Magnetic Interfaces and Nanostructures

Room: 619 - Session MI-FrM

Spin Injection, Transfer, and Tunneling

Moderator: G.J. Mankey, University of Alabama

8:00am **MI-FrM1 High-Efficiency Spin Injection through the Depleted Edge of a Magnetic Semiconductor**, ***M.E. Flatté***, The University of Iowa **INVITED**

Dilute ferromagnetic semiconductors are composed of magnetic dopants (such as Mn) that interact strongly with each other through a host nonmagnetic semiconductor (such as GaAs) over distances of order one nanometer to establish the ferromagnetic state. The interaction is mediated by holes, which at low concentrations are bound to the dopants and at high concentrations become mobile. Theoretical and experimental studies of the Curie temperature and carrier spin polarization of $Ga_{1-x}Mn_xAs$ find them to depend strongly on the hole density, and a local mean-field theory has been developed that quantitatively accounts for many of the bulk properties of these materials in terms of the mean hole density. However, the properties near the edges of magnetic semiconductors, where the carrier concentration and dopant concentration are changing rapidly over the interaction's length scale of a nanometer, cannot be accounted for within a local mean-field theory. A theory of magnetic interactions in the highly depleted regime has been built on the foundation of a quantitatively-accurate theory of the interaction energy of a single pair of widely-separated Mn dopants in GaAs. Predictions from this theory of the interaction between Mn dopants have been confirmed by experimental measurements via scanning tunneling microscopy. This theory also provides a new explanation of the origin of the unusual magnetic anisotropies in strained low-doped (even insulating) ferromagnetic $Ga_{1-x}Mn_xAs$. The resulting theory for the edges of a magnetic semiconductor suggests that the carrier spin polarization at those edges should be much larger than in the bulk of the material, and may even approach 100%. Measurements of carrier transport across highly-depleted $Ga_{1-x}Mn_xAs$ suggest that these very high spin polarizations are real, and that they may provide an alternate pathway to nearly 100% efficient spin injection.

8:40am **MI-FrM3 Spin Injection in Organic Spintronics**, ***C.-J. Sun***, Oak Ridge National Laboratory, *B. Hu*, University of Tennessee, Knoxville, *J. Shen*, Oak Ridge National Laboratory

Organic spintronics is an emerging field of nanoscale electronics involving the detection and manipulation of electronic spins in heterostructures that consist of organic and magnetic materials.[1] Compared to conventional inorganic spintronics, organic spintronics offer distinct advantages such as ease of device fabrication and intrinsic low spin scattering rate and high spin coherence over both time and distance.[2] These characteristics make organic spintronic devices plausible to operate at room temperature.[3] In this study, we fabricated spin valve devices that uses Co thin films and a manganite thin film as two ferromagnetic electrodes and an organic molecule layer as the spacer layer. A modified superconducting quantum interference device (SQUID) is used to measure local tunneling magneto-resistance (TMR) and determine spin injection efficiency as a function of thickness of Co thin films, bias voltage, and operating temperature. The mechanism of spin injection from Co thin films is addressed.

[1]Z. H. Xiong, D. Wu, Z.V. Vardeny, and J. Shi, "Giant magnetoresistance in organic spin-valves", Nature 427, 821 (2004).

[2]Alexander R. Rocha, Victor M. Garcia-Suarez, Steve W. Bailey, Colin J. Lambert, Jaime Ferrer, Stefano Sanvito, "Towards molecular spintronics", Nature Mater. 4, 335(2005).

[3]V. Dediu, M. Murgia, F. C. Matacotta, C. Taliani, S. Barbanera, "Room temperature spin polarized injection in organic semiconductor", Sol. Stat .Comm. 122, 181(2002). .

9:00am **MI-FrM4 Edge Emitting Spin-Lasers**, ***A.T. Hanbicki***, *G. Kioseoglou, O.M.J. van 't Erve, C.H. Li, I. Vurgaftman, J.R. Meyer, B.T. Jonker*, Naval Research Laboratory

