## Magnetic Interfaces and Nanostructures
## Room: 206 - Session MI-ThM

## Magnetic Surfaces, Interfaces, Thin Films and Heterostructures
**Moderator:** J. Shen, Oak Ridge National Laboratory

8:00am **MI-ThM1 Exchange-Split Surface State on Gd(0001) Revisited**, ***M. Budke***, *M. Donath*, WWU Münster, Germany

Gd is considered to be a prototype Heisenberg ferromagnet, because its magnetism originates from the strongly localized electrons in the half-filled f shell and is mediated via RKKY interaction by the conduction electrons. Close to the Fermi energy $E_F$ an exchange-split d-like surface state is found, which is thought to be responsible for peculiar magnetic effects of the Gd(0001) surface. The behaviour of this surface state close to Curie temperature $T_C$ has been controversially discussed: spin-resolved inverse photoemission (IPE) has identified a surface state with both, minority and majority components right above the Fermi energy $E_F$ already 10 years ago.[1] While the majority state shifts to higher energies upon approaching $T_C$ the minority state shifts to lower energies. This Stoner-like collapsing band behaviour is in contradiction to results from spin-resolved photoemission (PE), where the surface state shows up at 0.2 eV below $E_F$ and exhibits spin-mixing behaviour upon approaching $T_C$.[2] The present widely accepted picture of the surface state on Gd(0001) comprises a majority component 0.2 eV below $E_F$ and a minority component 0.4 eV above $E_F$ at low T. As identified by spin-integrated scanning tunneling spectroscopy[3] the exchange splitting slightly reduces with increasing T and remains 0.4 eV at $T_C$.[3] However, the unoccupied majority component as identified by IPE still remains mysterious. One reason for the conflicting results might be found in different sample conditions since the Gd films are usually grown on W(110), a material with considerably different lattice constant than Gd. To overcome this suspicion, we performed combined spin-resolved PE and IPE measurements on one and the same sample preparation of a 30 ML Gd film grown on Y(0001). We were able to identify two surface states with their minority and majority components well separated from $E_F$. While the occupied surface state shows spin-mixing behaviour as observed in other PE experiments, the unoccupied surface state exhibits an exchange splitting of 250 meV that vanishes at $T_C$.

[1]Donath et al., PRL 77, 5138 (1996).
[2]Li et al., Phys. Rev. B 51, 13895 (1995).
[3]Getzlaff et al., JMMM 184, 155 (1998).

8:20am **MI-ThM2 Electrical Injection and Detection of Spin-Polarized Carriers in Silicon in a Lateral Transport Geometry**, ***O.M.J. van 't Erve***, *A.T. Hanbicki, M. Holub, C.H. Li, C. Awo-Affouda, G. Kioseoglou, P.E. Thompson, B.T. Jonker*, Naval Research Laboratory

The electron's spin angular momentum is one of several alternative state variables under consideration on the International Technology Roadmap for Semiconductors for processing information in the fundamentally new ways, which will be required beyond end-of-roadmap CMOS technology. Electrical injection / transport of spin-polarized carriers is prerequisite for developing such an approach. Significant progress has recently been made on spin injection into the technologically important semiconductor, Si, using vertical device structures.[1,2] Here we present the electrical injection, detection and magnetic field modulation of lateral diffusive spin transport through silicon using $Fe/Al_2O_3$ surface contacts.[3] The $Fe/Al_2O_3$ tunnel barrier contacts are used to create and analyze the flow of pure spin current in a silicon transport channel. A nonlocal detection technique has been used to exclude spurious contributions from AMR and local Hall effects. The nonlocal signal shows that a spin current can be electrically detected after diffusive transport through the silicon transport channel and the signal depends on the relative orientation of the magnetization of the injecting and detecting contacts. Hanle effect measurements demonstrate that the spin current can be modulated by a perpendicular magnetic field, which causes the spin to precess and dephase in the channel during transport. The realization of efficient electrical injection and detection using tunnel barriers and a simple device geometry compatible with "back-end" Si processing should greatly facilitate development of Si-based spintronics. This work was supported by ONR and core NRL programs.

[1] Jonker et. al., Nat. Phys. 3, 542 (2007)
[2] Applebaum et. al., Nat. 447, 295 (2007) .
[3] van 't Erve et. al., Appl. Phys. Lett. 91, 212109 (2007).

