Tuesday Afternoon, October 21, 2008

Magnetic Interfaces and Nanostructures
Room: 206 - Session MI+NC-TuA

Magnetic Microscopy and Magnetization Dynamics
Moderator: A.T. Hanbicki, Naval Research Laboratory

1:40pm **MI+NC-TuA1 Probing Individual Magnetic Nanostructures with Spin Excitation Spectroscopy**, ***A. Heinrich***, IBM Research Division **INVITED**

Understanding and controlling the magnetic properties of nanoscale systems is crucial for the implementation of future data storage and computation paradigms. Here we show how the magnetic properties of individual atoms can be probed with a low-temperature, high-field scanning tunneling microscope when the atom is placed on a thin insulator. We find clear evidence of magnetic anisotropy in the spin excitation spectra of individual magnetic atoms embedded in a non-magnetic surface. In extended one-dimensional spin chains, which we build one atom at a time, we find strong spin-coupling into collective quantum-spins, even for the longest chains of length 3.5nm. The spectroscopic results can be understood with the model of spin-excitations in a system with antiferromagnetic coupling, controlled on the atomic scale. High-spin atoms can show an interesting form of the Kondo effect when the magnetic anisotropy places a degenerate, low-spin Kramers-doublet in the ground-state.

2:20pm **MI+NC-TuA3 Magnetic Exchange Force Microscopy with Atomic Resolution**, ***U. Kaiser***, *A. Schwarz, R. Wiesendanger*, University of Hamburg, Germany

Magnetic Exchange Force Microscopy (MExFM) is a novel technique that allows magnetic imaging of surfaces with atomic resolution. The set-up of this microscope resembles that of a conventional atomic force microscope, but a magnetic probe tip is used to study short-ranged magnetic exchange forces between the foremost tip atom and the underlying sample atoms. Since MExFM is sensitive to the forces between tip and sample, it is not limited to well-conducting materials like spin polarized scanning tunneling microscopy (SP-STM).[1] In our study we investigated the (001) surface of the antiferromagnetic insulator NiO with an iron-coated tip.[2] The microscope was operated in ultrahigh vacuum at 8 K in an externally applied magnetic field with a flux density of 5 T. All measurements were performed in the non-contact attractive force regime between tip and sample using the frequency modulation technique. At small tip sample separations we imaged the surface oxygen and nickel atoms with an additional atomic scale modulation on neighboring rows of nickel atoms. This corresponds with the antiferromagnetic arrangement of the nickel atomic magnetic moments. Since all surface nickel atoms are structurally and chemically equivalent, we can unambiguously assign the observed contrast modulation to a magnetic exchange force between tip and sample. In this talk experimental prerequisites for this new method as well as the origin of the exchange interaction are discussed.

[1] M. Bode, Rep. Prog. Phys. 66, 523 (2003)
[2] U. Kaiser, A. Schwarz, and R. Wiesendanger, Nature 446, 522 (2007)

2:40pm **MI+NC-TuA4 Separation of Topographic Features from Magnetic Force Images using Capacitive Coupling Effect**, ***B.I. Kim***, Boise State University

Separation of topographic features from magnetic images has been an issue for the last 20 years in magnetic force microscopy (MFM). Although MFM is one of the most important imaging tools of nanoscale magnetic structures, this issue still remains largely unsolved and thus has limited the current capability of the MFM as a quantitative magnetic imaging tool. The frequent pickups of the topographic features are interpreted as transitions of the tip between bi-stable states of the tip-sample assembly in the noncontact and tapping regions in the conventional amplitude modulation MFM. The bi-stability originates from the long-range amplitude decrease due to the dc bias voltage for the uniform feedback polarity. As a method to make the amplitude increase in the noncontact region as the tip approaches the surface, an electrostatic force modulation method is introduced to utilize the capacitive coupling effect for magnetic imaging. MFM using electrostatic force modulation demonstrates the separation of the topographic features from the magnetic images with an enhanced stability. The stability is attributed to the different modulation method and servoing mechanism.

3:00pm **MI+NC-TuA5 Magnetic Reconstruction of Vortexes in Co Nanocrystals**, ***D.P. Pappas***, *L. Yuan, F.C.S. da Silva, A. Davydov*, National Institute of Standards and Technology

Co nanocrystals were prepared and MFM measurements revealed the dependence of the magnetization on the shapes of the nano-crystals. The nanodots were formed by depositing a 10 nm film of Co onto a c-axis oriented sapphire crystal, which was then annealed to 1000 C. Nanocrystals formed with average size of about 500 nm, with a variety of shapes. From the shapes, it is apparent that some random nucleation occured. The nanocrystals fall into two categories, hexagonal shaped and rectangular. The MFM images of the first type showed that the magnetization formed a central vortex core, with a magnetic reconstructions of either 3-fold or 6-fold symmetry around the core. The latter particles showed a maze-like magnetic configuration. These studies show that the strong uniaxial anisotropy persists in these particles, and the magnetic configuration is strongly dependent on the shape of the particles. Moreover, the circular dots have a strong tendency to form highly symmetric patterns.

4:00pm **MI+NC-TuA8 Complex Magnetic Order on the Atomic Scale Revealed by Spin-Polarized STM**, ***K. von Bergmann***, University of Hamburg, Germany **INVITED**

Magnetism in low-dimensions is a fascinating topic: Even in apparently simple systems -such as homoatomic monolayers- the nearest neighbor distance, the symmetry and the hybridization with the substrate can play a crucial role for the magnetic properties. This may lead to a variety of magnetic structures, from the ferromagnetic and antiferromagnetic state to much more complex spin structures. Spin-polarized scanning tunneling microscopy (SP-STM) combines magnetic sensitivity with high lateral resolution and therefore grants access to such complex magnetic order with unit cells on the nanometer scale. Different previously inconceivable magnetic structures are observed in pseudomorphic homoatomic 3d monolayers on late 5d transition metal substrates.[1,2] The broken inversion symmetry due to the presence of the surface can induce the formation of spin spirals, where the spin rotates from one atom to the next resulting in a nanometer sized magnetic period. The driving force for the canting of adjacent magnetic moments leading to such spirals is the Dzyaloshinskii-Moriya interaction and a unique rotational sense is found.

[1]K. von Bergmann et al., Phys. Rev. Lett. 96, 167203 (2006).
[2]M. Bode et al., Nature 447, 190 (2007).