Using a spin polarized current to drive a laser promises to provide threshold reduction, increased polarization of the output light, and intensity stabilization. Optically and electrically driven surface emitting lasers using InGaAs active regions have proven that indeed, spin currents can lead to threshold reduction.[1,2] We have designed and fabricated edge emitting structures based on the Fe/AlGaAs/GaAs spin injecting system to simplify and further understand this process. Samples were designed and grown to enable fabrication of either surface emitting spin-LEDs or edge emitting lasers. Specifically, a wide GaAs quantum well (QW) was grown between thick Al(35%)GaAs barriers. A 1500 Å QW serves as both a recombination region for surface emitting electroluminescence measurements and as a laser cavity for edge emitting structures. The top cladding layer is also 1500 Å, thick enough to prevent absorption by the spin injecting source, Fe, but thin enough to preserve spin injection into the recombination region. In the surface emission geometry, the behavior was similar to our standard wide-QW spin-LED structures.[3] At low temperature, emission in dominated by an H-band feature,[4] and by 20 K the emission is mainly from the bulk recombination feature. With the magnetization saturated out-of-plane, we measure electron polarizations of 24%. Cleaved cavity, gain-guided, edge emitting lasers show robust emission, however, the quality of cleaved interface greatly influences the emission spectrum.

[1]Rudolph et al., Appl. Phys. Lett. 82 (2003)

[2]Holub et al., Phys. Rev. Lett. 98 (2007)

[3]van 't Erve et al., Appl. Phys. Lett. 89 (2006)

[4]Kioseoglou et al., Appl. Phys. Lett. 87 (2005)

9:20am **MI-FrM5 High Frequency Nanoscale Spin Transfer Devices**, ***S.E. Russek***, National Institute of Standards and Technology **INVITED**

Spin transfers effects become important in multilayer magnetic devices whose dimensions are below 100 nm. The transfer of electron spin momentum can induce switching of magnetic layers or microwave precession of the magnetization. Spin transfer, coupled with giant magnetoresistance and tunneling magnetoresistance, can be used to develop new types of magnetic random access memory (SpinRAM), spin transfer nano-oscillators (STNOs), and spin transfer nano-detectors (STNDs). In this talk I will review high-speed spin transfer switching in nanoscale magnetic SpinRAM devices and the effects of thermal fluctuations and defects on the switching process. Next, I will present data on the linewidths, tunability, and phase control of STNOs, including data for both single domain oscillators and vortex oscillators. STNOs and STNDs have the advantage of small size, high tunability, broad frequency range (2 GHz to 100 GHz), and CMOS compatibility. However, there are intrinsic limitations in the linewidth due to thermal fluctuations, limitations due to the required applied fields, and limitations due to the sensitivity to nanoscale defects and patterning. I will discuss these challenges and the progress made towards making practical spin transfer devices for use in high-frequency communication and signal processing applications.

10:00am **MI-FrM7 Low Resistance Synthetic Antiferromagnet Coupled Spin Valves**, ***Z.R. Tadisina***, *S. Gupta, A. Highsmith, P. LeClair, T. Mewes, G.B. Thompson*, The University of Alabama

The magnetic properties of current-perpendicular-to-the-plane (CPP) giant magnetoresistive (GMR) spin valves employing synthetic antiferromagnet (SAF) pinning have been investigated. The standard CPP spin valve structure, with a ferromagnetic (F) layer pinned by an antiferromagnet (AF), exhibits high electrical resistance, the antiferromagnet typically being a high resistivity material. We have investigated pinning with a Co/Ru/Co SAF trilayer only, with no additional AF pinning. Elimination of the AF-induced parasitic resistance yields a higher GMR ratio. The full-film properties have been optimized using vibrating sample magnetometry (VSM) and current-in-plane (CIP) magnetotransport measurements, and related to CPP spin valve properties after patterning. A theoretical simulation of the M-H and R-H loops of the SAF-pinned spin valves is compared with these experimental results. Interlayer exchange energies for the SAF obtained from experimental measurements for the various structures were used in the theoretical simulations to improve the fit and optimize the structure. The thermal stability of various SAF structures and the corresponding SAF-pinned spin valves have also been studied and compared with those of AF+SAF-pinned and hard magnet-pinned spin valves reported on previously.[1] Structural characterization of the layers and interfaces have been carried out by high-resolution transmission electron microscopy (HRTEM). Three-dimensional atomic scale characterization of the interdiffusion between layers has been conducted using a Local Electrode Atom Probe (LEAP).

[1] "A Novel Scheme for Pinning Magnetic Layers in Current Perpendicular to the Plane Spin Valve Devices", C. Papusoi, Z. Tadisina, S. Gupta, H. Fujiwara, G.J. Mankey, and P. LeClair, presented at 53rd AVS International Symposium, San Francisco, CA, November 12-17 (2006).

