Wednesday Afternoon, November 15, 2006

Magnetic Interfaces and Nanostructures
Room 2006 - Session MI-WeA

Exchange Bias & TMR

Moderator: G.J. Mankey, University of Alabama

2:00pm **MI-WeA1 A Comprehensive Study of Exchange Bias***, **I.K. Schuller**, R. Morales, Z.-P. Li, C.-P. Li, I.V. Roshchin, S. Roy, S. Sinha,* University of California, San Diego*; M.J. Fitzsimmons,* Los Alamos National Laboratory*; X. Batlle,* Universitat de Barcelona, Spain*; J.B. Kortright,* Lawrence Berkeley National Laboratory*; D. Altbir,* Universidad de Santiago de Chile, Chile*; J. Mejia-Lopez,* Pontificia Universidad Catolica de Chile, Chile*; A. Romero,* Unidad Queretaro Libramiento Norponiente, Mexico **INVITED**

In recent years we have performed an extensive study of Exchange Bias in Antiferromagnetic (AF) Fluoride or Oxide/Metallic Ferromagnets (F) bilayers and nanostructures. To arrive at a comprehensive understanding of the phenomenon we have performed global (magnetization, Kerr effect, magnetotransport, ferromagnetic resonance), and local (magnetic circular dichroism, polarized neutron diffraction) magnetic measurements and combined these with detailed quantitative structural (X-ray and neutron diffraction) and growth studies. These studies were complemented by micromagnetic and Monte Carlo calculations to understand the role of various parameters in exchange bias and to clarify the importance of the various possible mechanisms. We discovered many unexpected surprises, such as large exchange bias in fully compensated surfaces, positive exchange bias, and reversal asymmetries. The overall emerging picture is that many phenomena can coexist even in the simplest exchange bias systems such as the one studied here. Domain walls and uncompensated spins in both the F and the AF, uncompensated spins and anisotropy in the AF, the interfacial coupling, inhomogeneities and roughness at the interface, and the detailed crystal structure of the constituents all play a major role. The overall picture that emerges is that pinned uncompensated spins in the bulk AF, coupled to pinned uncompensated spins at the interface, provide the unidirectional anisotropy needed for exchange bias. This together with interfacial inhomogeneities, interfacial coupling and the various anisotropies can explain the large variety of apparently disconnected phenomena. The origin and exact nature of the uncompensated spins remains a major unsolved issue. Time permitting, I will describe very recent attempts at beating the superparamagnetic limit and modification of the magnetism in magnetic nanostructures. Work supported by DOE and AFOSR

2:40pm **MI-WeA3 All Ferromagnetic Exchange Bias Systems***, **A. Berger**, D.T. Margulies, E.E. Fullerton,* Hitachi GST*; S. Polisetty, X. He, Ch. Binek,* University of Nebraska*; O. Hovorka, G Friedman,* Drexel University

We have recently demonstrated a novel pathway for studying exchange bias and the tuning of hysteresis loop properties by combining two ferromagnetic layers with very different properties.@footnote 1@ Specifically, we use one hard ferromagnetic layer (HL) that serves as the tuning element, hereby replacing the antiferromagnetic layer of conventional exchange biased systems, and one soft ferromagnetic layer (SL) that is the actual tunable magnetic film. This bilayer structure has the advantage that the pre-set tuning field and temperature ranges are more accessible than in the case of traditional exchange bias structures using antiferromagnets. Also, a ferromagnetic HL allows for simple magnetometry monitoring of its magnetic state, which enables further insight into its role as the tuning element. The structures that were successfully utilized in our approach consist of a 15 nm thick hardmagnetic CoPtCrB-film, the tuning layer HL, exchange coupled by means of a 0.6 nm thick Ru-interlayer to a 1-2 nm thick CoCr-film, which is the tunable layer SL. We observe that the SL bias field h@sub bias@ is proportional to the HL magnetization M@sub r@, which suggests that the effective bias field is determined by the volume-averaged magnetization of HL. We also studied the existence of training effects in these all ferromagnetic exchange bias systems and found it to be triggered by the SL magnetization reversal.@footnote 2@ Furthermore, we were able to demonstrate experimentally for the first time that the amount of training in exchange bias systems is correlated with the HL magnetization state, in particular its distance from equilibrium@footnote 2@. @FootnoteText@ @footnote 1@A. Berger et al., Appl. Phys. Lett. 85, 1571 (2004)@footnote 2@Ch. Binek et al., Phys. Rev. Lett. 96, 067201 (2006).

