100)(1x1) at room temperature (RT). The chemistry and structures of the interface during Fe film growth has been investigated by low energy electron diffraction (LEED), x-ray photoelectron spectroscopy (XPS). Prior to Fe deposition, commercial MgO(100) substrates were annealed at 750 °C in either furnace in air or ultra high vacuum (UHV) annealing in order to get well-ordered (1x1) reconstruction. We have found that band offsets toward valence band maximum (VBM) for MgO is 2.6 ± 0.2eV at Fe deposition of 5.0 monolayer (ML). We have also identified chemical states present on the initial stage of Fe deposition with elemental Fe@super 0@, Fe@super 2+@, and Fe@super 3+@ species. After deposition of more than 5.0 ML Fe, the elemental Fe becomes dominant, and finally body-centered cubic (bcc) Fe (100) films can be grown epitaxially on MgO(100)(1x1). Upon annealing for improving quality of the epitaxial Fe films, we have found there is an interdiffusion occurring between the Fe films and the MgO(100) substrates and becoming severe upon annealing to 500 °C.

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-WeM

Magnetic Nanostructures
Moderator: R.A. Lukaszew, University of Toledo

8:20am **MI-WeM1 Structural and Magnetic Properties of Ultrathin Co Film Grown on Pt(100)**, *M.H. Pan, K. He, L.J. Zhang, J.F. Jia, Q.-K. Xue,* The Chinese Academy of Sciences, China; ***W.D. Kim,*** Univ. of California at Berkeley and KRISS, Korea; *Z.Q. Qiu,* Univ. of California at Berkeley

Ultrathin Co films were deposited on Pt(100) at room temperature in ultrahigh vacuum, and investigated in situ by Low Energy Electron Diffraction (LEED), Scanning Tunneling Microscopy (STM), and Surface Magneto-Optiic Kerr Effect (SMOKE). The Co film was grown into a wedged shape to provide a continuous change of the film thickness. We find that the Co film forms single crystal ultrathin films at least up to 5ML. For as grown films, we observe only in-plane magnetization. After annealing the film, the Co film develops a perpendicular magnetic anisotropy, leading to a spin reorientation transition at 2.7 ML Co thickness. STM measurements were performed at room temperature both before and after annealing the film. We found very different surface morphology and alloy formation after the film annealing, and attribute the perpendicular magnetic anisotropy to the formation of the Co-Pt alloy layer at the Co/Pt(100) interface.

8:40am **MI-WeM2 Structure and Magnetic Anisotropy of Ultrathin Co Films on Au(111) Vicinal Substrates**, ***A. Tejeda,*** *G. Baudot,* Université Paris 7, France; *A. Coati,* Université Paris XI, France; *Y. Garreau,* Laboratoire Utilisation Rayonnement Electromagnetique, France; *Y. Girard,* Université Paris 7, France; *J.P. Jamet,* Université Paris XI, France; *V. Repain, S. Rohart, S. Rousset,* Université Paris 7, France

Nanostructured systems with magnetization along the surface normal are of technological interest for magnetic storing devices. We have studied ferromagnetic films of Co as they exhibit a strongly enhanced magnetic anisotropy with an easy axis perpendicular to the surface plane. Vicinal surfaces are a system model to control the roughness of the ferromagnetic films. We have deposited Co ultra-thin films on vicinal substrates of Au(111) in order to study the relationship between structure and magnetic properties. STM and Grazing Incidence X-ray Diffraction studies have been performed to determine the surface structure. X-ray diffraction shows that the vicinality of the substrate strongly modifies the Co film structure. While Co/Au(111) presents hcp structure, fcc Co is found on Au(233). Growth on an intermediate surface as Au(788) originates a structure with stacking faults. In a second part, we report on a magneto-optical study of the magnetic properties of these cobalt ultrathin films. In vicinal surfaces, the transition of the magnetisation from out-of-plane to in-plane orientation as a function of Co coverage appears in a more progressive way and at lower coverages than in Co/Au(111). Ex-situ measurements on samples passivated with a gold layer show an helicoidal reorientation transition. The easy axis of the magnetization changes from out-of-plane to in-plane, step parallel orientation. These results will be discussed in the light of the precise structural knowledge of these films.

9:00am **MI-WeM3 Growth and Magnetic Properties of Co Quantum-Platelets on Si(111) Surface**, ***Q.-K. Xue,*** The Chinese Academy of Science **INVITED**

Self-organized Co platelets with a singular height and of equilateral triangular shape are fabricated on a Si(111)-7Ã-7 surface pre-decorated with an periodic array of Al magic nanoclusters, as observed using the scanning tunneling microscopy. The selection of such a singular height is attributed to the suppression of chemical reaction between Co and Si by the Al nanoclusters, and the corresponding improved confinement in the motion of the conduction electrons within the Co platelets. Such quantum platelets exhibit intriguing magnetic properties in the hysteresis loop, which is shown to reflect a synergism between magnetic dipole interactions and magneto-crystalline anisotropy of the platelets. The present study demonstrates a promising pathway to directly integrate magnetic nanostructures with Si-based electronic devices. @FootnoteText@ In collaboration with Ming-Hu Pan, Hong Liu, Jun-Zhong Wang, Jin-Feng Jia, Xiang-Rong Wang, J. T. Markert, C. K. Shih, Zi-Qiang Qiu, and Zhenyu Zhang.

9:40am **MI-WeM5 Ferromagnetic Stability in Fe Nanodot Assemblies on Cu(111) Induced by Indirect Coupling through the Substrate**, ***M.A. Torija***[1], Oak Ridge National Laboratory, University of Tennessee, Knoxville; *J.P. Pierce,* Oak Ridge National Laboratory, Sandia National Laboratories; *Z. Gai,* Oak Ridge National Laboratory, Peking University, China; *E.W. Plummer,* Oak Ridge National Laboratory, University of Tennessee, Knoxville; *J. Shen,* Oak Ridge National Laboratory

To first order, assemblies of nano-scale magnetic dots are superparamagnetic. In these systems, thermal energy, which causes fluctuation of the dots' magnetic moments, becomes significant enough to overcome the anisotropy energy barrier and randomize their orientation at the so-called blocking temperature. This typically occurs far bellow room temperature. In real nanodots assemblies, it has been generally recognized that the magnetic dipole-dipole interaction can affect the barrier height for flipping the spin of each individual dot as well as the collective magnetic behavior of the dot assembly. In this work, we report collective ferromagnetic behavior in two- dimensional Fe dot assemblies on the Cu(111) surface that persists above room temperature. Our ability to tune the average size and spacing of the dots enables us to investigate the relative contributions of the mechanisms that support this unexpectedly robust magnetic order. Our experimental results and simulations indicate that the high-Tc ferromagnetism cannot be explained by either magnetic anisotropy or dipolar interaction. Direct comparison of the Curie temperatures (Tc) of similar dots prepared on vaious substrates including Cu(100) and Ge(111) allows us to conclude that the observed high-Tc ferromagnetism for Fe dots on Cu(111) is a result of an indirect exchange interaction via the surface states of Cu(111) substrate.

10:00am **MI-WeM6 Exploring New Magnetic Properties in Coupled Magnetic Nanostructures**, ***C. Won,*** *Y.Z. Wu,* University of California at Berkeley; *A. Scholl, A. Doran,* Lawrence Berkeley National Laboratory; *N. Kurahashi,* University of California at Berkeley; *H. Zhao,* 3 International Center for Quantum Structures, China; *Z.Q. Qiu,* University of California at Berkeley

Interaction between different magnetic entities in a magnetic nanostructure creates new properties that are not available in single phase bulk materials. In order to study how the magnetic interaction at nanometer scale generates new magnetic behaviors, we applied photoemission electron microscopy (PEEM) to investigate coupled magnetic nanostructures. The unique element-specific capability of PEEM allows the measurement of different magnetic species separately, thus enabling the identification of new magnetic properties caused the magnetic coupling. Several systems have been investigated by our group in the last a few years. In this talk, I will first give an overview of the research topics that we studied using PEEM. Then I will focus on a particular topic of magnetic phase transition in coupled magnetic layers. Co/Cu/Ni/Cu(100) and Co/Fe/Ni/Cu(100) are fabricated using epitaxial growth in which the Cu and Fe spacer layers controls the interlayer coupling between Co and Ni films. Element-specific measurements are performed to monitor the ferromagnetic to paramagnetic phase transitions of the Co and Ni films separately. Our results show that the interlayer coupling couples the magnetic fluctuations of the Co and Ni films to result in three types of magnetic phase transitions. A complete phase diagram is constructed in the Co-Ni thickness plane and a Monte Carlo simulation explains the conditions of having these three types of transitions.

