BEAMLINE
U4B

PUBLICATION
E. Negusse, A. Lussier, J. Dvorak, Y.U. Idzerda, S.R. Shinde, Y. Nagamine, S. Furukawa, K. Tsunekawa, and D.D. Djayaprawira, "Magnetic Characterization of CoFeB/MgO and CoFe/MgO Interfaces," *Appl. Phys. Letts.*, **90**, 092502 (2007).

FUNDING
Office of Naval Research

FOR MORE INFORMATION
Yves Idzerda, Physics Department, Montana State University
Idzerda@physics.montana.edu

Magnetic Characterization of CoFeB/MgO and CoFe/MgO Interfaces

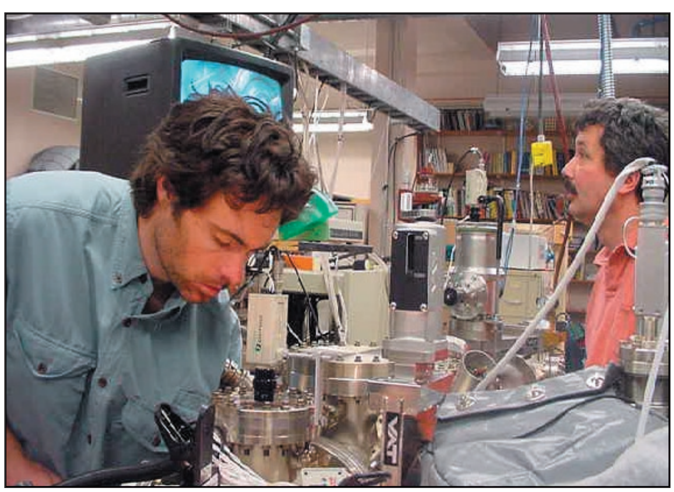
E. Negusse[1], A. Lussier[1], J. Dvorak[1], Y. U. Idzerda[1], S. R. Shinde[2], Y. Nagamine[2,3], S. Furukawa[2], K. Tsunekawa[2,3], and D. D. Djayaprawira[2,3]

[1]Department of Physics, Montana State University; [2]Canon ANELVA Corporation; [3]Canon ANELVA Corporation, Japan

The use of CoFeB ferromagnetic electrodes in place of CoFe has been shown to significantly increase the tunneling magnetoresistance (TMR) of tunnel junctions (MTJs) where the ferromagnetic electrodes are separated by an MgO tunneling layer. By using soft x-ray scattering techniques, we have shown that the behavior of the interfacial moments in CoFe electrodes is drastically different from the rest of the CoFe film, whereas the magnetic response of CoFeB interfacial moments is coherent with the film's bulk. Our results support the view that the high TMR values observed in MgO-based MTJs with CoFeB electrodes are due to the uniform magnetic response of the entire CoFeB electrode including the MgO interfacial moments.

Considerable efforts have been devoted to improving the fabrication and performance of magnetic tunneling junctions (MTJs) because of their potential applications in next-generation devices such as read-heads for ultra-high density hard disk drives and magnetoresistive random access memories (MRAMs). The extraordinarily high, room-temperature tunneling magnetoresistance (TMR) in MTJs that use an MgO tunneling barrier is due to coherent electron tunneling through this barrier. CoFe alloy, one of the most often used ferromagnetic electrodes in MTJ structures, typically grows in the body-centered cubic (BCC) polycrystalline structure, with little or no structural coherence across the MgO insulating barrier. However, when boron is added to CoFe, the resulting CoFeB is more pliant and the subsequent deposition of MgO results in a more crystalline structure, improving the coherent tunneling and significantly increasing the TMR value from below 100 to well over 200 percent.

To determine precisely how the improved crystalline quality enhances the spin-dependant tunneling across the electrode-MgO interface, we used x-ray absorption spectroscopy (XAS), x-ray magnetic circular dichroism (XMCD), as well as diffuse and specular x-ray resonant magnetic scattering (XRMS) to chemically and magnetically characterize each interface. The measurements were done at the Montana State University X-ray Material Characterization Facility located at NSLS beamline U4B. These nondestructive techniques provide element-specific and interface-sensitive information with magnetic contrast. XRMS is the angle-dependent reflectance of circular polarized soft x-rays, whose energy is tuned to the absorption edge of a magnetic element. It combines the chemical selectivity of x-ray resonant scattering with the magnetic contrast of magnetic circular dichroism.



Authors (from left) Alexandre Lussier and Yves Idzerda

The samples were prepared using Canon ANELVA C-7100 with the following structure: Si substrate/Ru(100Å)/electrode/MgO(18Å)/Ta(40Å), where the electrode is 30Å of either $Co_{70}Fe_{30}$ or $Co_{60}Fe_{20}B_{20}$. All layers were grown using DC magnetron sputtering except the MgO layer, which was grown using RF magnetron sputtering. The samples were cut in half and one half was annealed at 360°C for 2 hours in an 8 kOe magnetic field.