10:20am **MI-FrM8 Fabrication Technology for Magnetic Random Access Memory**, ***M.C. Gaidis***, *E.A. Joseph, E.J. O'Sullivan, S. Assefa*, IBM

Magnetic Random Access Memory (MRAM) offers the potential of a universal memory – it can be simultaneously fast, nonvolatile, dense, and high-endurance. Depending on application, these qualities can make MRAM more attractive than SRAM, DRAM, flash, and hard drive memories, with a market measured in the billions of dollars. Small-scale demonstrations have realized much of the potential of MRAM, but scaling the memory to competitive sizes or embedding the memory with logic circuitry creates unique processing challenges. The building of MRAM memories in back-end-of-line (BEOL) circuitry imposes additional requirements on processes which conform to existing semiconductor fabrication facility standards. This presentation provides an overview of the basic MRAM structure and operation, followed by a discussion of MRAM-specific processing techniques and developments to obtain high yield across 200mm substrates. The potential for scaling MRAM for future generations with spin-momentum-transfer (SMT) devices will be discussed in this framework. Practical limitations on SMT scaling, and SMT adaptation of conventional MRAM processing will be reviewed.

10:40am **MI-FrM9 Beyond Fe-MgO-Fe: Alternative Barriers and Systems**, ***P. LeClair***, University of Alabama **INVITED**

Magnetic tunnel junctions have been an intensely active area of research since the first reliable demonstrations of tunneling magnetoresistance (TMR). However, there are only a few systems to date that experimentally show a large TMR effect at room temperature. One of the most recent and effective are ordered Fe/MgO/Fe(001) trilayers (bcc FeCo-based alloys may also be substituted for pure Fe). This system was initially predicted theoretically by Butler et al. to exhibit large TMR, and later experimentally verified by Yuasa et al and Parkin et al. The nearly four-fold improvement in magnetoresistance over earlier polycrystalline/amorphous structures has been attributed to the complex energy band matching between Fe and MgO. This promotes the tunneling of electrons from specific ("delta-1") bands in Fe(001) which exist only for majority spin electrons. The MgO tunnel barrier thereby acts as a 'spin filter.' At the most basic level, the tunneling rates for specific metallic states are controlled by the symmetry of the insulating barrier, which gives a general mechanism for large TMR. In this talk, I will try to outline the theoretical and experimental criteria for large TMR effects based on this 'spin filtering' effect, and attempt to answer the questions "Why does the Fe-MgO system work so well?" and "Is Fe-MgO a unique system?" Both experimental and theoretical considerations are crucial for realizing large TMR effects in realistic structures, and both viewpoints are necessary to explain the (initially surprising) large TMR effects in, e.g., CoFeB/ MgO/CoFeB. I will review our recent work on predicting and fabricating new TMR systems analogous to Fe-MgO-Fe, with a particular focus on alternative tunnel barriers, including organic systems. Finally, I will discuss spin-polarized tunneling characterization methods, in particular Meservey-Tedrow tunneling. This work is supported by the National Science Foundation.

11:40am **MI-FrM12 High Frequency Magnetic Properties of Amorphous and Crystalline CoFeB**, ***M. Pathak***, University of Alabama, *P. Janssen*, Eindhoven University of Technology, The Netherlands, *L. Wen, H. Lee, J.L. Weston, T. Mewes, P. LeClair*, University of Alabama

The recent demonstrations of extraordinarily large tunneling magnetoresistance effects in CoFeB-MgO-CoFeB trilayer structures has generated an enormous interest in the magnetic and structural properties of CoFeB alloys. In particular, the amorphous to crystalline transition plays a crucial role in realizing large magnetoresistive effects. From an application point of view (e.g., hard disk read heads), a clear understanding of the high frequency magnetic properties of these materials is required. To this end, we have studied the ferromagnetic resonance properties of CoFeB thin films up to 40GHz. We sputter deposited $Co_{56}Fe_{24}B_{20}$ films of different thickness ranging from 5nm to 40nm on oxidized Si(100) substrates, and studied the magnetization damping and crystallization as function of film thickness and annealing temperature. FMR data from 0-7 GHz were obtained using a network analyzer with both frequency and field swept, and from 7-40 GHz using rectangular shorted waveguides. FMR results suggest an increase in damping (α=0.0068 to α=0.013) with decreasing film thickness, which is more pronounced after annealing. The observed increase in coercivity with decreasing thickness after annealing (e.g. 375°C) suggests crystallization of $Co_{56}Fe_{24}B_{20}$, which is confirmed by VSM, XRD, and TEM analysis.

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