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 $Al_2 O_3$ 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/$Al_2 O_3$ 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/$Al_2 O_3$/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/ $Al_2 O_3$/Si structure. While the zero bias resistance for the Fe/ $Al_2 O_3$/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).

Authors Index

Bold page numbers indicate the presenter