4:40pm **MI+NC-TuA10 Magnetization Damping in Magnetic Multilayers**, ***T. Mewes***, The University of Alabama **INVITED**

For the application of magnetic multilayers in spintronic devices the magnetization relaxation is of great importance. Of particular practical interest are multilayers which include an exchange biased ferromagnet, i.e. a ferromagnet/antiferromagnet bilayer system for which the hysteresis loop of the ferromagnet can be shifted along the field axis. In comparison to bulk properties the magnetization relaxation in thin magnetic films can be enhanced for example by spin-pumping and two-magnon scattering due to local inhomogeneities. We investigated the magnetization relaxation in metallic ferromagnet/antiferromagnet based multilayer systems, using broadband ferromagnetic resonance measurements. By inserting a thin non-magnetic spacer layer, we find that spin-pumping contributes significantly to the damping in these multilayers, even for structures with no shift of the hysteresis loop. However, in exchange biased systems we observe a strong additional contribution to the magnetization relaxation.

5:20pm **MI+NC-TuA12 Perpendicular Anisotropy Graded CoPt/CoPtCr Magnetic Pillars Patterned by Nanosphere Lithography**, ***X. Li***, *Z.R. Tadisina, A.L. Highsmith, S. Gupta, Y. Inaba, J.W. Harrell*, The University of Alabama

Patterned magnetic nanostructures such as nanodots and nanopillars are now an extremely active area of research for applications for next generation media,[1] as well as novel logic and spintronic memory devices. Bit patterned media is one of the most promising candidates to overcome the tradeoff between thermal stability and recording writability. This work will detail the deposition of perpendicular magnetic anisotropic media, a unique patterning approach using nanosphere lithography, and magnetic characterization of the patterned nanostructures. Process optimization of perpendicular magnetron sputtered CoPt and CoPtCr films of various compositions was carried out using seed layers of Ta and Ru. The anisotropy K_u ranged from 2×10^7 erg/cm^3 to 2×10^6 erg/cm^3 as a function of film thickness and Cr concentration. Nanosphere lithography[2] was used to pattern the magnetic films into nanopillars with controlled size. A self-assembled nanosphere monolayer was first prepared, tailored to a discrete dot mask by shrinking the spheres using reactive ion etching, and then

transferred to hard masks and, finally, the magnetic media, by a combination of ion milling and reactive ion etching. Magnetic nanopillars with diameters ranging from 90 nm to those approaching 10 nm with correspondingly increasing pitch are obtained. The size dependence of the magnetization process, the thermal stability, and switching dynamics of the pillars are characterized in an alternating gradient magnetometer (AGM) and magneto-optic Kerr effect (MOKE) system by using angle-dependent and time-dependent remanent coercivity measurements fitted to Sharrock's equation over a wide range of timescales. A significant increase of thermal stability and coercivity was demonstrated with the decrease of pillar size. The reversal mechanism is similar to reported results of nucleation of a small reversed volume followed by rapid domain wall motion.[3]

[1] Robert F. Service, Science 314, 1868 (2006).
[2] C. L. Haynes and R. P. Van Duyne, J. Phys. Chem. B 105, 5599 (2001).
[3] T. Thomson, G. Hu, and B. D. Terris, Phys. Rev. Lett. 96, 257204 (2006).

Magnetic Interfaces and Nanostructures
Room: 206 - Session MI+NC-WeM

Magnetic Thin Films, Nanoparticles and Nanostructures
Moderator: D.P. Pappas, National Institute of Standards and Technology

8:00am **MI+NC-WeM1 Reactive Biased Target Ion Beam Deposition of AlO_x Barrier Magnetic Tunnel Junctions**, ***W. Chen****, *J. Lu, K. West,* University of Virginia, *W. Egelhoff,* National Institute of Standards and Technology, *S.A. Wolf*, University of Virginia

Magnetic tunnel junctions (MTJs) with AlO_x barriers are deposited using a unique tool called Reactive Biased Target Ion Beam Deposition system (RBTIBD) utilizing low energy ion source (0~50eV) and target biasing (50eV~1200eV). The RBTIBD system applies bias voltage directly and only on the desired targets, providing sputtering energy and avoiding "overspill" contamination during film growth. The ability to control the low ion beam energy as well as the target bias, is suited for producing high quality atomic scale interface for the multi-layer structures, which is the key for high tunneling magnetoresistance (TMR) performance desired for application. A typical Exchange biased MTJs stack would be Si/SiO2/Ta/Ru/IrMn/CoFeB/AlO_x/CoFeB/Ta/Ru. The magnetic properties are measured by VSM and TMR ratio of unpatterned films is measured by CIPTech technology.

8:20am **MI+NC-WeM2 Anisotropic Competition in FM/AFM Bilayers: The Influence on Magnetic Easy Axis, FM/AFM Exchange Coupling, and Interfacial Coupled Spins**, ***B.Y. Wang****, National Taiwan University and TIGP, Academia Sinica, Taiwan, *W.C. Lin,* National Taiwan Normal University, *N.Y. Jih, C.-H. Chuang, C.W. Peng, S.S. Wong,* National Taiwan University, *Y.L. Chan, D.H. Wei,* National Synchrotron Radiation Center, Taiwan, *M.-T. Lin*, National Taiwan University

We present the studies of the magnetic easy axis, ferromagnetic/antiferromagnetic exchange coupling, and interfacial spins of Fe/fcc-Mn/Cu_3Au(001) ultrathin bilayers for probing both magnetic anisotropy of ferromagnetic Fe layer and antiferromagnetic Mn layer by using magneto-optical Kerr effect (MOKE) and photoemission electron microscopy with X-ray magnetic circular dichroism (XMCD-PEEM). Combining the experimental results with the analysis from phenomenological magnetic anisotropic model, we demonstrate that the Fe and Mn layer reveals intrinsic in-plane and out-of-plane magnetic anisotropy, respectively, in which the anisotropic competition between Fe and Mn layer significantly influences the orientations of magnetic easy axis, Fe/Mn exchange coupling, and interfacial coupled spins of Fe/Mn bilayers.

