Magnetic Interfaces and Nanostructures Technical Group Room 618/619 - Session MI-WeA

Giant Magnetoresistance

Moderator: B.A. Everitt, Seagate Technology

2:00pm **MI-WeA1 Hot Electron Attenuation Lengths in Magnetic Multilayers***, **R. Lu**, K.L. Kavanagh,* University of California, San Diego*; C.J. Powell, P.J. Chen, F.G. Serpa, W.F. Egelhoff, Jr.,* National Institute of Standards and Technology

We are using ballistic electron emission microscopy (BEEM) to measure electron transport across magnetic metal multilayers. Room temperature measurements in air have been carried out on Au/M/Si(100) or Au/M/Au/Si(100) diodes, sputter deposited at 175 or 300K, where M is Co, Fe, Ni, or NiFe(81:19). STM images of the 5nm thick Au surfaces show 10-20nm diameter crystallites, with a typical roughness of 3-6nm, depending on the deposition temperature. Corresponding BEEM images show grain dependent BEEM currents, with uniform contrast across each grain, independent of surface morphology, presumeably a function of the Au or magnetic-metal grain orientation. Averaged BEEM spectra for the Au/M/Si diodes, as a function of magnetic metal thickness (0 - 2nm) show decreasing (Ni or NiFe) or increasing (Co and Fe) BEEM thresholds with increasing metal thickness, indicative of changing magnetic metal/semiconductor interface coverage and/or reactions. Plots of log BEEM current versus M thickness are linear giving hot electron (1-1.5eV) attenuation lengths for Co, Fe, NiFe, and Ni of 2, 5, 8 and 13±2Å, respectively. Magnetic metal sandwich diodes, (Au/M/Au/Si) show comparable attenuation lengths but with smaller BEEM currents, likely the result of greater interface scattering. We are in the process of carrying out BEEM magnetotransport measurements on GMR layers and will report these results at the meeting.

2:20pm **MI-WeA2 Exchange Bias in Fe/Cr Double Superlattices***, **J.S. Jiang**, G.P. Felcher, A. Inomata, R. Goyette, C. Nelson, S.D. Bader,* Argonne National Laboratory

The exchange bias effect is a magnetic pinning phenomenon at the interface between a ferromagnet (F) and an antiferromagnet (AF). It is characterized by a field-offset, or "biased", hysteresis loop. Research on the exchange bias effect has been limited by difficulties in identifying the interfacial magnetic structure and in assessing the role of interfacial roughness. The strength of exchange bias typically observed experimentally is more than an order of magnitude smaller than that predicted by theory. We demonstrate the exchange-bias effect in sputter-deposited epitaxial Fe/Cr "double superlattice" structures that consist of ferromagnetically and antiferromagnetically coupled Fe/Cr superlattices. The AF/F interface in our novel double superlattices is coherent compared to conventional exchange bias systems consisting of dissimilar AF and F phases. The double superlattices offer flexibility in configuration and tunablity of the magnetic coupling and anisotropy. Magnetization results show that AF/F exchange coupling affects the nucleation of reverse magnetic domains, and that the magnitude of the exchange bias field is given directly by the classic formula for collinear spin structures. The collinear spin distribution is confirmed by polarized neutron reflectivity. Work supported by US-DOE BES-MS Contract No. W-31-109-ENG-38.

2:40pm **MI-WeA3 Surface Diffusion Mechanism for the Exchange Coupling between a Ferromagnetic Layer and an Antiferromagnetic Layer***, **C. Hou**[1], K. Zhang, T. Zhao, H. Fujiwara,* The University of Alabama