10:20am **MI-WeM7 Self-assembled Ferroelectric/Ferrimagnetic BaTiO@sub3@-CoFe@sub2@O@sub4@ Nanostructures**, ***H. Zheng***[2], *J. Wang, Z. Ma, L. Mohaddes-Ardabili, T. Zhao, S.R. Shinde, S.B. Ogale, M. Wuttig, A. Roytburd, L. Salamanca-Riba,* University of Maryland, College Park; *S.E. Lofland,* Rowan University; *D. Viehland,* Virginia Tech; *D.G. Schlom,* Pennsylvania State University; *R. Ramesh,* University of California Berkeley

Ferroelectric/ferrimagnetic BaTiO@sub3@-CoFe@sub2@O@sub4@ (BTO-CFO) nanostructures have been synthesized by pulsed laser deposition using a single Ba-Ti-Co-Fe-Oxide ceramic target. Spinel CFO and perovskite BTO phases spontaneously separated during heteroepitaxial growth on single crystal SrTiO@sub3@ (001) substrates. It is shown that films are epitaxial in-plane as well as out-of -plane, with CFO nano-pillar arrays embedded in a BTO matrix. CFO pillars have uniform size and spacing. As the substrate temperature increases from 750 °C to 950 °C, the average lateral size of the pillars increases from ~9 nm to ~70 nm. Magnetic

[1] **Falicov Student Award Finalist**
[2] **Falicov Student Award Finalist**

measurements exhibit that all the films have a large uniaxial magnetic anisotropy with an easy axis normal to the film plane. It is calculated that stress anisotropy is the main contribution to the anisotropy field. We measured the ferroelectric and piezoelectric properties of the films, which correspond to the present of BTO phase. The temperature dependent magnetic measurements illustrate a coupling between the two order parameters of polarization and magnetization by a change in magnetization at the ferroelectric Curie temperature. This approach to the formation of self-assembled ferroelectric/ferromagnetic nanostructures is generic and manifests itself in other such spinel-perovskite systems, thus making it of great interest and value to a broad materials community. This work is supported by the NSF-MRSEC under contract No. DMR-00-80008.

10:40am **MI-WeM8 Artifically and Self Organized FePd(001) Nanoparticles: Fabrication, Magnetic and Magneto-Photonic Properties**, ***A. Cebollada***, IMM (CNM-CSIC), Spain*; C. Clavero, A. Bengoechea,* IMM (CNM-CSIC) Spain*; J.L. Costa Kramer, A. Garcia-Martin, J.V. Anguita, G. Armelles,* IMM (CNM-CSIC), Spain*; Y. Huttel,* ICMM (CSIC), Spain*; L.l. Balcells,* ICMAB (CSIC), Spain*; V.F. Puntes,* Univ. de Barcelona, Spain
INVITED

The fabrication and investigation of ordered arrays of high anisotropy and magneto-optic activity L10 FePd nanoparticles is reported. These arrays of particles are grown in 2 and 3 dimensions and embedded on single crystalline MgO(001) substrates and matrices. The deposition conditions are optimised to obtain the chemically ordered L10 phase. Several approaches are followed to obtain two dimensional nanostructured arrays: self organization, artificial generation of nucleation centres prior to growth and post growth patterning using e-beam lithography and nano-masks. The deposition of an epitaxial MgO matrix that conformally covers the FePd islands allows the subsequent growth of further FePd nano-particle layers, obtaining a 3D array of single crystalline high anisotropy particles embedded in an insulating matrix. The magnetization reversal, inter-particle magnetic interactions and magnetic anisotropies are studied in both 2D and 3D arrays, with special emphasis on the role that the reduction in dimensionality and the chemical and spatial order play in the magnetic properties. The characterization of the magneto optic and magneto photonic properties of these new materials is also performed in the same context.

11:20am **MI-WeM10 Properties of Magnetic Wires, Dots, and Dot Chains Fabricated via Epitaxial Growth**, ***D. Li***, Argonne National Laboratory
INVITED

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-WeA

Exchange Coupling, Surfaces, and Interfaces
Moderator: M.E. Hawley, Los Alamos National Laboratory

2:00pm **MI-WeA1 Spin-Dependent Quantum Size Effects in Ultrathin Co Single Crystals**, ***R. Zdyb***, *E. Bauer,* Arizona State University

We have prepared micron-sized ultrathin (0001)-oriented Co single crystals with thicknesses varying between 1 and 10 monolayers by epitaxy on W(110) and studied the spin-dependent reflectivity of electrons with energies up to about 20 eV in spin-polarized low energy electron microscope. Similar to our previous study of ultrathin (110)-oriented Fe single crystals@footnote 1@ , quantum size effects allow the determination of the exchange splitting of the sp band above the vacuum level. We will also report the results of our attempts to understand the apparent oscillatory spin reorientation transition in ultrathin Co films@footnote 2@. @FootnoteText@ @footnote 1@ R. Zdyb and E. Bauer, Phys. Rev. Lett. 9 (2002) 1485. @footnote 2@ T. Duden and E. Bauer, Phys. Rev. Lett. 77 (1996) 2308.

2:20pm **MI-WeA2 Electronic Resonances of Isolated Mn and Interacting Mn-Mn Complexes on GaAs (110) Surfaces@footnote 1@**, ***A. Richardella***, *D. Kitchen, A. Yazdani,* University of Illinois at Urbana-Champaign

Using low temperature scanning tunneling microscopy (STM) Mn on GaAs (110) surfaces has been studied. We present results for isolated Mn adatoms evaporated at low temperature on in situ cleaved n-type and p-type GaAs substrates. Localized modifications of the density of states of the substrates due to Mn are shown. Isolated Mn adatoms can exhibit two equivalent stable bonding states which STM atomic manipulation can induce transitions between. Additionally, certain tunneling parameters lead to increased mobility of Mn on the surface. It is shown isolated Mn's display a strong preference to pair along certain lattice directions. This pairing presents a unique opportunity for studying the interaction of magnetic impurities mediated through the underlying semiconductor states. Resonances due to these Mn-Mn interactions are presented using local density of states (LDOS) spectra and energy resolved spatial maps. In particular it is shown that similarly spaced Mn-Mn pairs can exhibit a number of distinct localized electronic resonances. Studies are ongoing into whether these varied localized states result from the relative spin orientations of the impurities with respect to each other and the surface. @FootnoteText@ @footnote 1@ This work was supported by ARO MURI DAAD19-01-1-0541.

2:40pm **MI-WeA3 Non Linear Aspects of Ultrathin Film Magnetism**, ***D. Pescia***, *O. Portmann,* ETH Zurich, Switzerland*; M. Buess,* University of Regensburg, Switzerland*; A. Vaterlaus,* ETH Zurich, Switzerland*; C.H. Back,* University of Regensburg, Switzerland **INVITED**

We report on two experiments. In the first one, the stripe phase of perpendicularly magnetized ultrathin films is shown to form a Mermin-like 2D solid with algebraic correlations. The second one consists in exciting the spin motion in a vortex-like spin configuration by an ultrashort magnetic field pulse and imaging the local spin dynamics with pico-second time resolution. Both experiments reveal new non-linear aspects of ultrathin film magnetism.