8:40am **MI-ThM3 Room Temperature Ferromagnetism and Surface Morphology in Cr-doped $Ga_2Se_3$ Films on Si(001)**, ***E.N. Yitamben***, *T.C. Lovejoy*, University of Washington, *D.F. Paul, J.B. Callaghan*, Physical Electronics USA, *S.C. Fain, F.S. Ohuchi, M.A. Olmstead*, University of Washington

The intrinsic vacancy semiconductor $Ga_2Se_3$, which may be grown epitaxially on Si, presents several interesting issues for the study of dilute magnetic semiconductors. Transition metal doping may lead to occupation of either vacancy sites or Ga sites in the lattice, which could lead to n- or p-type doping, respectively. The vacancy-induced anisotropy and wide bandgap (2.3 eV) may also lead to high Curie temperatures. To probe the interaction between magnetism, morphology, and free carriers in this new class of magnetic material, experimental investigations of Cr-doped $Ga_2Se_3$ epitaxially grown on Si(100):As have been pursued. Inclusion of Cr into the $Ga_2Se_3$ lattice results in new states at the Fermi edge, signaling a metallic structure, and the films are ferromagnetic at room temperature (though with a saturation moment about 1/4 of the low temperature value.) Scanning tunneling microscopy reveals formation of clusters within trenches whose shape and size depend on the Cr concentration and whether or not an undoped $Ga_2Se_3$ buffer layer is deposited first. Scanning Auger microscopy reveals a compositional difference between the clusters and the terraces surrounding them, with a larger Cr:Ga ratio in the clusters. We suggest this concentration difference, and the resultant strain and/or difference in chemical potential, may control the size and shape of the trenches surrounding the clusters. Work supported by NSF grant DMR-0605601 and NER-0508216. ENY was supported by an IBM Fellowship; TCL was supported by an IGERT Fellowship, NSF/NCI DGE 0504573. Some experiments were performed at the Advanced Light Source, Berkeley, supported by DOE contract DE-AC02-05CH11231.

9:00am **MI-ThM4 Organic-based Magnetoelectronics from an Electronic Structure View**, ***A.N. Caruso***, U. of Missouri - Kansas City, *K.I. Pokhodnya*, North Dakota State U., *W.W. Shum*, U. of Utah, *W.-Y. Ching*, U. of Missouri - Kansas City, *B. Anderson, M.T. Bremer*, North Dakota State U., *E. Vescovo*, Brookhaven National Lab., *P. Rulis*, U. of Missouri - Kansas City, *A.J. Epstein*, Ohio State U., *J.S. Miller*, U. of Utah
**INVITED**

Successful semiconductor magnetoelectronic device operation requires solids with the ability to inject and/or retain carrier spin polarization across multiple interfaces. Inorganic transition metal doped semiconductors (postulated dilute magnetic semiconductors such as Co:TiO2 and Mn:GaAs) have not been able to meet these criterion at room temperature due to solubility problems.[1] Organic-based magnets however, offer increased interfacial stability and elastic spin carrier lifetimes, due to the small differences between their surface and bulk free energies, and low spin-orbit scattering and/or hyperfine interactions.[2] The remaining piece is to directly show that organic-based magnets are indeed capable of electron spin polarization at or near the Fermi edge. The first direct evidence of an organic-based magnet with a finite electron spin polarization at the Fermi edge, collected from spin resolved photoemission of $[Fe^{II}(TCNE)(NCMe)_2][Fe_{III}Cl_4]$[3] will be presented. An ab initio calculation of the spin resolved band structure will also be presented, backing the claim that $[Fe^{II}(TCNE)(NCMe)_2][Fe_{III}Cl_4]$ is a half-semiconductor. Lastly, the electronic structure relationship between magnetic exchange and structural bonding will be discussed within the context of the experimental and computational results.

[1]A. R. Rocha, V. M. Garcia-Suarez, S. W. Bailey, C. J. Lambert, J. Ferrer, S. Sanvito, Nature Materials 4, 335 (2005).
[2]Satishchandra Ogale, Darshan Kundaliya, Shareghe Mehraeen, Lian-feng Fu, Shixiong Zhang, Alexandre Lussier, Joe Dvorak, Nigel Browning, Yves Idzerda, Thirumalai Venkatesan, Chem. Mater. 20, 1344 (2008).
[3]K. I. Pokhodnya, M. Bonner, J.-H. Her, P. W. Stephens, J. S. Miller, J. Amer. Chem. Soc. 128, 15592 (2006).

