The spin polarization of Mn atoms in paramagnetic CuMn alloys induced by a Co layer

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Using the surface, interface, and element specificity of x-ray resonant magnetic scattering in combination with x-ray magnetic circular dichroism, we have spatially resolved the polarization, and hence the spin accumulation in Mn high susceptibility material in close proximity to a ferromagnetic layer. The magnetic polarization of Mn and Cu 3*d* electrons in paramagnetic CuMn layers is detected in a Co/Cu(x)/CuMn structure for varying copper layer thicknesses (x). The size of the Mn and Cu L_{2-3}-edge dichroism shows a decrease in the polarization for increasing copper thickness indicating the dominant interfacial nature of the Cu and Mn spin polarization. The Mn polarization appears to be much higher than that of Cu. © *2009 American Institute of Physics*.
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I. INTRODUCTION

Spin accumulation plays an important role in spin-polarized transport phenomena such as giant magnetoresistance, domain wall magnetoresistance, and magnetization reversal processes induced by transverse spin injection.[1,2] Thus, a detailed knowledge of the variation of the spin density in the region of spin accumulation is fundamental in the theory of spin accumulation and the optimization of devices based on these phenomena. These properties are primarily driven by the electronic interactions at the interfaces of the materials. Our interest lies in the fundamental nature of electronic interfacial structure.

We have undertaken x-ray resonant magnetic scattering (XRMS) measurements combined with the x-ray circular magnetic dichroism (XMCD) to characterize the proximity effect by determining the moment of delta-doped high susceptibility impurities in close proximity to a ferromagnetic layer. The interface sensitivity of the XRMS technique is ideal to characterize the spatial extent of the spin accumulation.[3–7]

To highlight the interfacial sensitivity we chose to study the polarization of Mn atoms in paramagnetic CuMn diluted alloy with a Mn 50% concentration when in contact with a Co layer. Mn is an ideal choice as electronic band structure calculations have shown that the Mn atoms possess almost a 100% spin polarization at the Fermi level.[8,9]

II. EXPERIMENTS

Three samples were grown with the nominal structure, Si(100)/Ta (200 Å)/Co (50 Å)/Cu (xÅ)/CuMn (20 Å)/Al (15 Å), with $x=0$, 5, and 10 Å, at room temperature by magnetron sputter deposition in a high-vacuum chamber. We shall refer to these samples as Co/Cu(x)/CuMn. All samples had an in-plane easy magnetization axis, saturation fields below 100 Oe, and remanent in-plane magnetization of nearly 100%.

XRMS experiments were performed on a two-circle diffractometer housed in a high-vacuum chamber on station 5U1 at the Daresbury SRS. Energies in the range of 200–1400 eV with a resolution of 50 meV and flux of typically 10^{10} photons/s per 100 mA were available. All measurements were taken with right circularly polarized light and the dichroism extracted by flipping the applied magnetic field. The applied magnetic field direction was along the intersection of the incidence plane and the sample surface plane. The XRMS data were taken alternating between two opposite direction of a saturation electromagnetic field (held at ±300 Oe) at each photon energy. In this paper, we will demonstrate that the particular choice of wave-vector scattering **Q** can give maximum interfacial sensitivity.

III. RESULTS AND DISCUSSION

We collected XRMS data at the L_{2-3} edges of Co, Cu, and Mn from the three Co/Cu(x)/CuMn samples for a fixed scattering vector, which gives the most interface sensitivity. The energy spectra are measured at the Cu and Mn L_{2-3}-edges for all samples in Figs. 1(a) and 1(b), respectively. The asymmetry ratios were found to be 0.7% and 5.4% at the peaks of the Cu L_3 and Mn L_2 edges for the Co/CuMn, respectively. In particular, we note the small size of the measured Cu dichroic effect, indicating the extreme sensitivity of the XRMS technique to small magnetic mo-