3:20pm **MI-WeA5 Overcoming Thermal Fluctuations in Ferromagnetic Nanostructures using Exchange Bias**, ***J. Nogués***, Inst. Catalana de Recerca i Estudis Avancats, Spain, Sapin*; V. Skumryev,* Inst. Catalana de Recerca i Estudis Avancats, Spain*; S. Stoyanov, Y. Zhang, G. Hadjipanayis,* U. of Delaware*; D. Givord,* CNRS-Grenoble, France*; K. Liu,* U. of California-Davis*; C. Leighton,* U. of Minnesota*; H. Masuda, K. Nishio,* Tokyo Metro. U., Japan*; I.V. Roshchin, I.K. Schuller,* UCSD*; J. Eisenmenger,* U. Ulm, Germany*; J. Sort, J.S. Muñoz, S. Suriñach, M.D. Baró,* U. Autònoma de Barcelona, Spain **INVITED**

Today's interest in nanoparticle magnetism is stimulated by a variety of potential applications, ranging from ultra-high density information storage to medicine. Most applications rely on the magnetic order of the nanoparticles being stable with time. However, in small particles, thermal fluctuations may affect the magnetization stability and possibly lead to superparamagnetism. In this study, we will demonstrate that the exchange coupling between ferromagnetic (FM) nanostructures and antiferromagnetic (AFM) hosts can lead to the magnetic stabilization, i.e. enhancement of coercivity (H@sub C@), increase of remanence (M@sub R@) and ultimately improvement of the superparamagnetic blocking temperature (T@sub B@). Three different cases will be discussed: (i) Co particles ball milled with NiO@footnote 1@, where a small increase of the coercivity and the remanence is observed. (ii) Fe nanostructures deposited on FeF@sub 2@ layers@footnote 2@, where a clear enhancement of the remanence of the hysteresis loop is seen and appears to be linked with its coercivity enhancement. (iii) Co nanoparticles embedded in CoO@footnote 3@, where the blocking temperature is substantially improved with the concomitant increase of H@sub C@ and M@sub R@. In particular, 4nm-Co particles, embedded in a CoO matrix, remain ferromagnetic up to the Néel temperature of CoO. This corresponds to almost 30-fold increase in the blocking temperature compared to the uncoupled nanoparticles. The AFM-FM coupling can be viewed as providing an extra source of anisotropy, thus leading to magnetization stability. @FootnoteText@ @footnote *@ Work supported by EU, CICYT and DGR (UAB), NSF, Seagate (UDEL) and US-DOE (UCSD)@footnote 1@ J. Sort et al., Appl. Phys Lett. 75, 3177 (1999)@footnote 2@ K. Liu et al., Appl. Phys Lett. 81, 4434 (2002)@footnote 3@ V. Skumryev et al. Nature 423, 850 (2003).

4:00pm **MI-WeA7 Growth and Study of Fe/Mn@sub 3@N@sub 2@(010)Bilayers for Use in Spintronics Applications**, ***R. Yang***, *M.B. Haider, H.A. Al-Brithen, A.R. Smith,* Ohio University

Exchange biasing(EB)systems have drawn much attention in recent years, prompted by the intriguing physics and its prominent role in magnetic sensing devices.@footnote 1,2,3@ Yet, the detailed mechanism, which includes the spins at the ferromagnetic(FM)/antiferromagnetic(aFM)interface, is not fully understood. In this paper, we investigate the growth of an EB system using Fe/Mn@sub 3@N@sub 2@ (010) bilayers. The Mn3N2 (010) surface aFM magnetic structure is well understood by means of recent spin-polarized scanning tunneling microscope (SP-STM) studies.@footnote 4@ Mn@sub3@N@sub 2@ has a face-centered tetragonal(fct)rocksalt-type structure. The magnetic moments of the Mn atoms are FM within (001) planes, and are layerwise aFM along [001]. The Néel temperature of Mn3N2 is 925K.@footnote 4,5@ The next step is to study the initial stages of Fe growth on this surface. In this paper, we try to investigate the atomistic changes to the surface which occur at the initial stages of the growth. The growth begins with a 440 nm thick Mn@sub 3@N@sub 2@ aFM layer and substrate is MgO(001). After that, a small coverage (0-10ML) of Fe is deposited in different growth temperatures in the range 350-550@super o@C. The growth is monitored by reflection high-energy electron diffraction (RHEED). After growth, samples are transferred under ultra high vacuum (UHV) directly to STM analysis chamber . STM images reveal a stepped surface with terrace width about 50 Å . The dependence of the film properties on growth parameters such as growth temperature, film thickness and annealing time will be discussed. @FootnoteText@ @footnote 1@W. H. Meiklejohn, et al., Phys. Rev. 102,1413 (1956).@footnote 2@ C. L. Chien, et al., Phys. Rev. B 68, 014418 (2003).@footnote 3@ L. Ritchie, et al., J. Mag. Mag. Mater. 247, 187 (2002).@footnote 4@ H.Q. Yang, et al., Phys. Rev. Lett. 89, 226101 (2002).@footnote 5@ G. Kreiner, et al., J. Alloys Compd. 183, 345 (1992).

4:20pm **MI-WeA8 Magnetic and Structural Properties of Lattice Matched Epitaxial Antiferromagnetic/Ferromagnetic Bilayers**, ***P. Mani***, *V.V. Krishnamurthy,* The University of Alabama*; S. Maat,* Hitachi Global Storage Technologies*; A. Kellock,* IBM Research Division*; G.J. Mankey,* The University of Alabama

The antiferromagnetism of FePt@sub 3@ films grown on Al@sub 2@O@sub 3@(11-20) and MgO(110) has been confirmed by neutron scattering. Fe@sub x@Pt@sub 1-x@ ($0.2 < x < 0.3$) exhibits antiferromagnetic ordering below 160K depending on the film growth temperature, substrate symmetry and composition of the alloy.@footnote 1@ These FePt@sub 3@ films offer a fascinating route to understand the relationship between structure and magnetism in exchange bias systems since Fe@sub x@Pt@sub 1-x@ grows as an ordered antiferromagnet when deposited at 750°C and as a disordered ferromagnet when deposited at 150°C. In addition, ferromagnetic films of CoPt@sub 3@ have the same lattice constant as FePt@sub 3@. Thus these film systems provide a pathway to create strain-free interfaces to test the current models of exchange bias. Both positive and negative exchange bias were observed in strained Fe/FePt@sub 3@ bilayers with different in-plane cooling field directions.@footnote 2@ In the present study, Fe@sub x@Pt@sub 1-x@ films are grown on MgO(111)and a-axis sapphire by co-sputtering Fe and Pt. Epitaxy and alloy ordering have been confirmed by x-ray diffraction. Rutherford backscattering spectrometry and energy dispersive analysis of x-rays were used to characterize the composition of these alloys, which

confirms that stoichiometry can be controlled within a tolerance of 1% in our ultra clean sputtering system. Detailed measurements of the structural and magnetic properties of lattice matched FePt@sub 3@/Fe@sub 0.25@Pt@sub 0.75@ and FePt@sub 3@/CoPt@sub 3@ and their relation to current models of exchange bias behavior will be discussed. @FootnoteText@ @footnote 1@ S. Maat, O. Hellwig, G. Zeltzer et al., Phys. Rev. B, 63, 134426 (2001).@footnote 2@ R.L. Compton, M.J. Pechan, S. Maat, and Eric. E. Fullerton, Phys. Rev. B, 66 (5), 054411 (2002).