10:40am **MI-ThM9 Electrical Spin Injection into InAs Wetting Layer**, ***C.H. Li***, *G. Kioseoglou, A.T. Hanbicki, R. Goswami, C.S. Hellberg, B.T. Jonker*, Naval Research Laboratory, *M. Yasar, A. Petrou*, SUNY Buffalo

Efficient electrical injection of spin-polarized electrons from a magnetic contact into a semiconductor is an essential requirement for utilizing the spin degree of freedom in semiconductor spintronic devices. InAs is an attractive material for optoelectronic and high-speed transistor devices due to its small bandgap and high electron mobility. Owing to its large Rashba spin-orbit coupling, the 2-dimensional electron gas (2DEG) formed in InAs-based heterostructures has also been proposed for spin transport within a spin field effect transistor (FET).[1] Here we demonstrate efficient spin injection from Fe into a thin (~3ML) InAs wetting layer (WL) that forms on GaAs before the formation of InAs quantum dots (QDs).[2] Cross sectional

scanning tunneling microscopy (STM) and transmission electron microscopy (TEM) show that the WL is continuous laterally over many microns, and that it is an intermixed InxGa1-xAs layer. Transport measurements reveal a 2DEG-like behavior. The WL electroluminescence is readily distinguished from that of the QDs, and dominates emission at higher biases over a wide temperature range up to RT. We measure an optical circular polarization of 26% at 5K due to the injection of spin-polarized electrons from a reverse-biased Fe Schottky contact, which corresponds to an electron spin polarization >50% after lifetime corrections, demonstrating that even this remarkably thin layer supports high spin polarization. This polarization stayed relatively constant up to 60K, and decreased to ~6% at room temperature, consistent with the D'yakonov-Perel spin relaxation mechanism which dominates at high temperatures.

Work at NRL are supported by ONR and NRL core funds. Work at SUNY are supported by NSF.
[1]S. Datta and B. Das, Appl. Phys. Lett. 56, 665 (1990).
[2]C. H. Li et al. APL 91, 262504 (2007).

11:00am **MI-ThM10 Phase Coexistence in the AF to FM Transition in Epitaxial FeRh Thin Films**, *D.A. Arena*, ***Y. Ding***, Brookhaven National Laboratory, *L.H. Lewis*, Northeastern University, *C.J. Kinane*, *B.J. Hickey*, *C.H. Marrows*, University of Leeds, UK, *J.-W. Kim*, *P.J. Ryan*, Argonne National Laboratory & Ames Laboratory, *M. Ali*, University of Leeds, UK

The near equiatomic, ordered alloy FeRh exhibits an unusual first order antiferromagnetic (AF) to ferromagnetic (FM) phase transition at around 380 K[1] and interest in this system has increased recently, driven both from unresolved scientific questions and potential applications in high-density storage media and advanced sensors. In these studies, highly ordered, epitaxial thin films of FeRh, grown by molecular beam epitaxy (MBE), were measured with a variety of techniques including using x-ray magnetic circular dichroism (XMCD), and conventional and surface x-ray diffraction (XRD). XMCD was measured in two modes: surface sensitive total electron yield (TEY) and bulk sensitive indirect transmission (IT). The TEY data reveal a persistence of ferromagnetism in the near surface region at room temperature while the indirect transmission data indicate that the bulk material is not FM ordered and is presumably AF. In general terms, conventional XRD measurements from our thin films show that the AF to FM phase transition, which is hysteretic in temperature, is accompanied by an abrupt lattice expansion; this behavior mirrors the expansion observed in bulk samples. However, high-resolution XRD data indicate that the lattice expansion is not smooth, but rather occurs via the coexistence of two distinct lattice parameters, where the smaller volume lattice is presumably associated with the AF phase and the larger lattice contains the FM ordered FeRh. Surface XRD, acquired near the critical angle for x-ray penetration, reveals that the temperature for the transition from the smaller to the larger lattice parameter occurs at a reduced temperature for the surface than for the bulk. Comparisons with the XMCD data for different capping layers of the FeRh films and sum-rule analyses of the Fe magnetic moment will also be discussed.

