Thin Film
Room: 10 - Session TF+MI-WeA

Thin Films for Memory and Data Storage
Moderator: S. Gupta, The University of Alabama

2:00pm **TF+MI-WeA1 Spin Transport Properties and Applications in Magnetic Multilayers**, ***R.H. Victora***, *S.H. Hernandez, T. Qu*, University of Minnesota **INVITED**

Since the discovery of giant magnetoresistance (GMR) in 1988, spin transport has rapidly evolved as a research area examining effects such as Current Perpendicular to Plane (CPP) GMR and spin torque transfer (STT). Giant Magnetoresistance is caused by spin-dependent scattering. High electrical resistance (R_{AP}) is measured for antiparallel magnetizations of adjacent layers, while low resistance (R_P) is measured for parallel magnetizations. CPP GMR shows an advantage in MR ratio ((R_{AP}-R_P)/R_P), because all electrons must pass through all layers. This geometry is widely used as the reader in high areal magnetic recording, where it is likely that the current non-magnetic insulator will ultimately be replaced by a metallic layer in order to limit resistance. The reciprocal effect, STT, occurs when an electric current passes through a pinned ferromagnetic layer and the angular momentum (magnetic moment) is transferred to a neighboring free magnetic layer. The magnetization in the free layer may stably oscillate or may achieve a collinear state to the pinned layer. Magnetization switching with the help of a current has been proposed as potential magnetoresistive random access memory (MRAM). However, the mechanism of spin transport is not fully understood for these effects.

We consider multiple reflections between the interfaces of the adjacent magnetic layers. If the ferromagnetic material is not 100% polarized, electrons with different polarizations are not perfectly transmitted or reflected. We show that reflections, although typically neglected, strongly affect the spin transport properties. They explain[1] the experimentally observed nonlinearity of GMR dependence on $\beta = \cos^2(\theta/2)$ (θ is the angle between the magnetizations of the fixed and free layers). Also the spin torque is decreased[2] by the reflection. The more orders of reflection we include in the spin torque, the more critical current is needed to switch the magnetization state. The spin torque oscillator (STO) is an attractive replacement for current microwave devices owing to its very small (nanoscale) size. However, a single STO does not provide sufficient power for many applications. An array of oscillators in series or parallel has been proposed to generate more power. The problem is to phase lock the non-uniform oscillators. We calculate the power spectrum of serial oscillators. We show that the oscillators' could be closely synchronized by a feedback ac current, even at room temperature.

1. T. Qu and R.H. Victora, J. Appl. Phys. 111, 07C516 (2012)

2. S. Hernandez and R.H. Victora, Appl. Phys. Lett. 97, 062506 (2010)

2:40pm **TF+MI-WeA3 Ta Seeded Ultrathin Free Layer for Fully Perpendicular Magnetic Tunnel Junctions**, ***A. Singh***, *A. Natarajarathinam, B.D. Clark, S. Gupta*, The University of Alabama

Studies of the effect of seed and capping layers on CoFeB free layers of magnetic tunnel junctions (MTJ's) originated from reports (1) of the crystallization of the CoFeB through diffusion of the B into the cap, as well as inducing an interfacial perpendicular magnetic anisotropy in the free layer (2, 3). We have also seen thatCoFeB can be made perpendicular[3, 4] with seed layers of certain materials, such as Ta and Ru. We deposited Ta and Ru seed layers with the following stack structure: (Ta/Ru/Hf/Zr) 2/ [tCoFeB*x*]/MgO 0.9/TaN5 nm. The thickness of CoFeB, tCoFeB, was varied between 0.8 to 1.4 nm. Samples with the Ta seed layer showed higher perpendicular anisotropy than that of Ru, Hf and Zr because of the B diffusion into Ta after annealing. At tCoFeB = 1nm, high perpendicular anisotropy was seen, with anisotropy energy density Kut = 0.24 erg/cm2. The optimized Ta-seeded CoFeB was used as the free layer in a fully perpendicular MTJ stack with a Co/Pd multilayer synthetic antiferromagnet pinned layer[5]. These MTJ stackswere then patterned into devices with photolithography and planarized at each step of fabricationwith a novel sputtered aluminum oxide passivation layer. After fabrication, these devices were subjected to a variety of annealing conditions: a) furnace annealed with a field of 0.5T applied in the plane of the sample at 1500C for 2 hours, b) rapid thermally annealed (RTA) at 3500C, 4000C and 5000C for various time periods. Magnetometry of the minor loops indicated that, as the RTA time was increased at each temperature, the free layer became fully perpendicular at 8 minutes and then went in-plane with longer annealing times of 12 minutes. These results matched closely with the transport measurements.Increase of annealing time improved the tunneling magnetoresistance (TMR) to a maximum of 50% at room temperature (nearly 60% at 4.2K). Further increase in annealing time degraded the TMR at all temperatures tested.Thusfor the first time, we have found that magnetometry on the free layer of fully perpendicular magnetic tunnel junctions (pMTJ) can be used to optimize the annealing conditions.