4:40pm **MI-WeA9 Momentum Transfer in Exchange Bias Systems of the Type F/af/aaf*, R. Mattheis,*** *K. Steenbeck,* IPHT, Germany

In F/AF exchange bias systems (F ferromagnet, AF antiferromagnet) momentum is transferred from the F film to the AF lattice by coupling via the AF interface net moment and the AF anisotropy. To study the dynamics of the AF lattice during rotation of the F layer magnetisation we sandwiched the F/AF system at the free AF side by a completely symmetric artificial antiferromagnet (AAF) of the kind CoFe/0.8 nm Ru/CoFe. At not too high magnetic field strength this AAF acts, due to its own coercivity and vanishing magnetic net moment, as a fixed spin system coupled at the opposite side of the AF. By means of torquemetry at 10K and 300K the rotational loss and exchange bias strength was determined for different AF thickness t. We found: a) The AAF can fix the AF spin system also at very low thickness t where K is zero. At this thickness exchange bias is found in F/AF system coupled to an AAF but not in the pure F/AF system. b) Fixing of the AF spins by coupling an AAF leads to a drastically reduction of the rotational losses in the AF and rotational anisotropy at a thickness where both where maximum without an AAF. The results show that overcoming the limited anisotropy in very thin AF films is possible by their coupling to an AAF. From the thickness dependence of the observed effects a deeper inside of the exchange bias phenomena is obtained and will be discussed in more detail.

5:00pm **MI-WeA10 Training in Exchange Bias Systems: The Role of Anisotropy*, A. Hoffmann,*** Argonne National Laboratory

The coupling between a ferromagnet and an antiferromagnet can give rise to a directional anisotropy called exchange bias. In order to establish the direction of the exchange bias, the coupled ferro-/antiferromagnetic system is generally cooled in the presence of an external magnetic field through the ordering temperature of the antiferromagnet. In many systems the magnitude of the exchange bias is reduced upon subsequent field cycling after the initial field cooling. These field-training effects are suspected to be due to irreversible changes in the magnetic microstructure of the antiferromagnet, but a comprehensive theoretical understanding is still missing. I will present numerical simulations based on a simple coherent rotation model, which suggest that the symmetry of the anisotropy in the antiferromagnet plays a crucial role for the understanding of these training effects. Namely, the existence of more than one antiferromagnetic easy anisotropy axes can initially stabilize a non-collinear arrangement of the antiferromagnetic spins, which relaxes into a collinear arrangement after the first magnetization reversal of the ferromagnet. This explains quite naturally why training effects are only observed for exchange bias systems with high symmetry antiferromagnets, while they are absent for antiferromagnets with uniaxial anisotropy. Furthermore, this simple and universal model reproduces many of the experimentally observed training effects. The model gives rise to a rotation of the effective easy axis for the ferromagnet after the first field reversal, such that the first magnetization reversal shows a large sudden jump, while all subsequent reversals are more gradual. I will compare in detail the calculated hysteresis loops with experimentally measured ones on the prototypical Co/CoO exchange bias system. This work was supported by the Department of Energy, Basic Energy Sciences under contract No. W-31-109-ENG-38.

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-ThM

Magnetic Oxides and Half-Metallics

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

8:20am **MI-ThM1 Defect Mediated Ferromagnetic Coupling Through an Insulating Barrier Layer@footnote 1@**, ***P.A. Dowben***, University of Nebraska; *R.-H. Cheng,* Argonne National Laboratory; *B. Doudin,* University of Nebraska **INVITED**

Interlayer exchange coupling between two ferromagnetic films, separated by a nonmagnetic non metallic spacer (semiconductor and insulator spacer materials) does occur. This coupling sometimes appears to be distinct from the very low temperature tunneling phenomena between two ferromagnets, through a dielectric spacer layer, as the coupling is sometimes oscillatory. The ferromagnetic coupling between Co and CrO@sub2@, through an insulator (Cr@sub2@O@sub3@) may be rel ated to defect states in the insulating barrier layer.@footnote 2@ In the native Cr@sub2@O@sub3@ surface layer, it appears that at low temperature the conduction band edge electrons are trapped or immobile, and at high temperature there is greater mobili ty. Combined photoemission and inverse photoemission temperature dependent studies confirm the occurrence of a defect mediated blockade energy. It may well be that many defect states are spin polarized, possibly by proximity to the ferromagnetic interface. Other complications exist. The interpretation of junction magneto-resistance results must now assume that ferromagnetic metals will NOT generally form abrupt interfaces with transition metal oxide dielectric barriers. It must be recognized that many met al to metal oxide interfaces involve further oxidation and reduction making such interfaces very heterogeneous, so that nominal CrO@sub2@/Cr@sub2@O@sub3@/Co magnetic junctions are, in fact, more complex multilayers systems akin to a CrO@sub2@/Cr@sub2@O@sub3@/CoO/Co system. @FootnoteText@@footnote 1@ The support of the Office of Naval Research, and the NSF MRSEC (DMR 0213808) are gratefully acknowledged. The authors would like to acknowledge a number of helpful conversations with E. Tsymbal.@footnote 2@ Ruihua Cheng, A.N. Caruso, L. Yuan, S.-H. Liou, and P.A. Dowben, Applied Physics Letters 82 (2003) 1443-1445 .

9:00am **MI-ThM3 Measuring Spin Polarization at the Fermi Level in Potential Half-Metallic Ferro-magnets**, ***J.G. Tobin***, Lawrence Livermore National Laboratory; *T. Komesu, G.D. Waddill,* University of Missouri-Rolla

We have utilized synchrotron-radiation-based techniques to investigate possibly half-metallic ferromagnetic (HMFM) materials. HMFM'Ts are, of course, potential sources of pure spin polarized electrons for spintronic and magnetic information storage devices. These investigations include the application of spin-resolved photoelectron spectroscopy (SPES) to systems such as Fe3O4@footnote 1@ and X-ray Absorption Spectroscopy (XAS) to Zintl compounds such as Yb14MnSb11. @footnote 2@ In the case of Fe3O4, despite having performed the studies at the relatively high photon energy of 160 eV, significant problems with residual surface effects were observed. In order to circumvent or at least minimize these surface complications and to get a better measure of the true bulk spin polarization, we have moved our spin-resolving spectrometer@footnote 3@ to Beamline 4 at the Advanced Photon Source,@footnote 4@ where an Elliptically Polarizing Undulator (EPU) can provide high brightness radiation in the range of 500 eV to 3000 eV. Our first spin-resolved results of the Fe2p core levels@footnote 5@ have confirmed the feasibility of these experiments. Plans for the interrogation of potential half-metallic ferromagnets such as GaMnAs and related materials at these higher energies will be discussed. @FootnoteText@This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48. @footnote 1@ S.A. Morton, G.D. Waddill, S. Kim, I.K. Schuller, S.A. Chambers, and J.G. Tobin, Surface Science Letters 513, L451 (2002). @footnote 2@ A.P. Holm, S.M. Kauzlarich, S.A. Morton, G.D. Waddill, W.E. Pickett, and J.G. Tobin, J. Amer. Chem. Soc. 124, 9894 (2002). @footnote 3@ M. Hochstrasser, J.G. Tobin, E. Rotenberg and S.D. Kevan, "Spin-Resolved Photoemission of Surface States of W(110)-(1X1)H," Phys. Rev. Lett. 89, 216802 (2002). @footnote 4@ J.W. Freeland et al, Rev. Sci. Instrum. 73, 1408 (2002). @footnote 5@ http://www-cms.llnl.gov/s-t/aps.html

9:20am **MI-ThM4 Transition Metal Oxides in Reduced Dimensions**, ***J. Shen,*** Oak Ridge National Laboratory **INVITED**

When the spatial dimension of a material becomes comparable or even smaller than the characteristic length scale of the relevant cooperative phenomena, it is expected that all related physical properties including phase transitions of this material will be dramatically changed. In this work, we focus on the discovery, understanding, and design of low-dimensional 3d transition metal oxides (TMO). We use both physical and chemical methods including laser MBE growth, hydrothermal synthesis, and nanoparticle-catalyzed processes to grow TMO thin films and nanowires. The electronic and magnetic properties of the TMO thin films have been investigated by in-situ scanning tunneling microscopy and ex-situ SQUID magnetometer. We have observed both large-scale (over a few tens nanometers) and nano-scale electronic phase separation (PS) in epitaxially grown thin films of (La5/8-0.3Pr0.3)Ca3/8MnO3. While the large PS domains are present only below the Curie temperature, the nano-scale PS clusters exist at temperatures both below and above Curie temperature. The latter implies that the small PS may originate from doping-related disorder. The TMO nanowires of doped manganites are single crystals with tunable diameters. SQUID magnetometer and e-beam lithography prepared four-point probes have been used to study their magnetic and transport properties.