It is the surface net spin that is considered to be responsible for the exchange coupling between a ferromagnetic (F) layer and an antiferromagnetic (AF) layer. For an AF surface with roughness, statistics shows that an AF grain with a total number of spins n = n@super +@ + n@super -@, has an average net number of spins pointing in one direction of n@sub net@ = absolute value of (n@super +@ - n@super -@) = n@super 1/2@ with n@super +@ and n@super -@ denoting the number of spins in "+" and "-" directions within one AF grain, respectively. For an AF layer with total grains N = N@super +@ + N@super -@, it is expected N@super +@ /N@super -@ = 1 as deposited without the F layer, where N@super +@ and N@super -@ denote the number of grains with net spin in the "+" and "-" directions, respectively. Therefore the surface spins of all the AF grains still cancel each other. When a F layer is deposited on top of the AF layer under a field in "+" direction, the balance of N@super +@ and N@super -@ is broken, resulting in N@super +@ / N@super -@ > 1. Thus, the overall net moments are obtained without changing n@sub net@ of each grain. It is generally accepted that this is the cause of the exchange coupling. A NiFe/FeMn/NiFe sample shows reasonable amount of exchange bias field H@sub eb@ and coercivity H@sub c@ for both of the NiFe layers as deposited in a field. With post annealing with a field in the pinned direction, it is found that both H@sub eb@ and H@sub c@ of the two NiFe layers are increased. The results can't be explained by the increase of only the ratio N@super +@ /N@super -@. It is concluded that it is the increase of the individual n@sub net@ that causs the above phenomenon. The increase of n@sub net@ is thought to occur through surface spin diffusions.

3:00pm **MI-WeA4 Magnetic Stability of Exchange Coupled Magnetic Systems***, **A. Inomata**, J.S. Jiang, C.-Y. You, J.E. Pearson, S.D. Bader,* Argonne National Laboratory

The growing demand for higher density magnetic recording and the development of magnetoelectronic devices require controllable magnetic properties on the nanometer scale.@footnote 1@ The application of interfacial exchange coupling is attractive for this purpose. The exchange bias effect occurring at the interface between a ferromagnet(F) and an antiferromagnet(AF) has been used for GMR heads in high density magnetic recording, and exchange-spring magnets consisting of exchange coupled hard and soft ferromagnetic phases are candidates for the next generation of permanent magnet materials. We present a comparison of the magnetic stability in exchange bias and exchange spring systems. The exchange bias system used is the Fe/Cr "double superlattice" structures constructed as [Fe/Cr]@super AF@/Cr/[Fe/Cr]@super F@ with appropriate Cr thickness representing the F and AF.@footnote 2@ And for the exchange spring system we used SmCo/Fe bilayer structures grown epitaxially on different templates to give uniaxial, biaxial and random in-plane anisotropy.@footnote 3@ The switching field and remanent magnetization of both systems were measured by the magneto-optic Kerr effect during repeated reversal of the soft layer magnetization by field cycling. All samples are stable after 10@super +6@ cycles. The effects of the pinning layer and the interfacial spin configuration will be discussed. Work supported by US-DOE BES-MS Contract No. W-31-109-ENG-38. @FootnoteText@ @footnote 1@ S.Gider et al. Science, 281, 797, 1998. @footnote 2@ J.S.Jiang et al. Submitted to Phys.Rev.Lett. @footnote 3@ E.E.Fullerton et al. Phys.Rev.B.58, 12193, 1998.

3:20pm **MI-WeA5 CPP-GMR for Magnetoelectronic Memory***, **K. Bussmann**, G. Prinz, B. Bass, S.-F. Cheng,* Naval Research Laboratory*; D. Wang, J. Daughton,* Nonvolatile Electronics, Inc. **INVITED**

Current perpendicular-to-plane giant magnetoresistance (CPP-GMR) has been demonstrated to provide enhanced GMR relative to that measured using the current-in-plane (CIP) geometry with similar multilayer architectures. We have been pursuing this advantage in work performed at the Naval Research Laboratory in developing a new non-volatile magnetic memory compatible with existing Si-CMOS technology. The functionality of this approach improves as the device dimension is reduced to sub-micrometer levels. At these dimensions the micromagnetic switching processes are strongly influenced by edge effects and it is important to include these terms, along with intrinsic magnetic materials properties, to obtain stable '0' and '1' configurations. We will show our results on circular disk devices that stabilize the magnetization in right or left-handed helicity. The devices are constructed as magnetic layers separated by non-magnetic spacer layers. Magnetic layers are alternately rendered 'hard' and 'soft' by varying the thickness of the layers as 'thick' or 'thin', respectively. The residual magnetic pole density at the device edge is minimized by the nature of the parallel alignment of the magnetization to the circumference of the disk, an effect driven by the exchange coupling intrinsic to each layer. Parallel and antiparallel helicity orientations of the magnetization are obtained by flowing current through the device, allowing programmability to '0' (parallel) and '1' (antiparallel) states. We show and interpret switching data on devices ranging from 0.25 - 0.6 micrometers in diameter and present an analysis of utility of these structures in CPP-GMR magnetoelectronic memory.

