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Polarized neutron scattering from polycrystalline, exchange-biased magnetic multilayers

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Abstract

Specular reflection and off-specular scattering of polarized neutron has been used to study the magnetization reversal in polycrystalline $[Ir_{20}Mn_{80}/Co_{80}Fe_{20}]_{N=3}$ exchange-biased multilayers. The reversal proceeds sequentially starting from the bottom (top) CoFe layer for decreasing (increasing) field. This behavior is related to the evolution of the grain size along the stack. The reversal of each CoFe layer is due to domain wall motions for both the decreasing and increasing field branch. The reversals are accompanied by fluctuations of the in-plane magnetization component perpendicular to the external field as evidenced by off-specular spin-flip scattering. The observed reversal mode is very similar to that of $[Ir_{20}Mn_{80}/Co_{80}Fe_{20}]_N$ multilayers with $N = 10$ although the grain size decreases from $N = 3$ to 10 by a factor of about four.

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An unidirectional magnetic anisotropy called exchange bias [1] is established when a ferromagnet (FM) in contact with an antiferromagnet (AF) is cooled below the blocking temperature of the AF in an external field H_{FC}. Consequently, the hysteresis loop of the FM is shifted.

Asymmetric hysteresis loops owing to asymmetric magnetization reversal processes are observed in many experiments [2,3] and have been examined by polarized neutron reflectometry (PNR) [4–6]. In PNR studies, reversal by magnetization rotation is identified by a significant increase of the specular reflectivities in the spin–flip (SF) channels (R^{+-} and R^{-+}), which arise from in-plane magnetization components perpendicular to the field H_a, which is applied collinear to H_{FC}, and is also a guiding field for neutron polarization. Reversal by domain nucleation and propagation does not provide enhanced SF

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intensities, because the magnetization is always collinear to H_a. Previous PNR studies employed epitaxially grown systems, but the dependence on the direction of H_{FC} with respect to the twinning axes in Ref. [4] and training effects in Ref. [6] hamper a direct comparison.

Recently, we have observed symmetric magnetization reversal for each CoFe layer. They proceed in sequence from layer to layer in $[Ir_{20}Mn_{80}/Co_{80}Fe_{20}]_{N=10}$ multilayers (ML) [7]. Atomic force microscopy (AFM) images of the specimens reveal a strong variation of the grain size of the topmost layer with the number of IrMn/CoFe bilayers N. The variation is from 650 nm for $N = 1$ to 60 nm for $N = 10$. Magnetic force microscopy (MFM) data shows the extended FM domains for $N = 1$ which gradually form structures of 500 nm in diameter for $N = 10$ [7,8]. In an AF, long-range dipolar interactions—the main driving force for domain formation in a FM—are absent, and domains are stabilized by defects such as grain boundaries. The smaller grain size at larger N gives rise to smaller AF domains yielding a higher density of uncompensated spins and, thus, stronger exchange bias [9–11], see Fig. 1.

The theoretical interpretation of the magnetization reversal as discussed in Ref. [12] is governed by an effective field H_{eff} arising from the anisotropy of the FM, the exchange bias field of the AF, and the applied field H_a. H_{eff} and the torque it exerts on the FM magnetization depend

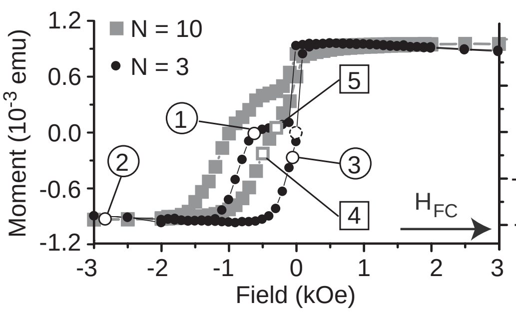

Fig. 1. SQUID magnetization loops of SiO_2/NiFe(10.0 nm)/[IrMn(6.0 nm)/CoFe(3.0 nm)]$_N$ MLs for $N = 3$ and 10. Open numbered circles and squares mark the locations of the PNR measurement along the loops for $N = 3$ and 10, respectively. The dotted circle is the reversal point of the increasing field branch of the $N = 3$ loop at about $H_a = -10$ Oe.

on the angle θ between H_a and the AF anisotropy axis. Beckmann et al. show that, depending on θ, the reversal mode is either by coherent rotation for both loop branches or asymmetric with a non-uniform reversal for the increasing branch. The authors leave the question of the influence of a granular structure open. Here, we address this question by studying and comparing the magnetization reversal of polycrystalline exchange-biased samples with different grain sizes.

Exchange-biased, polycrystalline $[Ir_{20}Mn_{80}(6.0\,nm)/Co_{80}Fe_{20}(3.0\,nm)]_{N=3}$ MLs are prepared by DC magnetron sputtering. We employ a 10 nm-thick NiFe buffer layer grown on oxidized Si wafers in order to improve the texture of the MLs. Prior to the measurements, the specimens are annealed for 60 min at 533 K, i.e. above the IrMn Néel temperature of 520 K, and then field-cooled to room temperature (RT) in an external field of $H_{FC} = 130$ Oe. Data concerning magnetic properties is taken after several remagnetization cycles.

PNR measurements are performed at the polarized neutron reflectometer with polarization analysis HADAS [13] at the Jülich research reactor FRJ-2 (DIDO). The neutron wavelength is fixed at $\lambda = 4.52$ Å. The instrument is equipped with a 2D detector with a special spin analyzer that covers the whole detector area and thus allows simultaneous measurement of specular and off-specular intensities with polarization analysis. The polarization efficiencies of the polarizer and analyzer are 96% and 95%, respectively. The specimens are kept at RT and field H_a up to 3 kOe is applied.

The microstructure and the layer quality are investigated by X-ray scattering as well as AFM and MFM imaging. These results are reported in Ref. [8]: We find for $N = 3$ an interface roughness $\sigma \approx 0.6$ nm, a lateral correlation length $\xi = 10 \pm 5$ nm, and a grain size of the topmost layer of about 250 nm. Magnetization loops are recorded by means of a superconducting quantum interference device (SQUID).

Fig. 1 shows SQUID magnetization loops for $N = 3$ and 10. There are always two hysteresis sub-loops, the narrow one corresponding to the magnetically soft NiFe buffer layer and the wider to the CoFe layers in the ML. The exchange bias