8:40am **MI+NC-WeM3 Time-of-Flight Secondary Ion Mass Spectrometry Study of Manganese Diffusion in Annealed MnAs/GaAs Layered Structures**, ***R.E. Goacher****, *H. Luo, J.A. Gardella, Jr.*, University at Buffalo

Layered structures of MnAs/GaAs grown by MBE are characterized using ToF-SIMS before and after low-temperature annealing. MnAs is studied both as a model system for investigating Mn diffusion from (GaMn)As into GaAs and as a material that may have importance for Spintronics applications in its own right.[1,2] Two challenges that must be overcome to create practical Spintronics devices are to achieve high Curie temperatures and efficient spin injection.[3] It has been shown that the Curie temperature of (GaMn)As is improved by post-growth annealing at low temperatures.[4] However, one hypothesis regarding the failure of efficient spin injection is that the physical diffusion of spin dopant atoms (Mn) from a magnetic to a neighboring non-magnetic layer decreases the coherence of injected spin-polarized electrons. Therefore, this work investigates the extent of Mn diffusion over the relevant temperature range between the growth temperature (as low as 200 C) and approximately 400 C. The in-depth chemical profiles obtained by the ToF-SIMS analysis reveal the extent of manganese diffusion from MnAs into GaAs. Quantitative diffusion information is obtained by calibrating the Mn concentration to ion-implanted standards and the depth scale to profilometry measurements. Depth profiles obtained for samples of ~5 nm MnAs over GaAs as grown and annealed at 200, 300 and 400 C reveal the migration of Mn towards the sample surface for temperatures up to 300 C, and then significant diffusion into the bulk GaAs after annealing at 400 C. Significant Mn diffusion after annealing a thick (~150 nm) MnAs layer over GaAs at 400 C is also detected. Quantitative analysis reveals that the integrated Mn concentration decreases as the annealing temperature increases, indicating some evaporative loss of Mn during annealing. The instrumental broadening function is also measured from a delta-layer sample in order to de-convolute the broadened diffusion profiles. The application of the measured diffusion information to device design and post-growth treatment is also discussed.

[1] Ramsteiner, M. et al., Phys Rev B: Cond Matt Mat Phys, 2002, 66, (8), 081304/1-081304/4.
[2] Dvakonov, M. I., Los Alamos National Laboratory, Preprint Archives, Condensed Matter. 2004, 1-10.
[3] Ploog, K. H., J Cryst Growth, 2004, 268, (3-4), 329-335.
[4] Stanciu, V. et al., Phys Rev B: Cond Matt Mat Phys, 2005, 72, (12), 12534/1-12534/5.

9:00am **MI+NC-WeM4 Molecular Beam Epitaxy Integration of Barium Hexaferrite on Wide Bandgap 6H-SiC**, ***Z. Cai****, *T.L. Goodrich, Z. Chen, F. Yang, V.G. Harris, K.S. Ziemer*, Northeastern University

Integration of nonreciprocal ferrite microwave devices (e.g. circulators, isolators, phase shifters, etc.) with semiconductor platforms is a necessary to meet the increasing security, usage, and portability demands of civilian and military communication systems by increasing microwave power and by reducing device volume. Barium hexaferrite (BaM, $BaFe_{12}O_{19}$) is ideal for microwave device applications because of its high resistivity and particularly large uniaxial magnetocrystalline anisotropy (17 kOe) with the easy direction along the c-axis. BaM films with improved ferromagnetic resonance linewidths (< 100 Oe) have been deposited on 6H-SiC by pulsed laser deposition (PLD) through the use of a 10nm single crystalline MgO template grown by molecular beam epitaxy (MBE). Since the improvement in magnetic properties of BaM films is linked to the initial stages of BaM film growth, MBE deposition of high quality BaM has the potential to be an ideal seed layer for thick BaM film deposition by PLD or liquid phase epitaxy (LPE). BaM growth by MBE was carried out using an oxygen plasma source at pressure ($<1\times10^{-5}$ Torr) and solid source Ba and Fe effusion cells at substrate temperature ranging from 300~800ºC. High quality film with strong c-axis aligned normal to the substrate and low coercivity (200 Oe) was achieved at 750 ºC and 2×10^{-6} Torr with 10nm MBE-grown MgO template. In-situ x-ray photoelectron spectroscopy and reflection high-energy electron diffraction showed stoichiometric chemistry and ordered crystal structure. Ex-situ atomic force microscopy revealed a smooth surface (1.2 nm root-mean-square roughness over a 2×2 μm^2) and x-ray diffraction patterns showed strong epitaxial growth of c-axis perpendicular to the substrate. Magnetic hysteresis loops confirmed that the easy magnetic axis of the BaM film was aligned perpendicular to the film plane. This is believed to be the first demonstration of oriented, crystalline BaM on SiC by MBE, and has the potential to be a simple and successful method to realize effective integration of BaM with SiC for next-generation microwave device application.

9:20am **MI+NC-WeM5 Exploring Complexity through Reduced Dimensionality: Novel Transport Properties of $La_{5/8-x}Pr_xCa_{3/8}MnO_3$ Wires**, ***T.Z. Ward****, *S. Liang,* Univ. of Tennessee & Oak Ridge National Lab., *K. Fuchigami,* Univ. of Tennessee & Oak Ridge National Lab. and IHI Corp., Japan, *L.F. Yin,* Oak Ridge National Lab., *E. Dagotto,* Univ. of Tennessee & Oak Ridge National Lab., *E.W. Plummer,* Univ. of Tennessee, *J. Shen*, Univ. of Tennessee & Oak Ridge National Lab.

Currently, the condensed matter physics community is devoting a great deal of attention to complexity and the nanoscale. By combining these two areas, even well studied complex systems such as the manganites might exhibit new and unexpected phenomena. Our work shows that this is indeed the case. We employ novel lithographic techniques to spatially confine single crystal $La_{5/8-x}Pr_xCa_{3/8}MnO_3$ (LPCMO) thin films to the scales of the inherent electronic phase separated domains. The results of this confinement are striking differences in the electronic transport properties which allow us new insights into the underlying balance of spin-charge-lattice interactions while increasing our knowledge of the formation of and interplay between domains. We expect this technique to offer similar rewards on other phase separated materials; and with the current trend toward reduced device sizes, this type of study will be critical for future applications.

