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Comparison of Exchange-Bias Using Epitaxial and Polycrystalline $Ir_{0.2}$ $Mn_{0.8}$ Antiferromagnetic Thin Films: A TEM and Lorentz TEM Study

A. Kohn,* A. Kovacs*, S. –G. Wang**, C. Wang*, J. Dean***, T. Schrefl***, A. Zeltser****, M. J. Carey****, A. K. Petford-Long*****, and R.C.C. Ward**

* Department of Materials, University of Oxford, Oxford OX1 3PH, UK
** Department of Physics, University of Oxford, Oxford OX1 3PU, UK
*** Department of Engineering Materials, University of Sheffield, Sheffield S1 3JD, UK
**** Hitachi Global Storage Technologies, San Jose, CA 95193
***** Materials Science Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

Exchange bias (EB) refers to interface coupling between ferromagnetic (FM) and antiferromagnetic (AFM) layers, which then results in unidirectional anisotropy. This anisotropy manifests itself by an asymmetric horizontal offset of the magnetization hysteresis curve, quantified by the so-called exchange-bias field, as well as an increase of the coercivity. Such anisotropy is of fundamental scientific interest and an important component in spintronic devices, e.g. magnetic tunnel junctions used for magnetic random access memory or sensors, and spin valve heads. EB is a complex interface phenomenon because in addition to the magnetic structure of the AF, it is sensitive to structural parameters such as interface roughness, chemical intermixing, grain boundaries, and crystallographic orientation [1]. Therefore, we employ electron microscopy to quantify these defects and their role in determining the magnetic properties of EB bilayers. We examined FCC $Ir_{0.2}$ $Mn_{0.8}$ (IrMn), which is widely used in information storage devices [2], comparing between sputter-deposited IrMn/$Co_{65.5}$ $Fe_{14.5}$ B_{20} [3] and molecular beam epitaxial growth of Fe/IrMn bilayers [4]. We used high-resolution (HRTEM) and analytical TEM for characterizing the structure and chemistry of the bilayers, and Lorentz TEM to image their micromagnetic structure in situ during magnetization reversal. Figure 1 shows cross-sectional HRTEM images of the two structures. For the first structure, a highly epitaxial Fe(001)[100]//IrMn(001)[110] is observed. In the latter case, the sputter-deposited IrMn layer has a (111) texture along with grain boundaries, interface roughness, and stacking fault defects. In the plane of this IrMn film, the crystallographic orientation of the grains is random. The structural difference between the bilayers results in significantly different EB properties. For the epitaxial bilayer, Fig 2(a,c), is an example of a Fresnel-contrast image and magnetization curves, respectively. These results both demonstrate that the EB is aligned to an Fe magnetocrystalline easy-axis direction. Effectively, unidirectional anisotropy is added to the four-fold cubic anisotropy of the Fe layer. However, for the sputter-deposited bilayer, Figs 2(b,d), which are comparable results, show that the EB properties are determined predominately by the random in-plane distribution of the AF anisotropy [5]. Therefore, the IrMn grain structure is the origin of widespread formation of 360° domain wall loops seen in Fig. 2(b).

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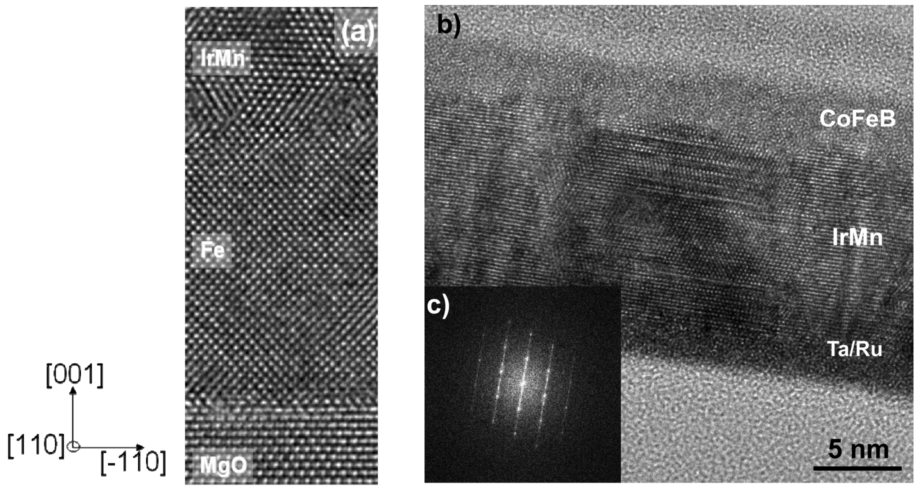

FIG. 1. (a) Cs-adjusted cross-sectional HRTEM image of the epitaxial Fe/IrMn bilayer grown on an MgO substrate. (b) HRTEM cross-sectional TEM of the IrMn/CoFeB bilayer and (c) power spectrum from a region in the central grain seen in (b).

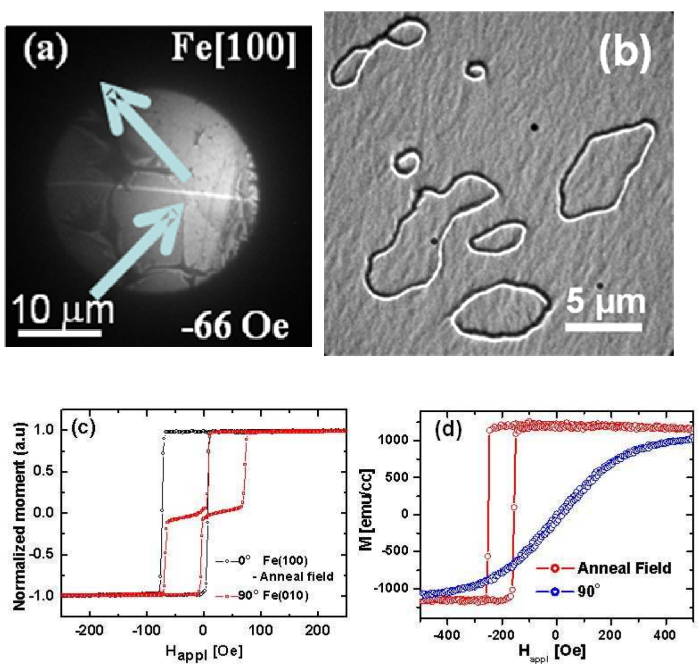

FIG. 2. Lorentz TEM Fresnel-contrast images of plan-view (a) epitaxial Fe/IrMn and (b) polycrystalline IrMn/CoFeB bilayers showing typical micromagnetic structure during reversal. (c, d) Magnetization curves from the epitaxial and sputter-deposited bilayers, respectively along the unidirectional anisotropy (Fe[100] for epitaxial or arbitrary in-plane direction for sputter-deposited)

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