Probing complex magnetic configurations

Magnetic thin films and multilayers are investigated both for their fundamental magnetic properties and for spintronics (the coupling of magnetism with electronic transport). Reduced dimensionality and an increased role of the interfaces give new properties with potential applications in information and communication technologies. For such systems, X-ray Resonant Magnetic Reflectivity provides element-specific, chemical and magnetic interface profiles with sub-nanometer spatial resolution.

Much of the work on these systems is concerned with the coupling between two magnetic layers that are either in direct contact or separated by another layer. In general, they have “in-plane magnetic anisotropy”, i.e. their axes of easy magnetization lie in the layer plane. There is also a strong interest in developing systems exhibiting perpendicular magnetic anisotropy (PMA) especially for high density magnetic storage. High stability of the magnetic state is sought for reliable storage and readout, but research aims also to reduce the energy needed to reverse the magnetization in the writing process. One way to achieve this is to realize a composite or hybrid structure, comprising layers with planar and perpendicular magnetization; the interlayer exchange coupling can ease magnetization reversals in the PMA layer. Optimizing such structures requires a detailed (i.e. layer resolved) and atomic-species selective picture of the non collinear magnetic configuration.

In collaboration with the Max Planck Institut, Halle, we have investigated the model layer system Fe_xCo_{1-x}/Rh/$Fe_{0.5}Co_{0.5}$ epitaxially grown on a Rhodium substrate. Here, the magnetic layers are separated by a nonmagnetic Rh layer. Alone, a $Fe_{0.5}Co_{0.5}$ layer exhibits perpendicular magnetization whereas an Fe layer (i.e. x=1) has an in-plane easy magnetization axis. Depending on the Rh separation-layer’s thickness, the orientation of the magnetic moments may depart from the easy magnetization axis and/or from the direction of an external applied magnetic field.

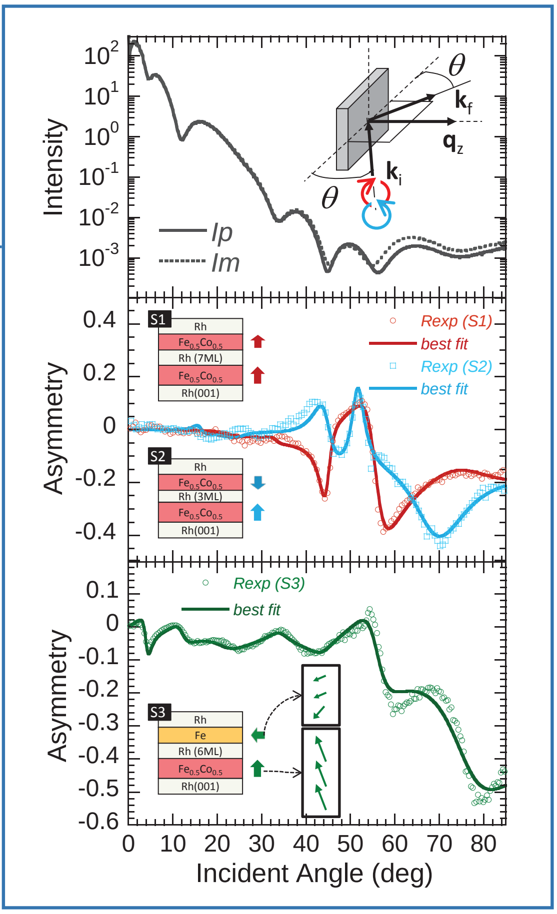

Figure: a) Reflected intensities Ip, Im (right and left circular polarizations) for 705.2 eV X-Rays (Fe L_3 edge) incident on FeCo/Rh(7 atomic monolayers)/FeCo sample S1; the geometry of the X-Ray experiment is shown at right. b): Magnetic asymmetry (Ip-Im) /(Ip+Im) at 705.2 eV for samples S1 and S2. c) Magnetic asymmetry at 705.2 eV for sample S3; the sketch shows distribution of the Fe magnetic moments in the two magnetic layers; thickness of each slice= 0.3-0.4 nm.

We used X-ray Resonant Magnetic Reflectivity for characterizing the vertical profile of the in- and out-of-plane contributions of the Fe and Co magnetization in the thin film structure. As shown in inset in Fig. (a), a monochromatic, circularly polarized, X-ray beam is incident on the sample surface at an angle θ, and the reflected X-rays are detected at an emerging angle θ. The photon energy is chosen in the vicinity of the Fe or the Co L_3 absorption edge, to benefit from the difference in the X-Ray scattering process related to the magnetization of the specific atom. Their L_3 thresholds lie in the soft X-ray range and the long wavelengths allow measuring the reflectivity at large angles of incidence, which is favorable for probing the out-of-plane magnetic components. We measure the θ dependent intensities of right and left circularly polarized beams (Ip and Im in Fig. (a)). The magnetic asymmetry (Figs (b,c)), i.e. the normalized difference of the two scans (Ip-Im)/(Ip+Im), is related to the magnetization profile.

First, we studied two systems exhibiting out-of-plane magnetization in the two FeCo layers (Fig. (b)). The magnetic asymmetry is close to zero at small angles and becomes strong at large angles. The two different Rh layer thicknesses produce parallel/antiparallel magnetic alignments. Fig. (b) shows the sensitivity of the magnetic asymmetry to reversal of the magnetization in the upper layer, illustrated by an opposite sign for the two magnetic configurations at around 40°.

Second, we studied a system with a Fe layer instead of a FeCo layer (Fig. (c)). We demonstrated that one can distinguish the net in-plane and out-of-plane components of the magnetization by using different acquisition modes. The analysis of the magnetic asymmetry due to in-plane magnetization revealed that the FeCo layer had an in-plane component, indicating its magnetization was now slightly tilted. Furthermore, the analysis of the asymmetry related to the out-of-plane magnetization showed that the Fe layer’s magnetism, normally in-plane, had an out-of-plane component. These effects result from the interlayer coupling. The asymmetry displayed in Fig. (c) is sensitive to both components (signal at both small and large angles). The vertical magnetization profile from this study is presented schematically (oriented arrows) in Fig. (c).

These measurements were done using an experimental device developed at the Néel Institute which is, to date, the only one which allows the investigation of a depth-resolved, out-of-plane magnetic profile.

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FURTHER READING

DIRECT IN-DEPTH DETERMINATION OF A COMPLEX MAGNETIC CONFIGURATION IN AN EXCHANGE-COUPLED BILAYER WITH PERPENDICULAR AND IN-PLANE ANISOTROPY
J.-M. Tonnerre, M. Przybylski, M. Ragheb, F. Yildiz, H. C. N. Tolentino, L. Ortega and J. Kirschner
Phys. Rev. B 84, 100407(R) (2011).

see also J. App. Phys. 111, 07C103 (2012)