9:40am **MI+NC-WeM6 Controlling Magnetic Anisotopy in Epitaxial FePt(100) Films**, ***Z. Lu****, *M.J. Walock, P. LeClair, W.H. Bulter, G.J. Mankey*, University of Alabama

L10 FePt is a good candidate for ultrahigh density magnetic recording media because it exhibits a perpendicular anisotropy which has a very high value of $K_u=7x10^7$ erg/cm^3. The high anisotropy allows for a smaller thermally stable magnetic volume in the written bits. However, writing the magnetic information on a film with such a high anisotropy is a technical challenge. To solve this problem, some new multilayered media such as exchange spring, exchanged composite and anisotropy graded media have

***** Falicov Student Award Finalist

been proposed. An important technical challenge for enabling these concepts is developing an ability to control the magnetic anisotropy of each magnetic layer. For FePt films, there are two methods to control the magnetic anisotropy, either by controlling the chemical order parameter S or by varying the composition to produce Fe-rich alloys. We will report our results obtained from epitaxial films fabricated by magnetron sputtering on MgO(100) substrates with Cr and Pt as buffer layers. By varying the growth temperature, epitaxial films of $Fe_{50}Pt_{50}$ were prepared with order parameters ranging from 0 to 0.95 as determined by x-ray diffraction. By carefully controlling the flux of the magnetron sources, epitaxial films of $Fe_{100-x}Pt_x$ with $25<x<50$ were also produced. Results of how the anisotropy changes with the order parameter and chemical composition will be presented.

10:40am **MI+NC-WeM9 Nanopatterning with Self-assembled Nanoparticle Arrays**, ***S.A. Majetich***, *C. Hogg, J.A. Bain*, Carnegie Mellon University **INVITED**

Magnetic information storage density is quickly approaching limitations, due to the noise introduced by the grain size dispersion. The noise can be mitigated by shrinking the grain size, yielding more grains per bit, but if the grains are too small they will be superparamagnetic. This is overcome by increasing the magnetocrystalline anisotropy of the material, or by patterning the media. Self-assembled nanoparticle arrays could be useful for noise reduction in conventional media, even without perfect order. In the longer term, with ordered arrays, they could potentially be used as patterned media with very small bit size. Lithographic methods have been used to fabricate nanopatterns, but the features must be written serially, which would lead to high manufacturing costs. There is a great need for parallel nanopatterning approaches; many of the proposed techniques have taken advantage of self-assembly. Here we explore the limits of nanomasking on even smaller structures based on self-assembled nanoparticle arrays. Arrays of FePt nanoparticles have previously been proposed as magnetic recording media, but there have been difficulties in obtaining the desired high anisotropy phase together with regular order within the array. In addition, the particles in self-assembled nanoparticle arrays are not crystallographically oriented, and variations in the easy axis direction would be an additional source of noise. The nanomasking approach uses self-assembled nanoparticle arrays to create a template pattern that is then transferred into an underlying thin film. Ion milling is a well-known technique for patterning materials on the micron scale, but questions remain about its application to nanoscale patterning. In an ideal ion milling process, a high-energy ion strikes a surface and knocks out an atom, which is then removed by the vacuum system. One of the advantages of ion milling is its relative insensitivity to the type of atoms in the sample, in contrast to reactive ion etching, where the selective reactive chemistry of the ions provides the energy for the reaction. Reactive ion etching (RIE) is gentler, but requires that the etching products be gaseous. Here we compare the nanopatterning results using self-assembled nanoparticle array nanomasks with argon ion milling and RIE.

11:20am **MI+NC-WeM11 Functionalized Gd_2O_3 Nanoparticles to be used for MRI Contrast Enhancement**, *M. Ahren, L. Selegard, N. Abrikossova, A. Klasson, F. Soderlind, M. Engstrom, P.-O. Käll,* ***K. Uvdal***, Linköping University, Sweden

The properties of very small particles, i.e. particles with a small volume to surface relative ratio, have been shown to clearly differ from both the atom and bulk material. Such low dimensional materials will be of main importance during material design and optimization in the future. We are now designing functionalized rare earth nanocrystals and this material is very promising as positive contrast agent in Magnetic Resonance Imaging (MRI). The core of the nanomaterial is characterized using X-ray Photoelcetron Spectroscopy (XPS), Transmission Electron Microscopy (TEM) and Photo Emission Electron Microscopy (PEEM). The functionalization steps are investigated by means of XPS, Infrared (IR) Spectroscopy and Dynamic Light Scattering (DLS). The proton relaxation times were measured as a function of dialysis time and functionalization, with a MRI scanner. The relaxivity is compared to commercially available Gd based chelates (Gd-DTPA). We have shown that the core consists of pure Gd2O3, the particles are crystalline and in the size of about 3-5 nm. The functionalization process and dialysis procedure are shown to increase the stability of the material. A considerable relaxivity increase for functionalized and dialyzed particles compared to corresponding values for Gd-DTPA is obtained. The long term goal is to design a powerful, directed contrast agent for MRI examinations with specific targeting possibilities with strong MR- signal on the cell- and molecular level.

11:40am **MI+NC-WeM12 Interfacial Interactions of Magnetic and Nonmagnetic Spacer Layers in FeCo/Pd and FeCo/Ru Multilayer Stacks**, ***M.J. Walock***, The University of Alabama, *H. Ambaye,* Oak Ridge National Laboratory, *G.J. Mankey*, The University of Alabama

Residing at the peak position on the Slater-Pauling curve, FeCo alloys are heavily used in the magnetic recording industry. However, higher magnetizations are desirable. Prior results have shown that alloying FeCo with minute amounts of 4d elements have produced materials with higher magnetizations. Another approach is the deposition of 4d elements as thin spacer layers between FeCo layers. With this tactic, we investigate the interfacial interactions between the 3d alloy and 4d elements. Among the 4d elements, Pd and Ru offer intriguing possibilities. Ru layers permit both ferromagnetic and antiferromagnetic exchange interactions, but Pd layers show only ferromagnetic coupling between the magnetic layers. A series of multilayer samples with Pd and Ru spacer layers was studied to explore these interactions. Polarized neutron reflectivity enabled the determination of the layer-specific magnetization vector distributions. The neutron experiments show that there is a small but finite magnetization of the 4d spacer layers, dependent on the distance from the interface. To confirm this observation, x-ray magnetic circular dichroism was used to probe the element-specific average atomic magnetic moments in both the 3d and 4d layers.