10:00am **MI-ThM6 Growth and Characterization of PLD Grown Co Doped TiO@sub 2@**, ***S.T. Prisbrey***, UC Davis, Lawrence Livermore National Laboratory; *S.P. Vernon,* Lawrence Livermore National Laboratory

14-20 nm thick 3.7%Co doped TiO@sub 2@ and 5.4% Co doped TiO@sub 2@ have been grown by PLD on LaAlO@sub 3@ (100) substrates. @theta@-2@theta@ x-ray diffraction scans suggest that the films are crystalline and oriented with the z-axis perpendicular to the film surface. AFM/MFM scans show the film to be smooth but with a high defect density (~10@super 6@/cm@super 2@). Defects on the surface of the film do have a magnetic response. X-ray absorption spectroscopy with CoTiO@sub 3@, CoO, and Co@sub 3@O@sub 4@ shows the cobalt to be in the Co@super +2@ formal oxidation state in the majority of the films grown but with no discernable correlation between known deposition parameters and the formal oxidation state of the Co. SQUID magnetic measurements and VSM measurements show that the films are magnetic at room temperature with T@sub c@ > 340°C. Surface ion mass spectrometry was employed to determine that the actual cobalt concentrations in the films are the same as those of the target. Samples were cooled in a field and B-H loops were measured to determine if the magnetic interaction is similar to that of a spin glass.

10:20am **MI-ThM7 Room-Temperature Ferromagnetism in Cr-doped TiO@sub 2@ Anatase**, *T.C. Droubay, S.M. Heald, S.V. Shutthanandan, S.T. Thevuthasan,* ***S.A. Chambers***, Pacific Northwest National Laboratory; *J. Osterwalder,* Physik-Institut der Universitat Zurich, Switzerland

Since the initial discovery in 2001, the possibility of ferromagnetism in doped oxide semiconductors has spawned a flurry of research activity around the world. Among the new materials that have been investigated, Co-doped TiO@sub 2@ anatase has garnered much attention due to its ferromagnetic response, which persists well above room temperature. Reports of doping TiO@sub 2@ anatase with other magnetic transition elements, however, are scarce. We have carried out a detailed study of the growth and properties of epitaxial Cr-doped TiO@sub 2@ anatase on LaAlO@sub 3@ (001) using oxygen-plasma assisted molecular beam epitaxy. These films are found to be single-phase and homogenous, with Cr uniformly substituting for Ti in the lattice. Cr K-shell x-ray absorption near-edge spectroscopy shows that the formal oxidation state of Cr is +3 throughout the films, with no evidence for either elemental Cr or half-metallic CrO@sub 2@. These films are insulating as grown, yet exhibit room temperature ferromagnetism aligned in-plane with a saturation magnetization of ~0.6 Bohr magnetons per Cr atom. Introduction of free electrons by incorporation of additional oxygen vacancies via post-growth annealing in UHV increases both the n-type conductivity and the saturation magnetization, without deleterious effects on the homogeneity or crystallinity of the films. None of the existing models of magnetism in semiconductors can explain ferromagnetism in the absence of free carriers for a dilute system. We will present a novel exchange mechanism to do so.

10:40am **MI-ThM8 Synthesis of Room-Temperature Ferromagnetic Materials by Ion Implantation: Transition-Metals-Doped TiO@sub 2@ (110) Rutile**, ***V. Shutthanandan***, *S.T. Thevuthasan, S.M. Heald, T.C. Droubay, M.H. Engelhard, C.M. Wang, D.E. McCready, T.C. Kaspar, S.A. Chambers,* Pacific Northwest National Laboratory*; P. Nachimuthu, B.S. Mun,* Lawrence Berkeley National Laboratory

There is growing interest in diluted magnetic semiconductors (DMS) in the emerging field of spintronics. It has recently been demonstrated that certain oxide semiconductors doped with magnetic transition metal elements show room-temperature ferromagnetism. In particular, titanium dioxide in both anatase and rutile phases appear to be among the most promising oxide semiconductors for DMS applications. In this study, we show that ferromagnetic transition metal doped TiO@sub 2@ (110) rutile single crystals can be successfully synthesized using ion implantation by carefully controlling implantation parameters such as temperature and ion fluence. Co, Cr, Ni and Fe ions with 100 keV energy were implanted at 875 K to 1075 K and an ion fluence of ~1.25x10@super 16@ ions/cm@super 2@. Vibrating sample magnetometer (VSM) measurements clearly show room temperature ferromagnetic responses with magnetic moments ranging from 0.30 to 0.70 μ @sub B@ /atom. X-ray photoelectron spectroscopy (XPS) depth profiling and Rutherford backscattering spectrometry (RBS) measurements reveal that most of the implanted dopants are uniformly distributed to a depth of ~300 nm with an average concentration of ~1 to 3 at%. K-edge x-ray absorption near edge spectra (XANES) obtained from the implants show that all of the implanted atoms are oxidized and that the formal oxidation is +2 for Co and Ni, +3 for Cr and a mixture of +2 and +3 for Fe. There is no evidence that the dopant is in the metallic state in these implanted samples. In addition, surface-sensitive total electron yield (TEY) and bulk-sensitive total florescence yield (TFY) obtained from the L-edge of Ti and implants and K-edge of O demonstrate that the structural environments in both surface and bulk regions of rutile TiO@sub 2@ are not significantly affected by the incorporation of implanted species.

11:00am **MI-ThM9 MBE Growth and Room Temperature Ferromagnetism in Epitaxial Co-doped SrTiO@sub 3@**, ***T.C. Kaspar***, *T.C. Droubay, S.M. Heald, C.M. Wang, V. Shutthanandan, S.T. Thevuthasan, S.A. Chambers,* Pacific Northwest National Laboratory

Room temperature ferromagnetism in dilute magnetic semiconductors (DMSs) is highly desirable for practical spintronic devices. The observation of room temperature ferromagnetic behavior in doped wide bandgap semiconducting oxides such as Co-doped ZnO, Mn-doped ZnO, and Co-doped anatase and rutile TiO@sub 2@ has raised the possibility of DMS behavior in other oxide systems. Work on these materials has also revealed the critical importance of thorough materials characterization to rule out ferromagnetic contributions from metallic clusters or other secondary phases. Recently, Co-doped La@sub 0.5@Sr@sub 0.5@TiO@sub 3@ was found to exhibit ferromagnetic behavior at room temperature.@footnote 1@ In the present study, epitaxial SrTi@sub 1-x@Co@sub x@O@sub 3@ thin films ($0 < x < 0.15$) have been deposited on SrTiO@sub 3@(001) substrates by oxygen-plasma-assisted molecular beam epitaxy (OPAMBE). Smooth films free of surface particles or clusters are obtained. As-deposited films are insulating (@rho@ > 5 k@Omega@-cm); however, room temperature ferromagnetism is observed for < 5% Co doping, with a high magnetic moment and 10-25% remanence. Films doped at higher concentrations (> 5%) do not exhibit ferromagnetism. Thorough materials characterization was employed, including XPS for film composition, AFM and TEM to observe film morphology and the possible inclusion of secondary phases, and RBS and PIXE to determine the precise Co concentrations. A comprehensive study of Co K-edge XANES and EXAFS data to determine details of the Co charge state and local environment was also carried out. F-center mediated exchange will be discussed as the possible mechanism of ferromagnetic ordering in Co:STO. In addition, preliminary results of epitaxial SrTi@sub 1-x@Co@sub x@O@sub 3@ growth on Si(001) will be presented, and the differences in deposition on oxide and semiconductor substrates will be discussed. @FootnoteText@ @footnote 1@ Zhao, Y.G., et al. Appl. Phys. Lett. 83, 2201 (2003).

