Reversal mechanism of exchange-biased magnetic bi-layers observed by Lorentz electron microscopy

A. Kovács[1,3], J. Dean[2], A. Kohn[1] and T. Schrefl[2]

1. Department of Materials, University of Oxford, Oxford OX13PH, United Kingdom.
2. Department of Engineering Materials, University of Sheffield, Sheffield S13JD, United Kingdom
3. Research Institute for Technical Physics and Materials Science, Konkoly-Thege 29-33, H-1121 Budapest, Hungary

andras.kovacs@materials.ox.ac.uk
Keywords: magnetic thin films, Lorentz microscopy, exchange-bias

Interfacial exchange coupling between a ferromagnetic (FM) and an antiferromagnetic (AFM) layer has attracted sustained interest over the past decades for both fundamental and technological interest. There are still ongoing controversies about its underlying mechanism due to many magnetic and structural parameters that contribute to this interfacial coupling phenomenon.

The aim of this research is to study the role of microstructure on exchange-bias, thus enabling to develop realistic models for micromagnetic simulations of this phenomenon [1,2].

To achieve this aim, the influence of the thickness of the AFM layer on exchange-bias (EB) was studied. Various TEM techniques, both imaging and analytical, were used to characterize the structure of polycrystalline IrMn (AFM) and amorphous CoFeB (FM) bi-layers. The reversal mechanism of these EB layers was then characterized using Fresnel images recorded in a Lorentz transmission electron microscope (LTEM).

The EB multilayered structure of TiOx/CoFeB/IrMn/Ru/Ta were sputter deposited on SiO_x / Si substrates for magnetic and structural characterization, and on Si_3N_4 membranes for imaging the micromagnetic structure. The thickness of the IrMn layer varied from 6 to 12 nm while the thickness of the $Co_{65.5}Fe_{14.5}B_{20}$ layer was 5 nm. Exchange bias induced post-deposition by applying a magnetic field of 15 kOe at a temperature of 240ºC.

Macro-magnetic measurements using vibrating sample magnetometry revealed an increase of the exchange-bias field and decrease of coercivity with increasing the thickness of the AFM layer. Minor intermixing at the interface and structural defects such as interface roughness, grain boundaries, and twin boundaries, were identified as possible sources of magnetic frustration in the AF layer (Fig.1).

We have used Fresnel images to study the magnetization reversal processes. Our set-up, a low-field objective pole piece and in-built magnetising coils in the TEM holder, allows exploring the reversal process *in situ*. We also used digital diffractograms of Fresnel-contrast images for qualitative analysis of small angle domain wall (ripple) orientation. As the ripple orientation is perpendicular to the direction of net magnetization in the CoFeB layer, thus the rotation of this contrast is due to the spins aligning away from the unidirectional anisotropy axis in the AFM/FM bi-layer (Fig. 2). Besides the ripple contrast, many 360º domain walls (DW) were found in the EB layers before applying the magnetic field. These 360ºDWs are typically circular in shape with a diameter of several micrometers (Fig. 2a). The difference in size and density of 360ºDWs of samples with different AFM layer thickness is measured from Fresnel images.

Along the unidirectional axis, the 360º DWs act as the nucleation sites for new domain walls (Fig. 2b). At relatively large magnetic fields, these micromagnetic features

W. Grogger, F. Hofer, P. Pölt (Eds.): MC2009, Vol. 3: Materials Science,
DOI: 10.3217/978-3-85125-062-6-620 , © Verlag der TU Graz 2009

were removed. New 360º DWs formed after the magnetic reversal, though typically no correlation was observed in their location before and after this process. Analysis of the ripple pattern revealed a continuous in-plane rotation before reversal in both descending and ascending branches.

It is found that the reversal mechanism is different when the magnetic field is applied away from the EB unidirectional-axis, also depending on the thickness of the AF layer. In the case of strong interfacial coupling, the ripple contrast shows a larger range of rotation of the magnetic moments and additionally, the 360ºDWs did not act as nucleation sites for new domains. By applying the field at larger angles away from the easy axis, the reversal took place at lower fields, resulting in a reduced coercivity of the EB FM layer. However, for weak coupling, 360ºDWs still contribute to the reversal mechanism.

1. D. Suess etal, Phys. Rev. B 67, (2003) p. 054419
2. M. Kirschner etal, IEEE Trans. Magn. 39, 2735 (2003)
3. The aid of Engineering and Physical Sciences Research Council is gratefully acknowledged. A. Kohn acknowledges the financial support of the Royal Academy of Engineering and EPSRC.

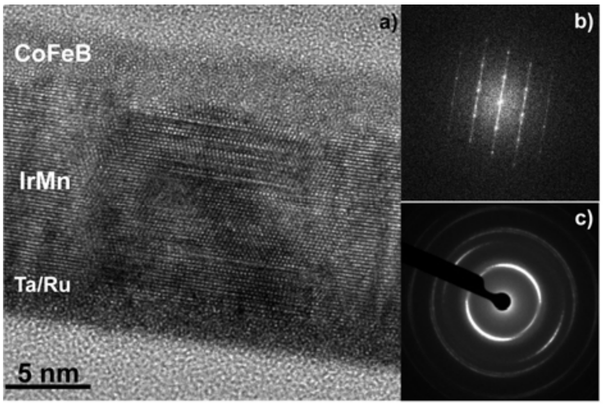

Figure 1. Fig. 1. High-resolution TEM image of the exchange-bias multilayer (a). b) Digital diffractogram shows the twin structure of an IrMn grain. c) Plan-view selected area electron diffraction pattern reveals the strong {111} texture of IrMn.

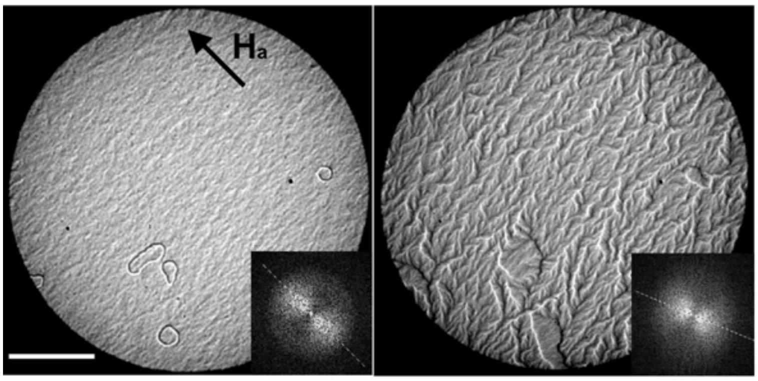

Figure 2. Fresnel-contrast images of EB layers with 12 nm thick IrMn at an applied field of 0 Oe (a) and at -205 Oe (b). The inset shows the ripple rotation using a digital diffractogram. The scale is 10 µm. The unidirectional anisotropy axis is parallel with the applied field (H_a)..

DOI: 10.3217/978-3-85125-062-6-620 , © Verlag der TU Graz 2009