3:00pm **MI-WeA4 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, P. LeClair,* University of Alabama

When an antiferromagnetic (AF) film is used to create anisotropy in a ferromagnetic (F) layer, the thickness of the AF is usually chosen to be greater than 5 nm to produce large loop shift of the pinned F layer. In current perpendicular to the plane (CPP) spin valves it is desirable for ancillary layers such as the AF to have a small electrical resistance. This creates a problem, since a fundamental property of antiferromagnets is an intrinsic high resistivity. A possible solution to this problem is to fabricate a device with a thinner AF layer (~2-4 nm) such that the coercivity of the F layer is enhanced while the loop shift is not fully developed. In this regime, the relaxation time of the AF grains is short enough to allow the AF surface moments to follow the F moments in an irreversible manner, due to the AF anisotropy, resulting in a supplementary loss mechanism and a substantial increase in the coercivity of the F layer. If the F layer is then replaced by a synthetic antiferromagnet (SAF), the applied field range where the SAF moments are antiparallel is enhanced with a concurrent increase in the giant magnetoresistance ratio (GMR). The thermal stability of spin valve stacks with the structure Ta(4)/Cu(10)/IrMn(x)/CoFe(3)/Ru(0.8)/CoFe(3)/Cu(2.5)/CoFe(1)/NiFe(3)/Ta(5) with x < 5 nm, is found to increase with increasing x. Magnetization and GMR measurements are compared to Stoner-Wohlfarth simulations which nicely show the applied field dependence of the relative orientations of the F layer magnetizations in the spin valve stack. These results will be compared to those obtained for similar spin valve stacks with thicker AF layers and stacks employing hard F layers to increase the pinned layer anisotropy.

3:20pm **MI-WeA5 Theory of Resonant Tunneling in Composite Fe/MgO/Fe Junctions with Nonmagnetic Interlayers***, **J. Mathon**,* City University, UK **INVITED**

Epitaxial Fe/MgO/Fe tunneling junctions with nonmagnetic interlayers bewteen the MgO barrier and Fe electrods are interesting since Au/Ag interlayers create quantum wells in the minority-spin channel which may give rise to resonant tunneling. Because of a good match between Fe and Au/Ag majority-spin bands there are no quantum wells in the majority-spin channel. The idea is to engineer a junction with resonant tunneling in the minority-spin channel in the ferromagnetic(FM)configuration while tunneling in the antiferromagnetic (AF) configuration remains nonresonant. We investigated Fe/Au/MgO/Au/Fe junction with two Au interlayers. In the AF configuration all electrons see a single quantum well and no resonant tunneling occurs. However, in the FM configuration the minority-spin electrons see two quantum wells adjacent to the MgO barrier. A barrier sandwiched between two wells can give rise to resonant tunneling with 100\% transmission through the barrier. A resonant enhancement of TMR is thus expected.

4:00pm **MI-WeA7 The Role of Interfacial Moments in High TMR MgO-based Structures***, **E. Negusse**, A. Lussier, J. Dvorak, Y.U. Idzerda,* Montana State University -- Bozeman*; S.R. Shinde, Y. Nagamine, S. Furukawa, K. Tsunekawa,* Canon-Anelva, Corporation

The large tunneling magnetoresistance (TMR) reported in MgO based magnetic tunneling junctions (MTJs) has attracted a great deal of attention for practical applications in spin-based electronic devices such as read-heads and nonvolatile memory.@footnote 1@ Recently it has been shown that adding boron to the cobalt-iron alloy electrodes created room temperature TMR of 230% by making the electrodes more amorphous and resulting in MgO barriers with good crystallinity.@footnote 2@ We used x-ray resonant magnetic scattering (XRMS), a nondestructive, element-specific and interface sensitive probe, to measure the effect of boron addition and annealing on the chemical and magnetic properties of the buried electrode-MgO interface. The specular and diffuse (interface-sensitive) scattered circularly polarized x-rays can be used to characterize the magnetic response of the moments at the interface compared to the entire film. The samples studied were 18 Å MgO films grown on 30 Å Co@Sub 70@Fe@Sub 30@ and Co@Sub 60@Fe@Sub 20@B@Sub 20@ electrodes using a UHV sputtering system (ANELVA C-7100). Our measurements showed that adding boron increased the squareness of the hysteresis loop and resulted in a significant decrease of the coercive field from 36 Oe to 5 Oe. Annealing (2 hours in an 8 kOe applied field at 360 °C) increased the grain size by 14% resulting in a slight increase in H@sub C@ for the boron containing electrode. We find that the interfacial moments for the more amorphous films behave identically to the bulk and may be the source of the increased TMR values. @FootnoteText@ @footnote 1@

S. S. P. Parkin, et al, Nat. Mater. 3, 862 (2004); S. Yuasa, et al., Nat. Mater. 3, 868 (2004).@footnote 2@ D. D. Djayaprawira, et al, Appl. Phys. Lett. 86, 092502 (2005).