11:20am **MI-ThM10 Characterization of Transition Metal Doped ZnO Films and Nanostructures**, ***D.H. Hill***, *L. Wielunski,* Rutgers University*; D.A. Arena,* Brookhaven National Lab*; R. Bartynski, P. Wu, Y. Lu,* 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 and sputter deposition on a variety of substrates. Doping with Mn, and Fe by either diffusion, co-sputtering, or ion implantation has been investigated, and each doping method results in very different dopant depth profiles as revealed by Rutherford backscattering spectrometry. Soft x-ray absorption spectroscopy (SXAS) indicates that the TM dopant may be in either the 2+ or 3+ oxidation state and depends upon doping method. Furthermore, the XAS results are consistent with the TM ions being substitutional for Zn. Squid magnetometry shows that some doping methods yield films exhibiting ferromagnetic behavior, with some Fe-doped films having the Curie temperatures above room temperature. Finally, we discuss the properties of MOCVD-grown ZnO nanotips that have been doped by TM ion implantation.

11:40am **MI-ThM11 Effects of Heat Treatment on the Magnetic Properties of Nickel Cobalt Oxide Films**, ***R.R. Owings***, *G.J. Exarhos, T.C. Droubay, C.F. Windisch,* Pacific Northwest National Laboratory

Spinel films of reactively sputtered nickel cobalt oxide exhibit an increase in saturation magnetization, up to ~5x, when rapidly quenched following heat treatment at 375° C for 10 minutes in air. The films appear to be weakly ferromagnetic with an in-plane saturation occurring in a field greater than 2000 G. Heat treatment followed by rapid quenching has also been shown to increase conductivity. Although the exact mechanism that relates the conductivity to the saturation magnetization is not well understood, the results of this work suggest that there is a relationship between the carrier movement and the spin orientation of the occupied orbitals in the octahedral or tetrahedral lattice positions. The effects of the heat treatment and cooling rate on the magnetic moment, electrical conductivity, index of refraction, IR transmission, and cation disorder are also discussed.

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-ThA

Molecular Spintronics and Dynamics
Moderator: S.E. Russek, NIST

2:00pm **MI-ThA1 Semiconductive Behavior of the Single Molecule Magnets Mn@super12@-Ac, Fe@super8@Br@super8@, and V@super15@**, ***N.S. Dalal***, *E.S. Choi, D. Zipse, R. Vasic, J.M. North, E. Jobiliong, J.S. Brooks,* Florida State University*; P. Kogerler,* Iowa State University **INVITED**

Single Molecule Magnets (SMMs) are clusters of transition metals that have garnered much theoretical and experimental attention due to their ability to show magnetic hysteresis on the single molecule level, and Macroscopic Quantum Tunneling. In order to advance our understanding of these materials for potential applications, the electrical transport properties of three of the most widely studied SMMs, Mn@sub12@-Ac, Fe@sub8@Br@sub8@, and V@sub15@, as well as the polyoxovanadate cluster V@sub12@ were examined. These materials all showed semiconductive behavior, with varying transport gaps, E@suba@, for each. Under the assumption that the optical band gap is twice the magnitude of the transport gap, E@subg@ = 2 E@suba@, the magnitude of the transport gap for Mn@sub12@-Ac (0.37 eV), V@sub15@ (0.2 eV), and V@sub12@ (0.48 eV) compares well with optical band gap measurements@footnote 1@,@footnote 2@ thus verifying the value of transport measurements in electronic structure calculations for SMMs. These data should provide a sensitive basis for comparing the various theoretical calculations and, thus, for understanding the electronic structure of these materials. @FootnoteText@ @footnote 1@ S.M. Oppenheimer, A.B. Sushkov, J.L. Musfeldt, R.M. Achey, and N.S. Dalal, Phys. Rev. B 65, 054419 (2002).@footnote 2@ J.Choi, L.A.W. Sanderson, J.L. Musfeldt, A. Ellern, and P. Kogerler, Phys. Rev. B 68, 064412 (2003). .

2:40pm **MI-ThA3 High Frequency Investigations of Molecular Nanomagnets by use of a Broadband SQUID-Detected Electron Paramagnetic Resonance Probe**, ***B. Cage***, *S.E. Russek,* National Institute of Standards and Technology*; D. Zipse, J.M. North, N.S. Dalal,* Florida State University **INVITED**

We are synthesizing and characterizing (by use of high frequency electron paramagnetic resonance (HFEPR)) molecular nanomagnets (magnetic molecules < 2 nm that behave as single molecule magnetic domains) for high-frequency spintronics applications. We will discuss current efforts to examine the magnetic susceptibility of these nanomagnets as 2-dimensional films vs the 3-dimensional bulk behavior of aligned single crystals. HFEPR data at 95 and 141 GHz, with magnetic resonance fields ranging from 0 - 12 Tesla indicate potential as tunable high-frequency low-applied-field oscillators from 5 - 80 K. This work represents some of the highest temperatures at which these magnets have been characterized, which is of importance for practical spintronics applications. To complement this work we have developed a new experimental technique that uses SQUID detection of the magnetic susceptibility as a function of applied magnetic field through the EPR transition at resonance frequencies > 60 GHz and magnetic fields up to 5 Tesla. One advantage over conventional EPR being the quantitative determination of the level of saturation. We will present data on the large electronic spin (S) S=10 molecular nanomagnet Fe8 that discretely identifies the spin-lattice-relaxation time, T1, of the individual ms quantum spin states. This is in contrast to the current non-resonant techniques, such as AC susceptibility, that only provide information on the global T1 properties averaged across all states.

3:20pm **MI-ThA5 Spin-Dependent Tunneling through Molecules**, ***A.N. Pasupathy***, Cornell University **INVITED**

We discuss two experiments involving spin-polarized tunneling through molecules. In the first experiment, we study nickel tunnel junctions made using a self-assembled-monolayer of octanethiol as a molecular barrier. The devices exhibit significant magnetoresistance, demonstrating that low-energy electrons can traverse the molecular barrier while maintaining spin coherence. In the second experiment, we measure Kondo-assisted tunneling via a carbon-60 molecule in contact with ferromagnetic nickel electrodes. We find that the Kondo peak in the differential conductance is split, by an amount that decreases as the magnetic moments in the two electrodes are turned from parallel to antiparallel alignment. We observe large negative values of the junction magnetoresistance due to the presence of the Kondo effect. @Footnotetext@In collaboration with J. R. Petta, S. R. Slater, R. C. Bialczak, J. Martinek, J. E. Grose, L. A. K. Donev, P. L. McEuen, D. C. Ralph

4:00pm **MI-ThA7 Excitation of Microscopic Spin Waves in Ultrathin Films by Spin-Polarized Electron Energy Loss Spectroscopy**, *R. Vollmer, W. Tang,* ***M. Etzkorn***, *P.S.A. Kumar,* Max Planck Institute of Microstructure Physics, Germany*; H. Ibach,* Institute for Surfaces and Interfaces, Germany*; J. Kirschner,* Max Planck Institute of Microstructure Physics, Germany **INVITED**

The properties of long wavelength spin waves have been investigated since decades by ferromagnetic resonance (FMR), Brillouin light scattering (BLS) and more recently by time domain optical techniques. The properties of these spin waves are determined largely by macroscopic and static quantities like the magnetization and anisotropy energies. In bulk materials inelastic magnetic neutron scattering can be used to measure microscopic spin waves with wavelength of atomic dimensions. We have shown recently that spin polarized electron energy loss spectroscopy (SPEELS) can be used to study these microscopic spin waves in ultrathin films up to the surface Brillouin zone boundary@footnote 1@. Up to now we have investigated ultrathin films of fcc Co, hcp Co, fcc Fe, fcc Fe, and bcc Fe on various substrates. In most cases the spin wave excitation can be observed as well pronounced peak in the loss spectrum. In this case, the acoustic spin wave branch of the surface spin wave mode can be described surprisingly well by a simple nearest-neighbor Heisenberg model. Nevertheless, the spectra indicate the itinerant character of the spin waves as discussed in Ref.@footnote 2@. The acoustic branch is significantly broadened and no clear indication of an optical mode (expected from a Heisenberg model) could be observed up to now. The spin wave peaks are visible in the SPEEL spectrum only for low (<10 eV) energies of the incident electrons. @FootnoteText@ @footnote 1@ R. Vollmer, M. Etzkorn, P.S. Anil Kumar, H. Ibach, and J. Kirschner, Phys. Rev. Lett. 91, 147201 (2003).@footnote 2@ A. T. Costa, Jr., R. B. Muniz, D. L. Mills, Phys. Rev. B 69, 064413 (2004).