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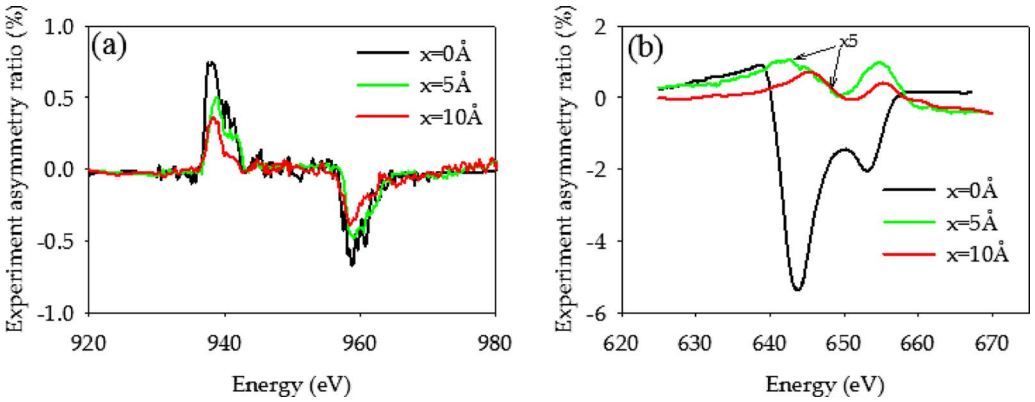

FIG. 1. (Color online) Experimental energy spectra measured at the Cu (a) and Mn (b) $L_{2,3}$ edges for the samples described in the text.

ments. The asymmetry ratios at Cu and Mn L_{2-3} edges exhibit a dichroism effect, unambiguously demonstrating a magnetic polarization of the Cu and Mn. The dichroism effect is observed for all samples but weakens with the increasing Cu thickness.

In order to provide a quantitative explanation for the circular dichroic effects observed and to extract the magnetic moment from resonant magnetic scattering, the data have been fitted using a classical electromagnetic model calculation which includes the complete polarization state of the incident light and spatial interference within the sample.[3]

We have divided the layer into slices along the z direction approximately one atomic plane in thickness (~2.5 Å). The interfacial structures were then modeled by varying the relative densities of Co, Cu, and CuMn densities through the sample. Note that for the specular reflectivity, we cannot distinguish between a topologically rough and a compositionally graded interface. An index of refraction for each slice have been determined from the resonant scattering where the absorptive parts were directly accessible from linear attenuation coefficient x-ray absorption spectroscopy and XMCD measurements and the dispersive parts were obtained by Kramers–Kronig transformation.

The magnetic dichroic effect was calculated by giving a magnetization to each slice of the interfacial structures containing Mn and Cu. The spectra have been fitted using a magnetic multiplying factor for each slice in the calculation. Since it is usually accepted that XMCD is proportional to the magnetic moment, the magnetic factor is used to reduce or increase the magnetic contribution to the reflectivity in order to fit our data. Figures 2(a) and 2(b) show the simulations at the L_{2-3}-edges of copper and manganese for all samples, respectively. The model reproduces very well the experimental data (Fig. 1). The resultant profile of the induced magnetization within the Mn and Cu components of all the samples are shown in the Fig. 3 and are scaled to the relative densities in each slice. The profiles have then been normalized to the total magnetic moment to give the induced Mn and Cu magnetization in units of μ_B/atoms. We can see that the polarization occurs mainly when the Mn and Cu atoms are close to the cobalt layer and the magnetization of the Mn and Cu fall off rapidly away from the Co layer. At the interface, the magnetic moment of the Cu is found to be about $0.05\mu_B$. This value is equivalent to the value found in the literature in Co/Cu multilayers.[10] The enhanced Cu d moment near the interface is the result of a considerable hybridization of the Cu and Co $3d$ orbitals near the interface.[10] For the Mn, the value of the magnetic moment is about $0.25\mu_B$ and decreases with the increasing copper thickness indicating the dominant interfacial nature of the Mn spin polarization (Fig. 3).

IV. CONCLUSIONS

Here we have presented clear evidence for an induced magnetism moment in a CuMn paramagnetic layer, i.e., Cu and Mn in Co/Cu(x)/CuMn samples varying with the Cu