4:00pm **MI-WeA7 High-Speed Dynamics of Submicrometer GMR Devices***, **S.E. Russek**,* National Institute of Standards and Technology **INVITED**

Most of the applications of GMR and spin-dependent tunneling devices require them to be very small (line widths of ~300 nm) and very fast (operation frequencies > 1 GHz). The simplest devices typically consist of 4 to 10 layers of magnetic, nonmagnetic, insulator, and conducting materials with thicknesses of 0.6 nm to 10 nm. In this talk I will present high-speed

[1] **Falicov Student Award Finalist**

measurements of sub-micrometer spin valves being driven by magnetic field impulses and step excitations with peak widths and ristimes of less than 300 ps. We have observed sub- 300 ps rotations and switching (180 degree rotation) of these devices and free induction decay (damped precessional motion) with characteristic frequencies of 2 - 6 GHz. The response of the devices have been compared to Landau-Lifshitz-Gilbert (LLG) micromagnetic simulations and high-speed measurements of magnetization rotation in sheet films using second-harmonic MOKE. The value of the dynamical parameters of the small devices, such as the damping constant, have been compared to those measured using more traditional methods on larger samples, with a smaller range of motion of the magnetization, and a less complex layer structure. The effect of disorder due to edge roughness, surface roughness, and variable interlayer coupling have been studied using LLG simulations and the results have been compared to the dynamical response of real devices to assess the importance of disorder in real systems. Both the damping constant and the degree of disorder are shown to be important in high-speed operation of these devices.

4:40pm **MI-WeA9 RF Diode Sputter Deposition of GMR Multilayers***, **W. Zou**, H.N.G. Wadley,* University of Virginia*; D. Wang, D. Brownell,* Nonvolatile Electronics, Inc.

Radio frequency (RF) diode sputtering has been used for the growth of giant magnetoresistive (GMR) metal multilayers. A systematic series of experiments have been conducted to evaluate the dependence of magnetic properties and magnetoresistance upon growth conditions (i.e. background pressure, input power) for NiFeCo/CoFe/CuAgAu multilayers with different CuAgAu thickness during RF diode sputter deposition using an argon plasma. Atomic force microscopy results have shown that the background pressure and plasma power have large effects upon column width and surface morphology that eventually affect GMR properties. A multiscale modeling study has been used to investigate the origin of these phenomena and to identify the origin of the relationships between the experimental observations and growth conditions. Novel deposition strategies for morphology control have been identified.

5:00pm **MI-WeA10 Effects of UV Illumination on Dry Etch Rates of NiFe-based Magnetic Multilayers***, **H. Cho**, K.P. Lee, K.B. Jung, S.J. Pearton,* University of Florida*; R.J. Shul,* Sandia National Laboratories

Dry etch patterning of magnetic multilayer stacks (eg. NiFeCo/CoFe/Cu/CoFe/NiFeCo) is possible under high density plasma (HDP) conditions using chemistries such as Cl@sub 2@/Ar or CO/NH@sub 3@. The etch mechanism is ion-assisted desorption of metal chloride or metal carbonyl products. Much higher (@>=@ factor of 3) etch rates are achieved with the Cl@sub 2@-based plasma chemistries, but the rates are still limited by desorption of the FeCl@sub x@ or Cu@sub 3@Cl@sub 3@ etch products. Simultaneous UV irradiation of the sample surface during HDP Cl@sub 2@ etching has been found to convert Cu@sub 3@Cl@sub 3@ into more volatile CuCl@sub 2@ and Cu@sub 2@Cl@sub 3@ species, lowering the activation energy for desorption and enhancing the Cu etch rate.@super (1)@ We have studied the effects of UV illumination on the etch rates of NiFe and NiFeCo in Cl@sub 2@/Ar and CO/NH@sub 3@ discharges, and on the etch selectivity of these materials over a variety of different mask materials (SiO@sub 2@, photoresist, photo-definable polymers) as a function of illumination flux, process pressure and HDP source power. For prevention of post etch corrosion it is still necessary to use H@sub 2@O rinsing or in-situ H@sub 2@ or SF@sub 6@ plasma removal of chlorinated etch residues.

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