4:40pm **MI-ThA9 Ferromagnetic Resonance: An Ultimate Tool to Study the Dynamical Response of Nanostructured Magnetic Systems**, ***J. Lindner***, Universität Duisburg-Essen, Germany*; K. Baberschke,* Freie Universität Berlin, Germany*; M. Farle,* Universität Duisburg-Essen, Germany **INVITED**

Ferromagnetic resonance (FMR) measurements probe the dynamical response of magnetic systems subsequent to an excitation within the microwave regime. Due to the high sensitivity of FMR this technique is well suited for the investigation of nanostructures and ultrathin magnetic films or multilayers@footnote 1@. As the resonance condition is determined by internal fields in the sample like anisotropy fields or interlayer coupling fields within layered structures, FMR experiments give a direct access to these quantities based on an analysis that uses the Landau-Lifshitz equation of motion. This will be demonstrated for the case of Ni/Cu/Ni and Ni/Cu/Co films grown epitaxially on Cu(100) subtrates. A unique possibility to grow and measure the films within an ultrahigh vacuum environment allows to stepwise study the layered structures and, thus, also to investigate the effect of capping layers. Besides investigating the FMR resonance field a careful analysis of the FMR linewidth yields information about relaxation processes within the magnetic system. From frequency dependent experiments we show for the case of Fe/V multilayers that a purely Gilbert-like damping term is not sufficient to explain the observed values of the linewidth@footnote 2@. In this system the relaxation is strongly influenced by the decay of the uniform precession mode due to two-magnon processes. Finally, also within laterally structured systems FMR can be applied to study magnetic properties. This is demonstrated for the case of monodisperse Co/CoO core/shell particles of about 10nm diameter, for which the temperature dependence of the anisotropy energy is discussed. @FootnoteText@ @footnote 1@ J. Lindner, K. Baberschke, J. Phys.: Condens. Matter 15, R193 (2003); S465 (2003).@footnote 2@ J. Lindner, K. Lenz, E. Kosubek, K. Baberschke, D. Spoddig, R. Meckenstock, J. Pelzl, Z. Frait, D. L. Mills, Phys. Rev. 68, 060102(R) (2003).

Magnetic Interfaces and Nanostructures
Room 304A - Session MI-FrM

Advanced Magnetic Data Storage and Thin Film Processing
Moderator: E. Dobisz, Hitachi

8:20am **MI-FrM1 Magnetic Tunnel Junctions for Magnetoresistive Random Access Memory**, ***J.M. Slaughter***, *J. Åkerman, B. Butcher, R.W. Dave, M. DeHerrera, M. Durlam, B.N. Engel, G. Grynkewich, J. Janesky, J. Martin, S.V. Pietambaram, N.D. Rizzo, K. Smith, J.J. Sun, S. Tehrani,* Freescale Semiconductor **INVITED**

Magnetoresistive random access memory (MRAM) employs a magnetoresistive device integrated with standard silicon-based microelectronics, resulting in a combination of qualities not found in other memory technologies. For example, MRAM is non-volatile, has unlimited read and write endurance, and has demonstrated high-speed read and write operations. Fundamentals of MRAM based on Magnetic Tunnel Junction (MTJ) devices, and recent technology developments in the areas of magnetic materials and magnetic device design is reviewed. The properties of our unique toggle-switching MRAM bit, as well as specific magnetic and electrical properties required for that bit will is discussed and compared to the conventional switching approach. The new bit cell uses a balanced synthetic-antiferromagnetic free layer and a phased write pulse sequence to provide robust switching performance with immunity from half-select disturbs. The use of this bit cell in a 4Mb MRAM circuit also is described.

9:00am **MI-FrM3 Processing Challenges in the Magnetic Recording Industry**, ***J.A. Katine***, Hitachi Global Storage Technologies **INVITED**

Following the introduction of the giant magnetoresistive sensor in 1997, the areal density of magnetic storage doubled annually for five years. This doubling meant that the critical dimension of the smallest features on the thin film recording head, the sensor trackwidth and the writer poletip width, decreased by 30 percent per year. Recently, though, there has been a dramatic slowdown in rate of increase for areal recording density, in large part due to the processing challenges associated with scaling the critical features to sub-100 nm dimensions. This talk will present an overview of the processing of magnetic recording heads, emphasizing the key challenges facing the industry. These include lithographic tooling options for printing critical dimensions that will soon be smaller than the smallest features used in IC processing. Of particular interest to the industry is the feasibility of using direct write electron beam lithography for the production of recording heads. Another obstacle to overcome will be developing etching techniques for magnetic materials that do not produce unacceptable damage at the edges of the devices. Advances are also required in developing the thin insulating gap materials with thermal and electrical properties suitable for ultrahigh areal density recording. In addition to processing challenges in the recording head, to reach areal densities approaching 1 Terabit per square inch, it is likely that the magnetic media itself will require lithographic patterning. I will outline the formidable challenges involved in producing economically viable patterned media.

10:00am **MI-FrM6 Reversal Mechanism of Patterned Co/Pd Multilayer Islands**, *G. Hu, T. Thomson,* Hitachi Global Storage Technologies*; C.T. Rettner,* IBM Almaden Research Center*;* ***B.D. Terris***, Hitachi Global Storage Technologies

Arrays of patterned Co/Pd magnetic islands with perpendicular anisotropy and sizes ranging from 30nm to 5 microns have been fabricated and characterized. Applying a field along the easy axis results in individual magnetic islands switching as a single unit, as observed by the magnetic optic Kerr effect and magnetic force microscope (MFM) measurements. The angle dependence of switching closely resembles the behavior predicted by the Stoner-Wohlfarth model with a minimum in island coercivity at 45 degrees. These results are expected for small islands which may reverse by rotation, but are surprising for the larger islands. The nominally identical continuous film exhibits a completely different behavior, where the film coercivity increases with the angle (t) between the applied field and film normal as 1/cos(t), as predicted for domain wall motion controlled reversal. These data leads to a model whereby the reversal of the larger islands is controlled by a nucleation event, followed by a rapid wall motion. The observed switching field of the island is the switching field of the small nucleation site, which reverses coherently. To test this model, we artificially introduce nucleation sites into the islands by applying an in-plane field. This results in a domain wall motion controlled angle dependent behavior in all islands capable of supporting a multi-domain ground state (size ranging from 200nm to 5 microns). The reversal behavior of the larger islands therefore depends on the initial state of the islands. In an island with no nucleation sites the reversal is governed by rotation, whereas in the same island into which nucleation sites have been pre-created, the reversal is governed by wall motion.