4:20pm **MI-WeA8 Tunnel Magnetoresistance Effect in Sputtered MTJs with MgO Barrier and Various Ferromagnetic Electrodes***, **J. Hayakawa,*** Hitachi Ltd. and Tohoku University, Japan*; S. Ikeda, Y.M. Lee, R. Sasaki, T. Meguro, F. Matsukura,* Tohoku University, Japan*; H. Takahashi,* Hitachi Ltd., Japan and Tohoku University, Japan*; H. Ohno,* Tohoku University, Japan **INVITED**

Magnetic tunnel junctions (MTJs) with a crystalline MgO barrier offer giant tunnel magnetoresistance (TMR) ratio@footnote 1-5@ and current-induced magnetization reversal at low critical current and are of considerable interest in terms of physics involved as well as of application to advanced magnetic memories (MRAMs). Here we report high TMR ratio over 360% at room temperature in (100) oriented CoFeB/MgO/CoFeB MTJ sputtered on Si/SiO wafers. The MTJs consist of Ta (5nm) / NiFe (5nm) / MnIr (10nm) / CoFe (2nm) / Ru (0.8nm) / CoFeB (3nm) / MgO / CoFe(B) / Ta (5nm) / Ru (5nm). The thickness of the MgO barrier was varied from 0.80 to 2.4 nm. We found that the TMR ratio increases with increasing the annealing temperature (Ta), and reaches 361% at RT when the Ta is 400°C (578% at 5 K). These TMR ratios correspond to tunneling spin-polarizations of 0.80 and 0.86 by using Julliere's formula. HRTEM images revealed that the as-deposited CoFeB electrodes were amorphous and the as-deposited MgO barrier had highly (001)-oriented NaCl structure with good uniformity. The images also showed that by annealing at 375°C, full crystallization of the CoFeB ferromagnetic electrodes in body centered cubic structure took place. The observed giant TMR ratio is attributed to the formation of highly (100) oriented crystalline MTJs with an MgO barrier and bcc CoFeB by annealing, which satisfies the conditions for high TMR ratio predicted by the theoretical studies.@footnote 6-8@ We will also show the tunnel magnetoresistance effect in the MTJs with CoFe-B free layers with different Co, Fe, and B (Boron) compositions. This work was supported by the IT-program of Research Revolution 2002 (RR2002): Development of Universal Low-power Spin Memory, Ministry of Education, Culture, Sports, Science and Technology of Japan. @FootnoteText@@footnote 1@S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando, Nat. Mater. 868, 3 (2004). @footnote 2@S. S. Parkin, C. Kaiser, A. Panchula, P. M. Rice, B. Hughes, M. Samant, and S.-H. Yang: Nat. Mater. 3, 862 (2004). @footnote 3@D. D. Djayaprawira, K. Tsunekawa, M. Nagai, H. Maehara, S. Yamagata, N. Watanabe, S. Yuasa, Y. Suziki, and K. Ando, Appl. Phys. Lett. 86, 092502 (2005). @footnote 4@J. Hayakawa, S. Ikeda, Y. M. Lee, R. Sasaki, T. Meguro, F. Matsukura, H. Takahashi, and H. Ohno, Jpn. J. Appl. Phys, 44, L1267 (2005). @footnote 5@S. Ikeda, J. Hayakawa, Y. M. Lee, R. Sasaki, T. Meguro, F. Matsukura, and H. Ohno, Jpn. J. Appl. Phys, 44, L1442 (2005). @footnote 6@W. H. Butler, X.-G. Zhang, T. C. Schulthess and J. M. MacLaren, Phys. Rev. B. 63, 054416 (2001). @footnote 7@J. Mathon and a. Umersky, Phys. Rev. B. 63, 220403R (2005). @footnote 8@X.-G Zhang and W. H. Butler, Phys. Rev. B 70, 172407 (2004).

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