Magnetic Interfaces and Nanostructures
Room: 206 - Session MI-WeA

New Directions in Spintronics
Moderator: G.J. Mankey, University of Alabama

1:40pm **MI-WeA1 Spin Tunneling and Transport through Organic Semiconductors - Towards Large Spin Relaxation Length**, ***J. Moodera***, Massachusetts Institute of Technology **INVITED**

The emerging field of organic spintronics is merging the two hot fields - organic electronics and spintronics. Chemical tunability of electrical properties in organic semiconductors (OS) with a bottom-up approach, along with the mechanical flexibility and low-cost fabrication processes has given rise to organic-electronic devices, such as light-emitting diodes (OLED) and field effect transistors (OFET). From the spintronics viewpoint, of growing interest is the potential to transport and manipulate spin information in OSs. Spin-orbit and hyperfine interactions, the main cause of spin-decoherence, being weak in OSs, suggest a large λ_s in these materials. Electron spin polarized tunneling is explored with ultrathin layers of the molecular organic semiconductor tris(8-hydroxyquinolinato)aluminum (Alq3) and Rubrene ($C_{42}H_{28}$). Significant tunnel magnetoresistance (TMR) was measured in magnetic tunnel junctions at room temperature, which increased when cooled to low temperatures. Spin polarization of the tunnel current through these OS layers directly measured using superconducting Al as the spin detector, shows that minimizing formation of an interfacial dipole layer between the metal electrode and organic barrier significantly enhanced elastic tunneling characteristics and greatly improves the spin transport. For example, directly measured spin diffusion length (λ_s) in amorphous rubrene by spin polarized tunneling is large in comparison to amorphous Si or Ge, where no spin-conserved transport has been reported. These results will be discussed. Based on our findings, λ_s in single crystalline OS can be expected to reach even millimeters, showing the potential for organic spintronics development. Work done in collaboration with Tiffany Santos, Jenny Shim, Karthik V. Raman and supported by KIST-MIT project fund and ONR grant.

2:20pm **MI-WeA3 Magnetism and Magnetoresistance in Multilayer Thin Film Rings**, ***C.A. Ross***, Massachusetts Institute of Technology **INVITED**

Magnetic data storage devices, including magnetic random access memories and patterned media, are based on thin film magnetic nanostructures. Magnetic multilayer thin film rings present a particularly interesting geometry, and their rich behavior offers opportunities for development of multibit magnetic memories and programmable, non volatile logic devices. A single layer magnetic ring can adopt a variety of stable and metastable magnetic states characterized by different numbers of domain walls, and the behavior of a multilayer ring is further complicated by magnetostatic and exchange interactions between the individual magnetic layers. In this study, rings with nanoscale to micron scale dimensions are made using electron beam lithography and self-assembled block copolymer lithography. We will describe the behavior of single layer, multilayer and exchange-biased magnetic rings, including control of the chirality of the magnetization direction, and magnetotransport measurements made on electrically contacted rings that show large relative changes in resistance, and we will discuss how these structures may be used in multibit memory cells and logic devices.

4:00pm **MI-WeA8 Electrical Spin Injection into Silicon: A Comparison between Fe/Schottky and Fe/Al_2O_3 Tunnel Contacts**, ***G. Kioseoglou***, *A.T. Hanbicki, C.H. Li, P.E. Thompson, O.M.J. van 't Erve, M. Holub, C. Awo-Affouda, R. Goswami, G. Spanos, B.T. Jonker*, Naval Research Laboratory

Electrical spin injection is a prerequisite for a semiconductor spintronics technology. While significant progress has been realized in GaAs, little has been made in Si, despite its overwhelming dominance of the semiconductor industry. Si is an ideal host for spin-based functionality due to its smaller spin orbit than GaAs (responsible for spin relaxation) and to its long spin lifetimes (microseconds). Recently[1] we have reported successful injection of spin-polarized electrons from an Fe film through an Al_2O_3 tunnel barrier into Si (001). The circular polarization of the electroluminescence (EL) resulting from radiative recombination in Si and in GaAs (in Si/AlGaAs/GaAs structures) tracks the Fe magnetization, confirming that these spin polarized electrons originate from the Fe contact. The polarization reflects Fe majority spin. We determined a lower bound for the Si electron spin polarization of ~30% at 5K, with significant polarization extending to at least 125K. Here we compare electrical spin injection from Fe into MBE grown Si n-i-p heterostructures using different tunnel barriers- a reversed biased Fe/Si Schottky contact and an Fe/Al_2O_3 barrier. For both types of structures the EL spectra are dominated by transverse acoustic and optical phonon emissions in the Si and the circular polarization of the EL due to radiative recombination in the Si tracks the Fe out of plane magnetization. However, the polarization is almost 50% lower for the Fe/Si contact than that of the Fe/Al_2O_3/Si system. This could be due to different interface structure or it may result from changes in the transport mechanism involved. Systematic TEM analysis has been performed to correlate the interface structure with the observed optical polarization, and reveals some Fe/Si intermixing that is absent in the Fe/ Al_2O_3/Si structure. While the zero bias resistance for the Fe/ Al_2O_3/Si system shows very weak temperature dependence, the resistance for the Fe/Si system increases orders of magnitude with decreasing temperature. This implies that two different transport mechanisms may be responsible for the spin injection.

[1]B.T. Jonker, G. Kioseoglou, A.T. Hanbicki, C.H. Li, and P.E. Thompson, Nature Physics 3, 542 (2007). This work was supported by ONR and core programs at NRL.

4:20pm **MI-WeA9 Current Perpendicular to Plane Giant Magnetoresistance in Magnetic Multilayers***, ***W.P. Pratt, Jr.***, Michigan State University **INVITED**

Giant magnetoresistance (GMR) in magnetic multilayers, consisting of alternating ferromagnetic and non-magnetic (F/N) layers, is now a major field of study in metallic magnetic materials both for fundamental physics and important sensor applications, especially read heads in computer hard drives. Until recently, applications of GMR mostly used Current-In-Plane (CIP) geometry. However, the Current-Perpendicular-to-Plane (CPP) GMR can be larger, and the CPP geometry has certain fabrication advantages. Indeed, CPP tunneling-MR read heads are now in computers, and CPP-GMR in metallic multilayers is competing for next-generation read heads. There is also great theoretical and experimental interest in the inverse phenomenon to CPP-GMR, where a high-density (~10^7 A/cm^2) spin-polarized CPP current exerts a large enough torque on a given nano-size F-layer to cause its magnetization to precess and then switch. Such current-induced magnetization switching (CIMS) has potential applications in magnetic random access memories. Progress in this field is tied to understanding the spin-polarized transport parameters of existing and new materials. The CPP-GMR usually gives more direct access to these fundamental parameters: F/N interface resistances, asymmetries of conduction electron scattering in the bulk of F-layers and at F/N interfaces, and the length scales for electron spin-memory loss due to spin-flip scattering. After a brief review of the CPP-GMR and CIMS phenomena, I will present examples of important CPP-transport parameters that we have quantified for a wide variety of F and N metals. I will then illustrate applications of this knowledge of the CPP parameters to CIMS in F/N/F trilayer structures.