10:20am **MI-FrM7 Hierarchical Self-Assembly as a Route to Future Magnetic Data Storage**, ***S.B. Darling***, Argonne National Laboratory*; D. Sundrani, S.J. Sibener,* The University of Chicago

A novel hybrid top-down/bottom-up approach is used to hierarchically organize magnetic nanoparticles on the nanoscale. Lithographically prepared substrate channels direct the self-assembly of a high-aspect ratio diblock copolymer template resulting in nearly defect-free alignment over arbitrarily long distances.@footnote 1@,@footnote 2@ Selective wetting of the channel sidewalls by one block initiates the organization and is followed by coarsening until the entire channel volume contains aligned domains. Overfilling the channels further extends the alignment, originally nucleated on the sidewalls, both above and beyond the confined space. This approach may be useful for globally aligning domains across an entire surface with the top interface being nearly flat despite the corrugated substrate underneath. The oriented structures are surprisingly defect-tolerant, accommodating roughly 10% variations in channel width without introducing disclination or dislocation defects. The laterally alternating nanoscale structure of the diblock film is then used to template the adsorption of FePt nanoparticles. Attractive interaction of the nanocrystal capping molecules with one of the polymer blocks leads to nearly 100% selective adsorption. Hybrid hierarchical approaches such as this are promising candidates for high density storage media. @FootnoteText@ @footnote 1@ D. Sundrani, S.B. Darling, S.J. Sibener, Nano Letters, 4 (2004) 273-276.@footnote 2@ D. Sundrani, S.B. Darling, S.J. Sibener, Langmuir, In Press.

10:40am **MI-FrM8 Enhanced Magnetic Moment in Iron Nitride Thin Films**, ***R.A. Lukaszew***, University of Toledo, US*; D. Pearson, Z. Zhang,* University of Toledo

In magnetism, maximum interest is focused on iron and iron-based alloys because these materials are of greatest practical use. Iron-based alloys are most susceptible to modification by nitrogen, which can turn them from weak to strong ferromagnets. Nitrogen enters 3d metals as an interstitial provoking a dilation of the lattice. The Fe-N system exhibits several phases of technological importance including several Fe-N intestitial compounds with nitrogen ordering. The ordered iron nitrides are metastable compounds which can persist at moderate temperature because of kinetic constraints. In particular, the magnetic properties of the @alpha@"-Fe@sub 16@N@sub 2@ phase have been of interest for both scientists and technologists since it was first discovered to exhibit magnetization as great as 2.4 T, significantly higher than that of @alpha@-Fe. An important issue is the role of nitrogen in enhancing the iron magnetic moment. Current theories explain the enhanced magnetic moment in terms of a reduced moment on the iron sites that are the nearest-neighbours of nitrogen, and an enhanced moment on the more distant sites due to hybridisation of the 3d states of the iron that is a nearest neighbour and charge transfer from the more distant iron @footnote 1@. No polarization of the N atoms is assumed. In order to evaluate the potential of these materials for magnetic recording head as well as to understand the origin of the observed enhanced magnetic moment more detailed research is required. We will present our studies on epitaxial FeN films grown using reactive magnetron sputtering. We will show magnetic characterization of the films, performed using SQUID, MOKE and XMCD. In particular XMCD data indicates that in addition to Fe, N is also polarized in these films. Thus we believe that N polarization may be the primary reason for enhanced magnetic moment in these materials. @FootnoteText@ @footnote 1@. J.M. D. Coey and P. A. I. Smith, J. Mag. Mag. Mat. 200, 405-424 (1999).

11:00am **MI-FrM9 Direct Observation of Nano-Oxide Formation in Spin Valve Multilayers**, ***A.T. McCallum***, NIST, U.S.*; S.E. Russek,* NIST

The addition of thin oxide layers, that specularity reflect electrons, to spin valve trilayers has been shown to increase the giant magnetoresistance of these structures. Usually the specularity of an oxide is deduced by comparing the resistance and magnetoresistance of samples with and without nano-oxide layers. These comparisons are clouded by sample to sample variations and the fact that adding an oxide changes the growth mode of material deposited on top of the oxide. In-situ conductance measurements allow direct observation of the specularity increase as the

oxide forms. One key advantage of this measurement is that on one sample the effects of a range of oxygen exposures are measured. The Co free layer of bottom pinned spin valves was oxidized and the conductance and magnetoconductance were measured. These measurements show that the CoO@sub x@ layers become specular within ~5 monolayers of oxygen exposure. Conductance measurements during the oxidation of relatively thick layers of Co show a specularity increase of at least 0.10. Subsequent oxidation does not change the specularity of the nano-oxide. RHEED patterns taken during the oxidation show the appearance of a new face centered cubic, fcc, 111 lattice with a lattice constant consistent with CoO. The region between these two lattices is probably the region that determines the amount of specularity at that interface with the nano-oxide. A second set of bottom pinned spin valves were made with a 1 nm thick Co@sub 1-x@Fe@sub x@ cap on the free layer. This material was then exposed to oxygen. One nm should be about the amount of metal oxidized. The more Fe that was included in the free layer cap the less the specularity increased with oxygen exposure. The sample with a Co cap had a increase in the magnetoconductance of 0.00020 @ohm@@super -1@ during oxidation. The sample with a pure Fe cap had a decrease in magnetoconductance of 0.00005 @ohm@@super -1@ with oxidation.

11:20am **MI-FrM10 Novel Green Plasma Etch Chemistries for Magnetic Metals.**, ***A.S. Orland***, *A.A. Dyachenko, R. Blumenthal,* Auburn University

Chlorine, an enviromental menace, is traditionally used to etch magnetic metals in manufacturing of semiconductor devices. In this work, the etching of magnetic metals with hydrogen plasmas containing environmentally friendly gases such as carbon monoxide, carbon dioxide and cyclopentadiene (Cp) is investigated by means of supersonic pulse, plasma sampling mass spectrometry. Previous results, in our group,@super 1@ have indicated that the etch rates of nickel are significantly enhanced in CO/H@sub 2@ plasmas and CO@sub 2@/H@sub 2@ plasmas at the same time that formate and oxalate signals appear in the mass spectrum. It is further assumed that these species serve as new primary etchants resulting in the formation of volatile metal formates and oxalates. The etch rates and chemical mechanisms responsible for the etching in CO/H@sub 2@, CO@sub 2@/H@sub 2@ and Cp/H@sub 2@ plasmas will be presented. @FootnoteText@ @footnote 1@ A.Orland, Ph.D. thesis, Auburn University, 2003.

11:40am **MI-FrM11 Characterization of FePt-based Magnetic Nanocomposite Thin Films Prepared by Pulsed Filtered Vacuum Arc Deposition**, ***Y.W. Lai***, *M.F. Chiah, N. Ke, Q. Li, W.Y. Cheung,* Chinese University of Hong Kong*; S.P. Wong,* Chinese University of Hong Kong, Hong Kong

We have prepared FePt-X (X = C, Cu or Ag) nanocomposite thin films of various compositions consisting of FePt grains embedding in carbon, copper or silver matrices using a pulsed filtered vacuum arc deposition technique. In addition to usual co-deposition processes, another process was adopted where multilayers of the three elemental components with an appropriate design of thickness and sequence were first deposited followed by a rapid thermal annealing (RTA) in an argon atmosphere. Characterization of these films was performed using Rutherford backscattering spectrometry, x-ray diffraction, transmission electron microscopy, and vibrating sample magnetometry. The dependence of the structure and magnetic properties, such as the phase and size of the magnetic grains and the coercivity of these films, on the deposition parameters, annealing conditions and the matrix materials were studied in details. Both x-ray diffraction and transmission electron microscopy analyses confirmed the formation of L1@sub 0@ phase FePt nano-grains after appropriate annealing. For example, for the film with a particular composition of Fe@sub 43@Pt@sub 45@Cu@sub 12@, the L1@sub 0@ phase formation was observed after the RTA process at 400@super o@C, and the film exhibited a coercivity of 6.5 kOe. Compared to films prepared by usual co-deposition process, those films prepared using the multilayer deposition approach see a significant lowering in the ordering temperature at which the L1@sub 0@ phase started to form. The degree of lowering in the ordering temperature was seen to depend on the species of the matrix material. It is believed that different mechanisms are responsible for such ordering temperature lowering in films of different matrices. This work is supported in part by the Research Grants Council of Hong Kong SAR (Ref. Number: CUHK4216/00E).

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