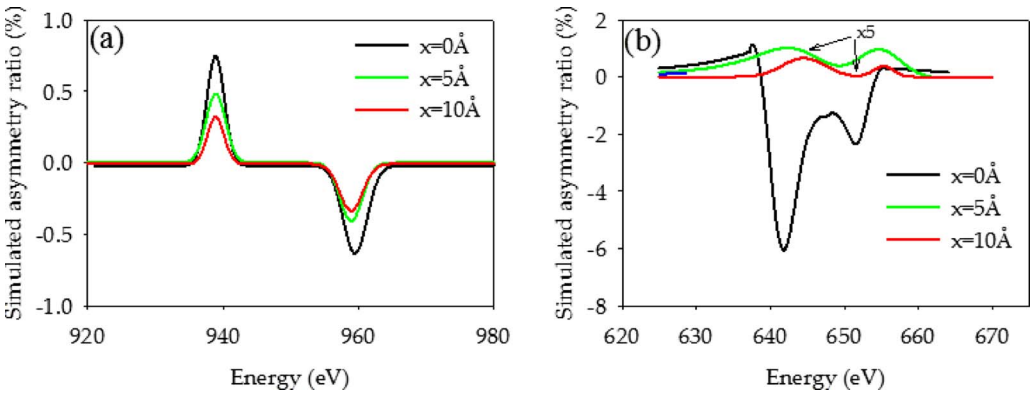

FIG. 2. (Color online) Simulated energy spectra calculated at the Cu (a) and Mn (b) $L_{2,3}$ edges for the samples described in the text.

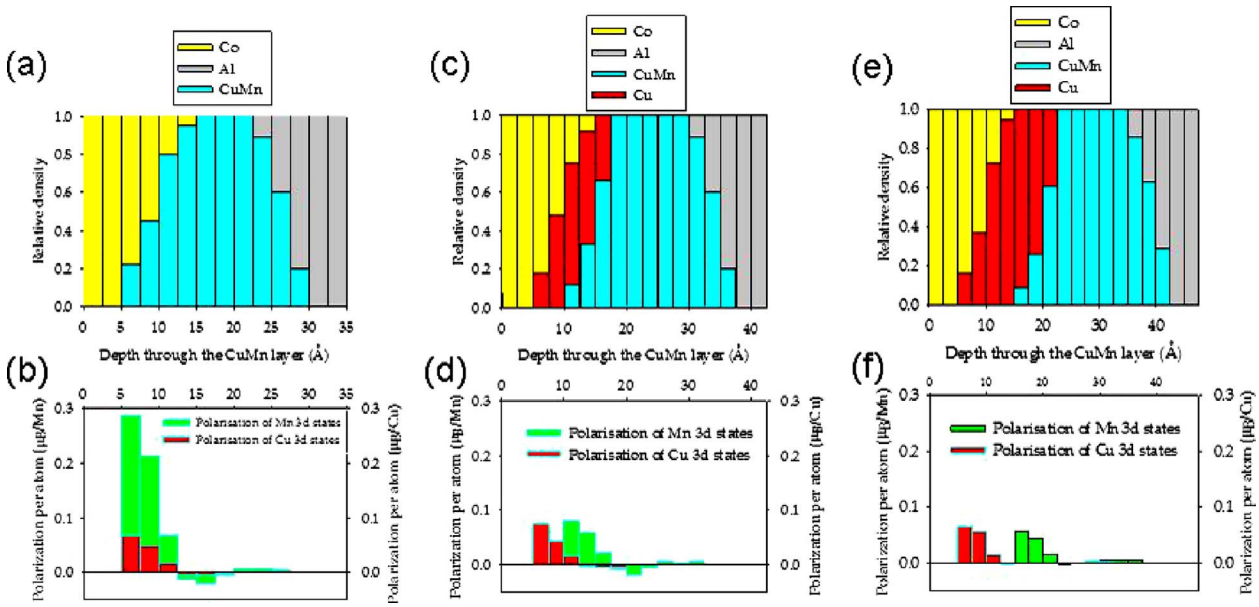

FIG. 3. (Color online) Profiles of the relative Co, Cu, and CuMn densities as a function of CuMn layer depth are shown in panels (a), (c), and (e) of Fig. 3 for samples Co/CuMn, Co/Cu(5 Å)/CuMn, and Co/Cu(10 Å)/CuMn, respectively. The errors in the relative density are estimated as ± 0.1. Panels (b), (d), and (f) present the profiles of the Cu and Mn polarizations, given in units of μ_B/Cu and μ_B/Mn determined from XMCD measurements. The error bars are estimated as $0.02\mu_B$/Mn and $0.01\mu_B$/Cu.

thickness (x). The Cu and Mn polarizations are found to be concentrated near the Co interface and that of Mn seems to be much higher than Cu.

ACKNOWLEDGMENTS

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