*Work supported by US National Science Foundation, the MSU Keck Microfabrication Facility and Seagate Technology.

5:00pm **MI-WeA11 Spin Transport between Spin-Polarized Sources and Drains: Advantage of Carbon Nanotubes on Semiconductors**, ***A. Fert***, Université Paris-Sud, France, *J.-M. George, H. GeorgeJaffres, R. Matttana*, CNRS, France, *L.E. Hueso, N.D. Mathur*, Oxford University, UK **INVITED**

Spin transport in a nonmagnetic lateral channel between a spin-polarized source and a spin-polarized drain is at the basis of several concepts of spin transistor. So far, the problem has been mainly studied for structures in which the nonmagnetic channel is a conventional semiconductor.[1] Spin injection into a semiconductor from a spin-polarized electrode begins to be well mastered. More difficult is the transformation of the spin information – related to the magnetic configuration of the electrodes- into a large electrical signal, ideally DV/V » 1 or larger, if V is the bias voltage and DV its variation when the magnetic configuration is changed. In experiments on structures in which the lateral channel is a semiconductor, DV/V does not generally exceed a few 1% and the electrical signal DV is only in the mV range.[1] In contrast, in the experiments on carbon nanotubes between ferromagnetic contacts we will present, high values of DV/V (above 70%) and large DV (of the order of 100 mV) can be obtained.[2] After a description of the theoretical background, we will discuss the origin of the difficulties for semiconductors and explain why large values of DV/V and DV can be easily obtained with carbon nanotubes. We will emphasize the potential of carbon nanotubes, graphene and other molecules for spintronics, and conclude by presenting some next challenges for molecular spintronics.

[1] Jonker, B.T. and Flatté, M.E.F. Electrical spin injection and transport in semiconductors, in Nanomagnetism (eds. Mills D.L. & Bland J.A.C.) (Elsevier, 2006).

[2] Hueso, L. E., Pruneda J-M., Ferrari V., Burnell G., Valdés-Herrera J.P., Simons B.D., Littlewood P.B., Artacho E., Fert A. and Mathur N.D.. Transformation of spin information into large electrical signals via carbon nanotubes, Nature 445, 410 (2007).

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 $Fe_{25}Pt_{75}$.

Biomaterial Interfaces
Room: 202 - Session BI+TF+MI+NS+NC-ThA

Plasmonics and Magneto/Plasmonics Aimed at Biosensing
Moderator: F. Höök, Chalmers University of Technology, Sweden

2:00pm **BI+TF+MI+NS+NC-ThA1 Optical Meta Materials and Nano Plasmonics**, ***X. Zhang***, University of California, Berkeley **INVITED**

Recent theory predicted a new class of meta structures made of engineered sub wavelength entities - meta "atoms" and "molecules" which enable the unprecedented electromagnetic properties that do not exist in the nature. For example, artificial plasma and artificial magnetism, and super lens that focuses far below the diffraction limit. The metamaterials may have profound impact in wide range of applications such as nano-scale imaging, nanolithography, and integrated nano photonics. I'll discuss a few experiments that demonstrated these intriguing phenomena. We showed, for the first time, the high frequency magnetic activity at THz generated by artificially structured "meta molecule resonance", as well as the artificial plasma. Our experiment also confirmed the key proposition of super lens theory by using surface plasmon. We indeed observed optical superlensing which breaks down so called diffraction limit. I'll also discuss nano plasmonics for imaging and bio-sensing. The surface plasmon indeed promises an exciting engineering paradigm of "x-ray wavelength at optical frequency".

2:40pm **BI+TF+MI+NS+NC-ThA3 Gold and Silver Nanocrescents as Tunable Substrates for Surface Enhanced Infrared Absorption Spectroscopy**, *R. Bukasov*, ***J.S. Shumaker-Parry***, University of Utah

Controlling the size, shape, and orientation of metal nanoparticles in order to tune and optimize the particles' optical properties for specific applications remains a challenge in the field of plasmonics. Tuning the localized surface plasmon resonance (LSPR) wavelength as well as the localized field enhancements is especially important for spectroscopy applications such as surface enhanced Raman spectroscopy (SERS) and surface enhanced infrared absorption spectroscopy (SEIRA). Although SERS has receive a lot of attention with the engineering of nanoparticle-based substrates, the activity in SEIRA development has been less, most likely due to the lack of tunable substrates for the IR spectral region. We describe the development of gold and silver nanocrescents as tunable substrates for SEIRA studies. We use nanosphere template lithography to fabricate gold and silver crescent-shaped structures which exhibit multiple, polarization-sensitive plasmon resonances that are tunable from the visible through the infrared. Large electromagnetic field enhancements are expected due to the sharpness of the crescent's tips and the ability to bring these sharp tips into close proximity to each other. Using the crescent-shaped structures as substrates, we demonstrate the importance of spectral tunability for maximizing signal enhancements in SEIRA. The nanocrescent area normalized SEIRA signal enhancement increases from 7,700 to 46,000 with an increase in the extent of overlap of the nanocrescents' LSPR frequency with the frequency of the probed molecular vibration. The broad tunability of the nanocrescents' LSPR properties makes the structures excellent candidates for a range of spectroscopic and sensing applications including SEIRA.

