Studies of Interfacial Magnetism with Circularly Polarized X-rays

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Introduction

Understanding interfacial magnetism in atomically engineered magnetic nanostructures is a key issue in magnetic storage and related technologies. Magnetic devices such as read-write heads are based on interfacial effects such as exchange-bias and coupling in heterogeneous layered systems. Achieving ever-smaller devices is contingent upon progress in this area as interfacial phenomena, including roughness, become increasingly important. Here we report on the application of two circularly-polarized x-ray based techniques, x-ray magnetic reflectivity and magnetic circular dichroism (MCD) to study interfacial properties of a sputtered [Gd (50 Å)Fe(15 Å)]$_{15}$ ferrimagnetic multilayer. X-ray energies near Gd $L_{2,3}$ resonances are used, allowing measuring Gd-specific magnetic properties averaged over the whole multilayer thickness (penetration depth of several microns). Absorption (scattering) of circularly polarized x-rays near these resonances produces real (virtual) spin-polarized photoelectrons through spin-orbit coupling. The real (virtual) dipole allowed transitions into 5d final states are spin-dependent due to exchange splitting of these final states, resulting in the different absorption (scattering) of left and right helicities of the incident radiation. The exchange splitting is proportional to the net magnetic moment on the resonant atom, giving rise to the techniques' sensitivity to element specific magnetization.

Experimental

Experiments were performed at Sector 4 of the SRI-CAT. X-ray linear polarization was converted to circular by a diamond quarter-wave plate operated in Bragg transmission case. Opposite helicities were obtained by offsetting the phase plate away from Bragg condition resulting in ≥ 95 % circular polarization. The sample was placed in a permanent magnet with a H=2.1 kG field parallel to its surface (coercive field is < 100G). The sample was in thermal contact with the cold finger of a displex refrigerator mounted in the ϕ circle of a Hubber diffractometer. Magnetic specular reflectivity was measured with a photon energy near the Gd L_2 resonance (E=7929eV) across six of the multilayer Bragg peaks by switching the helicity of the incident radiation at each scattering vector q_z. MCD was measured in fluorescence by switching the helicity at each energy point within a 100 eV range around Gd $L_{2,3}$ absorption edges.

Results and Discussion

Figure 1 shows magnetic reflectivity data at 300K together with refinements of a first Born approximation model of the charge-magnetic interference measured with this technique. The model includes charge and magnetic roughness[1] as well as refraction and absorption corrections. Charge (magnetic) anomalous scattering factors needed in the model were determined from charge (dichroic) absorption measurements and their Kramers-Krönig transforms. The magnetic structure of Gd derived from this fit is also shown. A region 4.2(3) Å in size near the Gd/Fe interface remains magnetized at 300K, i.e., above the Curie tem-

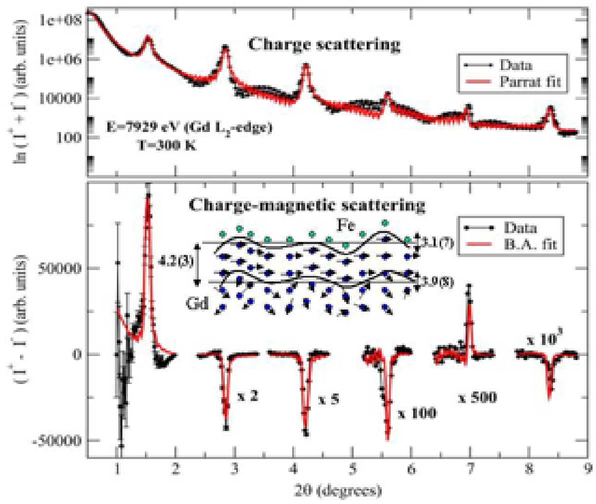

FIG. 1. Charge and charge-magnetic specular reflectivity data and fit results. Charge and magnetic rms roughnesses at the Gd/Fe interface are the same within uncertainties, 3.1(7) Å. This value is similar to the magnetic rms roughness, 3.9(8) Å, of the pure magnetic interface dividing magnetically ordered and disordered regions in the Gd layers.

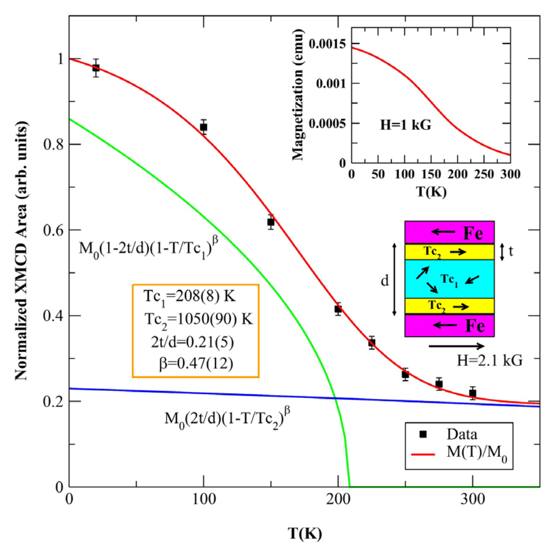

FIG. 2 MCD intensities at the Gd L_2 edge. Inset shows SQUID magnetization measurements which includes contributions from both Gd and Fe. The Gd layer thickness is refined from the specular charge reflectivity to d=50.24(4) Å. The total model function was convoluted with a 12K-rms gaussian to account for disorder in the sputtered multilayer.

perature of bulk Gd (293K). The enhanced Curie temperature is likely due to the strong AF exchange coupling between Gd and Fe layers; therefore the size of this region is a measure of the spatial extent of this coupling. We also observed clear transverse and longitudinal charge-magnetic diffuse scattering indicating correlated charge and magnetic roughnesses. Their similar rms values are then not surprising. Figure 2 shows integrated MCD intensities at the Gd L_2 edge in the 20-300K range. The MCD intensity is proportional to the Gd magnetization. The data is modeled assuming two components within each Gd layer: an interfacial region with elevated Curie temperature and an inner region behaving closer to bulk Gd. Fits with a mean field expression for the magnetization with variable fractional volumes of both components show ~20% of the Gd volume remaining magnetized at 300K; i.e., about 5 Å near each Gd/Fe interface. This is consistent with the magnetic reflectivity result. Moreover, the enhanced Curie temperature of this region is ~1000K, similar to that of Fe (1024 K). This gives an estimate for the strength of the AF exchange coupling at the interface. MCD sum rules at T=20K and 300K indicate nearly identical orbital and spin moments of Gd 5d states in the interior and the interfacial region. This is consistent with a small contribution of intermixing/interdiffussion to interfacial roughness.

Summary

Magnetic reflectivity and MCD allowed determining interfacial magnetic properties. These include charge and magnetic roughnesses and the spatial extent and strength of AF exchange coupling at a Gd/Fe interface.

Acknowledgments

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