Depth profile of magnetization in $Fe_{0.34}Zn_{0.66}F_2$/Co bilayer

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1. Introduction

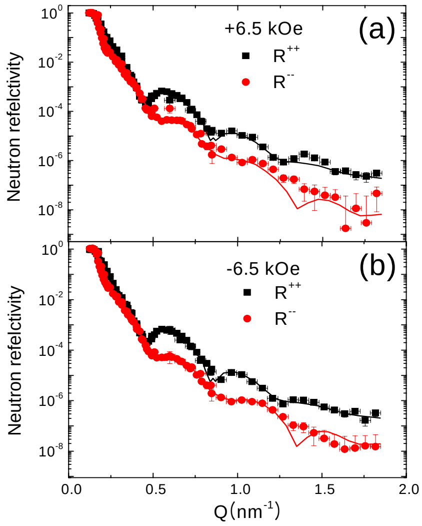
Exchange bias (EB) has been extensively investigated since its discovery [1] in ferromagnet (FM) Co particles whose surface was oxidized to form antiferromagnet (AF) CoO due to its technological importance in spin-valve electronic devices [2]. Most EB theories rely on uncompensated spins in the AF for an AF/FM coupling mechanism [3]. There have been many experiments to find depth profiles of magnetization in magnetic multilayer systems [4-7]. Recently, uncompensated Fe spins at the FeF_2/Co "interface" were observed using x-ray magnetic circular dichroism [6.7]. In addition, evidence for the existence of uncompensated spins within the "bulk" FeF_2 antiferromagnetic layer was obtained using polarized neutrons and soft x-ray magnetic scattering [6].

Among the uncompensated spins, some are pinned, and thus should result in a shift of the hysteresis loop along the magnetization (vertical) axis, in addition to the shift along the magnetic field (horizontal) axis normally associated with HE. In pure FeF_2/Co bilayers, the shift is very small and difficult to detect via conventional magnetometry, and its magnitude depends strongly on cooling fields and microstructure of the AF layer [8]. On the other hand, a relatively large pinned uncompensated spins has been observed via conventional magnetometry in dilute, single-crystalline AF/FM $Fe_xZn_{1-x}F_2$/Co bilayers [9].

In this study we have investigated the pinned magnetization using magnetometry and polarized neutron reflectivity (PNR) for a $Fe_{0.34}Zn_{0.66}F_2/FeF_2$/Co at 5 K. This sample has a significant pinned magnetization that can be easily measured via standard magnetometry techniques. We found that the pinned magnetization parallel to the cooling field exists in the $Fe_{0.34}Zn_{0.66}F_2$ layer from both the magnetization and PNR measurements. PNR showed that the pinned magnetization at the interface was also parallel to the FM magnetization, which means that the coupling is ferromagnetic at the AF/FM interface.

2. Experiments

The $Fe_{0.34}Zn_{0.66}F_2$ (110) (23 nm)/FeF_2 (1 nm)/Co (15 nm) was grown on a MgF_2 (110) single crystal via molecular beam epitaxy. The AF $Fe_{0.34}Zn_{0.66}F_2$ layer was epitaxial and the FM Co layer was polycrystalline. A capping layer of Al was used to prevent Co oxidation and the pure FeF_2 layer between $Fe_{0.34}Zn_{0.66}F_2$ and Co was introduced to get a large pinned uncompensated magnetization [9]. The magnetic properties were measured using a SQUID magnetometer with the magnetic field H applied along the [001] direction which is the magnetic easy axis of FeF_2. The sample was cooled from T = 95 K to T = 5 K with a filed of 2 kOe. Hysteresis loops between H = ± 10 kOe were obtained in the range of T = 5 K to 300 K. The polarized neutron reflectivity was measured at Los Alamos National laboratory after cooling the sample to T = 5 K with a field of 2 kOe in the [001] direction, the same condition for the magnetization measurement. The two cross sections corresponding to the non-spin-flip reflectivity profiles for spin-up (R++) and spin-down (R--) neutrons were measured.