References

1. E. Chen et al., IEEE Trans. Magn. **46**, 1 (2010).

2. S. M. Watts et al., Digest FV-11, 11th Joint MMM-Intermag Conference, Washington, DC(2010)

3. D. Worledge et al., Digest HB-10, 11th Joint MMM-Intermag Conference, Washington, DC(2010)

4. D. C. Worledge, G. Hu, David W. Abraham, J. Z. Sun, P. L. Trouilloud, J. Nowak, S. Brown, M. C. Gaidis, E. J. O'Sullivan, and R. P. Robertazzi. Appl. Phys. Lett. **98**, 022501 (2011).

5. A. Natarajarathinam, R. Zhu, P.B. Visscher and S. Gupta, J. Appl. Phys 111, 07C918 (2012).

3:00pm **TF+MI-WeA4 Epitaxial $Fe_{38.5}Pd_{61.5}$ Films Grown by Pulsed Laser Deposition: Structure and Properties**, ***M.A. Steiner***, *R.B. Comes, J.A. Floro, W.A. Soffa, J.M. Fitz-Gerald*, University of Virginia

Thin films of 3d-4d/5d metallic alloys such as Fe-Pt, Co-Pt, and Fe-Pd are of technological interest due to their ordered $L1_0$ tetragonal phase which exhibits high magnetocrystalline anisotropy comparable to that of 3d-4f rare earth magnets. A combination of hard magnetic properties with ductility and corrosion resistance makes this family of alloys ideal for applications including micro-electro-mechanical systems and ultra-high-density magnetic storage. These alloys are known to develop unique microstructures, including a novel strain-induced chessboard eutectoid microstructure featuring exchange coupling effects that has been found between the hard $L1_0$ and soft $L1_2$ magnetic phases of the Co-Pt system. Within this class of materials, Fe-Pd alloys possess a somewhat lower magnetocrystalline anisotropy compared to Co-Pt and Fe-Pt, but the Fe-Pd phase diagram showing considerably lower order-disorder transition temperatures renders them well-suited for nanostructured magnetic applications and study.

Epitaxial films of $Fe_{38.5}Pd_{61.5}$ at the $L1_2$-$L1_0$ eutectoid composition have been grown on MgO 001 oriented substrates by pulsed laser deposition. These films exhibit atomic ordering with increasing temperature, transitioning from the disordered A1 (FCC) phase to the ordered $L1_2$ phase. $Fe_{38.5}Pd_{61.5}$ films grown at 550°C have been found to possess a two-phase microstructure of prismatic 50-100 nm disordered A1 secondary phases with 110 oriented facets embedded within an ordered $L1_2$ matrix. These secondary phases exhibit single domain magnetic axis rotation, while the easy magnetic axis of the ordered $L1_2$ matrix lies in plane due to strain induced by epitaxy. The growth these two-phase films has been studied as a function of deposition time. The films grown in this study were characterized by x-ray diffraction, vibrating sample magnetometry, atomic and magnetic force microscopy, and high resolution scanning electron microscopy.

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