[1]J. S. Kouvel and C. C. Hartelius, J. Appl. Phys. 33, 1343 (1962).

11:20am **MI-ThM11 A Surface-Driven Route to the Synthesis of Mn-Si and Mn-Ge-Quantum Dot Nanostructures**, ***C.A. Nolph***, *H. Liu*, *P. Reinke*, University of Virginia

The combination of the group IV semiconductors silicon and germanium with an element with a large magnetic moment, such as Manganese, is a critical step in the development of novel and versatile spintronics devices. The goal of our studies are to firstly, incorporate Mn as delta-doped layers in a crystalline Si matrix, which is predicted to present a ferromagnetic structure with a half-metallic character, and secondly, to magnetically dope Ge-quantum dots, which are fabricated by a strain-driven Stranski-Krastanov growth on a Si(100) surface. The synthesis of both types of nanostructures begins with the deposition of Mn on a Si(100)-2x1 surface, which serves as the template for the subsequent Si or Ge overlayer growth. The evolution of nanostructures is observed with scanning tunneling microscopy (STM), and photoelectron spectroscopy (PES) to study bonding and electronic structure at the surface. The prerequisite for a successful synthesis of the Mn-doped Si and Ge nanostructures is to control the Mn-surface structure on Si(100)-(2x1), which is achieved by establishing the surface phase diagram as a function of temperature and Mn-coverage. At room temperature the formation of short monoatomic Mn wires, oriented perpendicular to the Si-dimer rows, dominates. Upon heating the Mn-adatom wires are first transformed to subsurface Mn-Si then the formation of Mn-silicide crystallites occurs. At the same time, the defect density on the Si surface rises dramatically, including a loss of structural integrity at the terrace edges. The surface phase diagram establishes guidelines for the subsequent formation of Si-overlayers and Ge QD growth, and shows the variability in Mn-surface structures and bonding within the Mn-Si(100)-(2x1) system; the consideration of these factors will decisevely influence the resultant magnetism of Mn-delta doped Si-structures. A first assessment of the magnetism in the layered structure is obtained from a measurement of the anomalous Hall-effect contribution to transport and will be discussed. The deposition of Ge was explored in the low temperature and mobility regime and the Mn-nanostructure remains indeed unperturbed by the growth of the Ge-overlayer. After the room-temperature deposition of a thin Ge buffer layer in order to contain and protect the Mn-nanostructure, the transition is made to conditions which allow the formation of Ge quantum dots, and presumably will allow the Mn to move into the QD from the Si-Ge interface.

11:40am **MI-ThM12 Magnetic Exchange Bias in Epitaxial $Fe_{25}Pt_{75}$**, ***G.J. Mankey***, University of Alabama, *P. Mani*, Western Digital, *D. Lott*, GKSS Research Center, *F. Klose*, Australian Nuclear Science and Technology Organisation, *H. Ambaye*, Oak Ridge National Laboratory, *M. Wolff*, Ruhr-University Bochum, Germany, *A. Schreyer*, GKSS Research Center, *H.M. Christen*, *B.C. Sales*, Oak Ridge National Laboratory, *M.J. Walock*, *Z. Lu*, *P. LeClair*, University of Alabama

Epitaxial films of $Fe_{25}Pt_{75}$ have a number of different magnetic phases as a function of temperature and chemical order. For example, chemically-ordered epitaxial films have two distinct antiferromagnetic phases at temperatures below ~160K, and exhibit paramagnetism above that temperature. In sharp contrast, chemically-disordered epitaxial films are ferromagnetic with a Curie temperature that is greater than 400K. Since both antiferromagnetic and ferromagnetic phases can exist in a partially-ordered film at temperatures below 160K, a magnetic exchange bias in the chemically-disordered ferromagnetic component can be induced through contact with the chemically-ordered antiferromagnetic component of the film. By varying the process conditions during growth, an alloy with the same composition throughout the film can exhibit a modulated magnetic structure. Using a combination of polarized neutron reflectivity and other magnetic characterization techniques, the observed exchange bias in such films is demonstrated to originate at the interfaces between the ferromagnetic and antiferromagnetic phases of $Fe_{25}Pt_{75}$.

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