3:00pm **BI+TF+MI+NS+NC-ThA4 Use of Angle-Resolved SPRi for the Characterization of Protein Binding and Agglomeration Dynamics**, ***M.S. Golden***, *J.A. Ruemmele, A. Whitty, R.M. Georgiadis*, Boston University

Transient protein-protein interactions are essential on almost every level of cellular function. In addition, protein aggregates play various roles in cell signaling pathways and have been implicated in the onset of many neurodegenerative conditions such as Alzheimer's disease. Although various structures of protein complexes have been widely studied, the mechanisms involved in protein binding events are not clearly understood, and the transient dynamics of this formation have proven difficult to study. Investigation of the mechanisms of protein agglomeration and binding, however, is essential to elucidating the role of these structures in diseases. Here we exploit the multi-array quantitative capabilities of angle-resolved surface plasmon resonance imaging (SPRi) to perform kinetic and thermodynamic measurements of protein-protein interactions. Specifically, the agglomeration and small molecule inhibition of Tumor Necrosis Factor (TNF) family members whose primary role is the regulation of immune cells is under investigation. Surface fabrication techniques coupled with multi-channel microfluidic delivery will be employed in order to introduce protein binding partners and small molecules to the surface. Effects of density, orientation, and heterogeneity of surface immobilized protein molecules on protein binding efficiency and kinetics will be investigated and optimum surface fabrication conditions will be identified. In addition, a unique multi-wavelength SPRi approach will be implemented to simultaneously determine dielectric constants and thicknesses of protein layers on a surface. These studies will therefore allow aggregate and nonaggregate structures at the surface to be clearly differentiated. The results of these fundamental studies will allow a broader understanding of how proteins act cooperatively.

3:20pm **BI+TF+MI+NS+NC-ThA5 Sensitivity Enhancement of Surface Plasmon Resonance Imaging by Nanoarrayed Organothiols**, ***P. Lisboa***, *A. Valsesia, I. Mannelli, P. Colpo, F. Rossi*, JRC-European Commission, IHCP, Italy

The implementation of sensor platforms providing high sensitivity of detection is a crucial step for the design of the new analytical device generation for biosensor developments. Designing platform with active/non-actives region at nanoscale has shown already a drastic increase of detection sensitivity.[1,2] The use of organothiols to create nanopatterns has been already studied showing that this type of chemistry is indicated to produce chemical contrasts for bio-applications.[3] In this work, the effect of organothiols-nanopattern in Surface Plasmon Resonance imaging (SPRi) detection was studied. The gold surface of the SPRi chip was divided in two areas, one modified with a chemical nano-contrast based in two different organothiols (thiolated polyethylene oxide (PEO) and Mercaptohexadecanoic acid (MHD) and the other modified uniformly with MHD. The SPRi study was based on the detection of the immunoreaction between Human IgG and anti-Human IgG (Ab specific) by comparing the results obtained with nanostructured and uniform carboxylic surface. First Human IgG was immobilised on the chip and after the recognition of different concentrations of anti-Human IgG was realised. The achieved SPRi signal was higher in the case of the nanostructured areas for all the tested concentrations. Since the active surface with carboxylic functionalities presented only 3% of the total area, one would expect the detection signal to be 3% of the signal obtained for the uniform MHD surface. The fact that the signal from the nanostructures is higher than in the MHD surfaces in SPRi detection is related to an amplification of signal due to the 2D crystalline character of the structures. This type of arrangement presents the geometry of a photonic crystal leading to the interaction between the Surface plasmon polaritron modes and the regular modulation of the dielectric constant of the surface above the gold film modifying the plasmon effect and consequently increasing the measured reflectivity. These results indicate that SPRi detection performance can be improved by the rational functionalisation of the prism surface with 2D crystalline nanopatterns. Moreover adhesive – nonadhesive nanopatterns are recognized to be good platforms for the correct immobilization of the biomolecules on biosensing surfaces.

References
[1]K. Lee, et al., Nano-Letters, 2004 4, 1869.
[2]A. Valsesia, et al., Langmuir 2006, 22, 1763.
[3]P. Lisboa, et al., Applied Surface Science, 2006, 253, 4796.

4:00pm **BI+TF+MI+NS+NC-ThA7 New Developments in Magneto-Plasmonic Devices**, ***C. Clavero***, *J.R. Skuza, K. Yang, R.A. Lukaszew*, College of William and Mary **INVITED**

In recent years Surface Plasmon Resonance (SPR) sensors have been extensively used in bio-sensing applications. SPR is a charge density oscillation at the boundary between a metal and a dielectric material that gives rise to highly confined fields at the interface. As a consequence the SPR excitation condition is very sensitive to changes in refractive index in the dielectric medium and hence to bio-molecules adsorbed at the metal surface. Nevertheless, the required detection sensitivity for low concentrations of small molecules exceeds current SPR sensors. A new kind of sensors combining plasmonic and magneto-optical (MO) properties, i.e. magneto-plasmonic devices, is being actively investigated. In particular, Au-Co-Au trilayers have been found to increase sensitivity in this type of biosensors.[1] This is due to MO activity enhancement in the Co film caused by the high electro-magnetic field created by SPR.[2] We will report on Au-Co-Au thin film tri-layers grown on glass using UHV magnetron sputtering. The optimization of growth conditions and accurate control of films thickness is critical to achieve a remarkable increase in MO activity and hence in overall sensitivity. A practical issue in these multilayer systems is the bad adhesion of Au to glass causing degradation of the sensor when exposed to a water flux. We will show how to circumvent this problem by inserting Cr or Ti thin buffer layers. A different approach to magneto-plasmonic materials, namely fabrication of Au-Co nano-composite

materials in thin film form, will also be presented. These materials are expected to exhibit enhanced MO response due to localized surface plasmon resonances (LSP) within the Co nano-particles and also considerable reduction of light absorption associated with ferromagnetic materials thus increasing the overall sensitivity of the bio-sensor. Parameters such as shape, size and inter-particle distance can be tuned to control the optical and magnetic properties of the material. Au-Co nano-composite materials in thin film form were obtained by magnetron sputtering co-deposition of Au and Co where parameters such as Au and Co concentration, deposition temperature and film thickness were accurately controlled. Finally, different optical configurations for the excitation of the surface plasmon resonance will be discussed.

[1] B. Sepulveda et al. Opt. Lett. 31, 1085 (2006).
[2] V. I. Safarov et al. PRL 73, 3584 (1994).