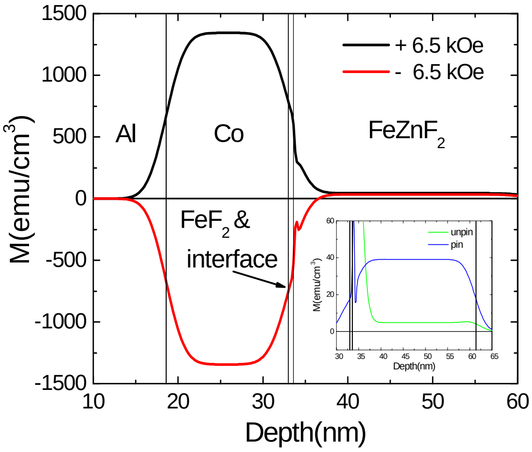


Fig. 1. Polarized neutron reflectivity profiles taken at T = 5 K for H = +6:5 kOe (a) and H = -6:5 kOe (b) shown by the symbols. Lines are results of fits to the data with the magnetization pro¯les shown in Fig. 2.

Fig. 2. Depth profile of magnetization from polarized neutron reflectivity at T = 5 K. The black line is for H =+6.5 kOe and the red one for H = -6.5 kOe. Inset: The depth profile of the unpinned and pinned magnetization calculated from the depth profiles of magnetization at $H = \pm 6.5$ kOe.

3. Results and discussions

The results of the polarized neutron reflectivity are shown in Fig. 1 after correcting for instrumental back ground and polarization efficiencies. The symbols are the experimental results and the lines are the results of the fitting with the depth profile of the magnetization shown in Fig. 2. Since the difference between the reflectivities, R++ and R--, is related to the component of magnetization which follows the external magnetic field, the magnetization profile at each magnetic field and unpinned and pinned magnetizations was obtained. Fig. 2 shows the depth profile of magnetization from fitting the polarized neutron reflectivity profiles at H = ±6.5 kOe. The black line is for H = +6.5 kOe and the red line for H = -6.5 kOe. These fits represent the depth profile of unpinned and pinned magnetizations shown in the inset of Fig. 2. The green lines represent unpinned magnetizations which follow the magnetic field while the blue ones pinned magnetizations which do not follow the magnetic field. For the $Fe_{0.34}Zn_{0.66}F_2$/Co bilayer, the uncompensated magnetization in the AF $Fe_{0.34}Zn_{0.66}F_2$ layer is clearly observed with the polarized neutron reflectivity as shown here. Most of the uncompensated magnetization is positive, that is, it points in the same direction of the cooling field ,and is pinned regardless of the magnitude external magnetic field. The uncompensated magnetization aligns parallel to the cooling field and the magnetization of Co, which indicates that there is ferromagnetic coupling between Co and $Fe_{0.34}Zn_{0.66}F_2$. Other $Fe_xZn_{1-x}F_2$/Co bilayers also have the ferromagnetic coupling between $Fe_xZn_{1-x}F_2$ and we confirmed this ferromagnetic coupling in order to control the sign of the exchange bias [10]. By integrating the depth profile of the pinned magnetization, we calculated the pinned magnetic moment to be 0.06 ±0.02 of the total magnetic moment. This is comparable with the result of 0.03 ± 0.01 obtained from the direct magnetization measurements.

4. Conclusions

The depth profile of the magnetization showed that the pinned uncompensated magnetization is in the bulk of the $Fe_{0.34}Zn_{0.66}F_2$ layer and that the amount is comparable with the result of the magnetization measurements. An small unpinned magnetization component in the dilute antiferromagnet was also observed. At the interface, the pinned magnetization was positive, indicating that for the cooling field used in the experiment (2 kOe) the interface pinned magnetization aligns parallel to the ferromagnet's magnetization.

5. References

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