The XAS and XMCD spectra showed that both CoFe and CoFeB electrodes were metallic with no significant changes upon annealing. The x-ray scattering data, done in the configuration shown in **Figure 1** (inset), revealed high-quality interfaces for both electrodes but a distinct difference in the interfacial moments' hysteretic behavior.

As observed from the specular hysteresis loops in **Figure 1**, where the specular scattered intensity of circular polarized x-rays tuned to the Co (or Fe) L-edge is measured as a function of applied field, the improved switching behavior of the CoFe films with the incorporation of boron and subsequent annealing explains the improvement in the TMR behavior but does not fully explain the magnitude of the increase in TMR values. Better insight can be obtained by comparing the hysteretic behavior of the magnetic moments at the electrode-MgO interface by examining the diffuse (nonzero qX) hysteresis behavior of x-ray scattering at the Co L3-edge. The off-specular hysteresis loops in **Figure 2** were normalized so that the intensity at saturation is equal to ±1. They reveal a striking difference in the magnetic behavior of the interfaces. As can be seen in the left panels of **Figure 2**, the specular and off-specular loops for the CoFeB sample are nearly identical, indicating that the interfacial moments reverse in unison with bulk spins.

On the other hand, for the CoFe sample, the off-specular hysteresis loop's shape is highly unusual. The nature of the measurement tells us that during magnetization reversal, the spins responsible for the off-specular scattering in the CoFe film adopt a state of high in-plane magnetic disorder, momentarily giving rise to an increase in diffuse scattering intensity. This behavior is observed in both the as-grown and annealed CoFe films with the annealed films showing nearly an order of magnitude increase in magnetic contribution to the off-specular scattering intensity. Clearly, these moments behave dramatically different from the bulk moments, and degrade coherent tunneling through the MgO barrier leading to lower TMR. Improving the behavior of these moments is vital to the further increase in the TMR values.

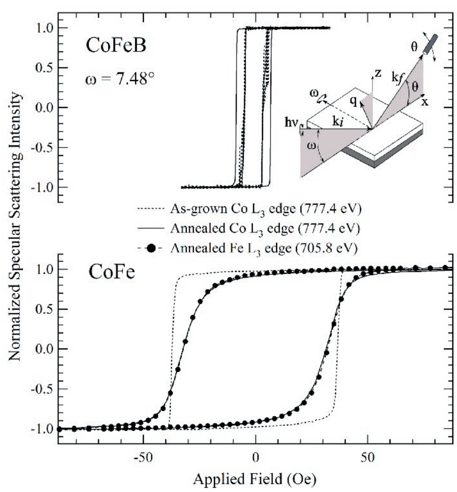


Figure 1. *Specular scattering intensity for circular polarized x-rays at energies resonant with the Co L3-edge as a function of applied field for CoFeB (top panel) and CoFe (bottom panel) films as grown (dashed lines) and annealed (solid lines). Inset: configuration of the scattering setup.*

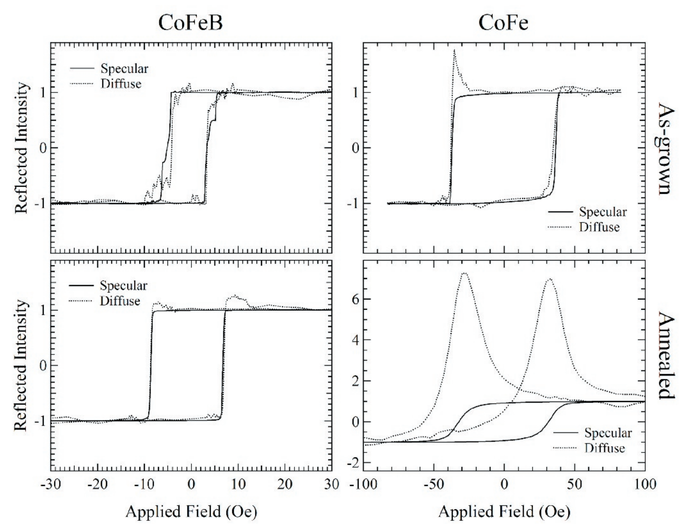


Figure 2. *Specular (solid lines) and off-specular (dashed lines) scattering intensity for circular polarized x-rays at energies resonant with the Co L3-edge as a function of applied field for CoFeB (left panels) and CoFe (right panels) films that are as-grown (top panels) and annealed (bottom panels). Note the different field scales in the right and left panels.*