4:40pm **BI+TF+MI+NS+NC-ThA9 Grafting Thermoresponsive Polymers on Gold Nanoparticles with Atom Transfer Free Radical Polymerization**, ***S. Chakraborty***, *V.H. Perez-Luna*, Illinois Institute of Technology

Thermoresponsive polymer brushes on colloidal gold were formed through Atom Transfer Free Radical Polymerization (ATRP) of N-isopropylacrylamide (NIPAAM) in aqueous media. In this approach, the "grafting from" technique was used with Atom Transfer Radical Polymerization (ATRP) to grow polymer chains from the surface of gold nanoparticles (~20nm). 'Grafting from' using the ATRP technique enables more uniform/homogenous coverage of polymer chains on the surface of gold nanoparticles. Other advantages of ATRP are the growth of polymer chains without chain termination or chain transfer and that the presence of an active initiator site at the end of the growing polymer chain facilitates synthesis of block copolymers. In the present work, PNIPAAM was grown from the surface of nanoparticles with the help of 2-bromopropionyl bromide as the initiator. The reaction was carried out at room temperature under inert atmosphere and aqueous conditions. The system was found to exhibit thermoresponsive behavior with increase in temperature above 32oC. This behavior could be exploited to develop aggregation based assays. The hybrid polymer-gold nanoparticle system was characterized using Optical Absorption Spectroscopy, Fourier Transform Infra-Red Spectroscopy (FTIR) and Dynamic Light Scattering (DLS). These analytical techniques confirmed the growth of polymer chains in the reaction scheme yielding the final product. The ability to make block copolymers with this metal-polymer hybrid system opens up a wide range of applications such as drug delivery systems, detection assays and bioseparations.

5:00pm **BI+TF+MI+NS+NC-ThA10 Reconfigurable Core-satellite Nanoassemblies as Molecularly-Driven Plasmonic Switches**, *D.S. Sebba, J.J. Mock, D.R. Smith, T.H. LaBean,* ***A.A. Lazarides***, Duke University **INVITED**

Colloidal metal nanoparticles support localized surface plasmon resonances that are sensitive to the presence of molecules, materials, and other polarizable particles that assemble in their near fields. Biomolecule nanoparticle conjugates have been implemented in various molecular detection applications in formats that allow monitoring of plasmonic response. Each specific format has vulnerabilities as well as advantages. For instance, monolayers of immobilized particles functionalized with receptors respond sensitively to target molecules and can be used to track kinetics, but are equally sensitive to non-specific adsorbates, a disadvantage shared with traditional, thin film surface plasmon resonance (SPR). Other formats, such as target induced particle aggregation offer strong plasmon modulation, but involve a complex bulk phase process that presents a significant barrier to quantitative interpretation of the optical data. Here, we report plasmon modulation in pre-formed, few particle assemblies linked by reconfigurable DNA nanostructures. The investigation is motivated by the potential of reconfigurable few particle assemblies to provide control of plasmon coupling, and ultimately, to yield a signal that is distinguishable from plasmonic variations associated with non-specific interactions. In the coupled system upon which we report, DNA nanostructures tether satellite particles to a core particle of like or unlike composition. The DNA nanostructures use duplex DNA to control interparticle separation and are responsive to target strands that modulate interparticle helix length. The reconfigurable assemblies are characterized structurally using dynamic light scattering and transmission electron microscopy and optically using elastic scattering spectroscopy. We demonstrate that DNA nanostructures provide molecular control of interparticle separation by correlating measured plasmonic signals with simulated signals derived from models based upon measured structural parameters. In order to study the sensitivity of core-satellite spectral response to colloid material properties, single assembly scattering spectroscopy and multi-color CCD image analysis are used to monitor perturbation of the core plasmon resonance induced by assembly of satellites of various composition.

Magnetic Interfaces and Nanostructures
Room: Hall D - Session MI-ThP

Magnetic Interfaces and Nanostructures Poster Session

MI-ThP1 Fabrication of Permalloy Nanowire Structure to Realize a Magnetic Analog to a Coupled Pendulum, ***M.S. Seo***, *S.U. Cho, C.W. Yang, Y.D. Park*, Seoul National University, Republic of Korea

We report on the fabrication of NiFe nanowires structures to demonstrate a magnetic analog to a coupled pendulum. Coupled high-frequency resonators have already been demonstrated in magnetic nanostructures.[1] Recently, an analog to a mechanical pendulum system has been applied to measure the mass of a domain wall in NiFe nanowires.[2] We have designed a NiFe nanowires structures akin to two semicircular arc segments, arranged with a mirror symmetry about the tangent, with a separation distance $\leq$ 100 nm. From symmetry arguments, the magnetostatic forces couple the domain walls formed at the apex of each semicircular segment. By varying the separation distances as well as driving current densities, the coupling strengths can also be modulated. The structures are patterned by e-beam lithographic techniques on a UHV sputter deposited NiFe. Each segment is probed electrically allowing for driving force as well as to detect current induced resonance effects on domain wall resistance for each segment. Along with experimental data at the extremes of coupling strengths, we will also compare the results with finite element analysis modeling.

[1] S. Kaka et al., Nature 437, 389 (2005); F.B. Mancoff et al., ibid 437, 393 (2005).
[2] E. Saitoh et al., Nature 432, 203 (2004).

MI-ThP2 Magnetic Dot Polarity Switching Via Current Generated Magnetic Fields, ***M.R Rao***, *J.C Lusth, S. Burkett, Y.K Hong*, University of Alabama

This paper describes the manipulation of the magnetic alignment of nickel dots using a magnetic field generated by current flowing through an aluminum wire. This architecture has the potential to operate as a memory device offering low power dissipation, high integration density, and room temperature operation. The aluminum wire had dimensions of 250 nm in thickness, 10 µm in width, and 40 µm in length. The nickel dots were formed by electron beam lithography and had a thickness of 100 nm and diameter ranging from 200 nm to 500 nm. The dots were deposited in an array such that some dots lay on the wire and some dots lay nearby. A magnetic field was applied to the ferromagnetic dots by passing current through the aluminum wire. Switching of the dots magnetic polarity was observed using magnetic force microscopy (MFM). MFM cantilever phase and amplitude images were used to identify the reversal of the polarity of the dots. Contrast changes were detected upon reversing the current flow. The fabrication of this device concept is relatively simple. Microscale aluminum wires are patterned with conventional photolithographic techniques while a separate electron beam lithography step is used to pattern nickel dots at variable position across the wire. The nickel dot's magnetic field is oriented in a specific direction after passing electric current through the aluminum wire. On reversal of the current, the dot's magnetic field is oriented in the opposite direction. These directions can be treated as a logic '1' or logic '0'. The orientation of the magnetic dots remains even after switching off the current. This indicates potential operation as a memory device.

Authors Index

Bold page numbers indicate the presenter