ASYMMETRIC MAGNETIZATION REVERSAL IN EXCHANGE-BIASED HETEROSTRUCTURES

Exchange bias refers to a shift of the ferromagnetic hysteresis loop along the field axis, by an amount H_e (see Fig. 1 for an example.) The bias is a consequence of an exchange interaction across the interface between dissimilarly ordered magnetic materials, e.g. a ferromagnet and an antiferromagnet (AF). This exchange interaction induces a unidirectional anisotropy as the AF material is cooled through its Néel temperature, T_N [1,2]. Exchange bias is an example of a bulk property whose fundamental origin is attributed to physical processes occurring at the nanometer length-scale. This phenomenon is not simply a scientific curiosity; it underpins present-day magnetic recording technology.

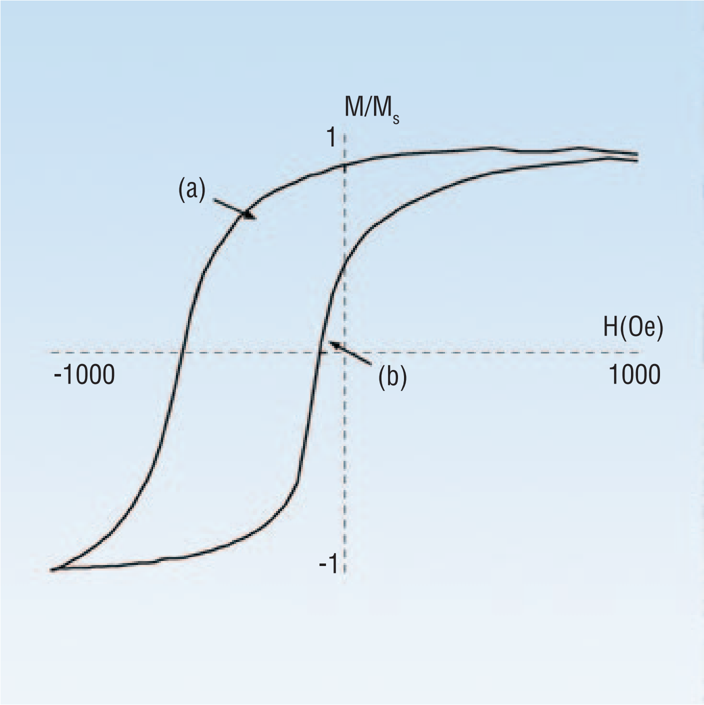

FIGURE 1. Magnetization versus applied magnetic field. Exchange bias is the shift of the ferromagnetic hysteresis loop (in this case to negative *H*) from being centered at *H* = 0. Measurements displayed in Figs. 2 and 3 were taken, respectively, near the coercive fields at (a) and (b). Large exchange bias is correlated with asymmetry in the magnetization reversal processes, as noted in those figure captions.

Read-write heads used with magnetically stored data are based on giant magnetoresistance (GMR) sensors. These sensors consist of layers of ferromagnetic thin films separated by non-ferromagnetic ones. When the the magnetizations in the ferromagnetic layers are all oriented the same way, conduction electrons pass through them relatively easily, but when the electrons must cross from films having one orientation to another they encounter more resistance through magnetic scattering. GMR arises when an external field can change the relative orientations of the magnetization in the films easily. To keep the layers from all reorienting together in the presence of an external field, some of them must be pinned. One way to accomplish pinning is exchange biasing.

Despite its technological importance, theoretical models are unable to convincingly explain observations of exchange bias (e.g. positive exchange bias), and phenomena associated with it. Even in the simplest experimental systems such as Fe on TMF_2 where TM = Mn or Fe, the asymmetric reversal of magnetization and the unusual temperature dependence of coercivity are not well understood.

Using polarized neutron reflectometry we recently, examined the magnetization reversal processes of a ferromagnetic Fe film exchange-coupled to twinned AF (TMF_2) films as a function of magnetic field [3]. Neutron scattering measurements typical of those from a sample exhibiting large exchange bias are shown in the figure for fields at coercivity on either side of the loop. Spin-flip (SF) scattering observed on the left hand side of the loop indicates magnetization reversal via magnetization rotation. Lack of SF scattering on the right hand side is consistent with domain nucleation (with opposite magnetization) and growth. These two fundamentally different (asymmetric) reversal processes have distinct neutron scattering signatures. The ability to discern so easily between these processes sets neutron scattering apart from magnetometry.

Comparisons of measurements like those in the figure taken from many samples, including single crystalline and polycrystalline AF films, lead to the following picture: In the case of samples with twinned AF's, which exhibit large exchange bias, "45° exchange coupling" is energetically favorable as each AF domain independently tends to perpendicular coupling but is frustrated due to

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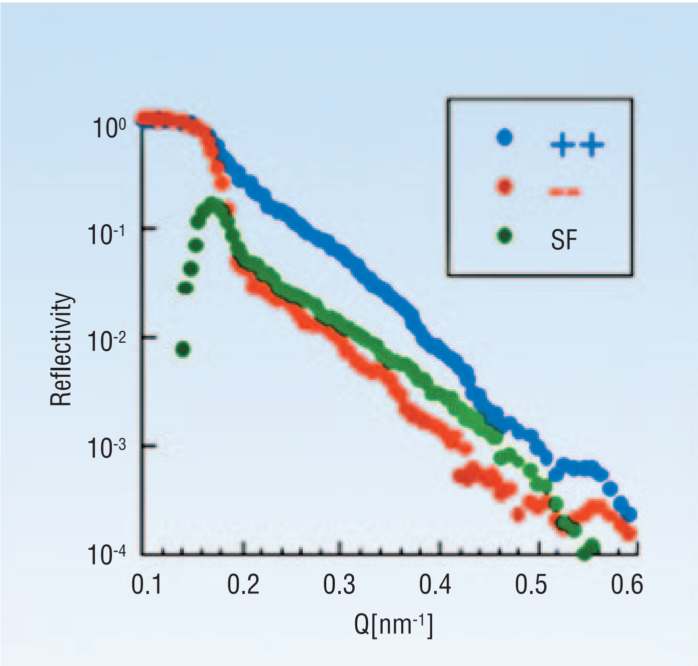

FIGURE 2. Reflectivity of scattered neutrons experiencing no flip in spin (++ and - -) and for which the spin is flipped (SF) versus *Q*. These data were taken at the coercive field on the (a) side of the loop in Fig. 1. The spin-flip scattering observed in this region indicates magnetization reversal through rotation.

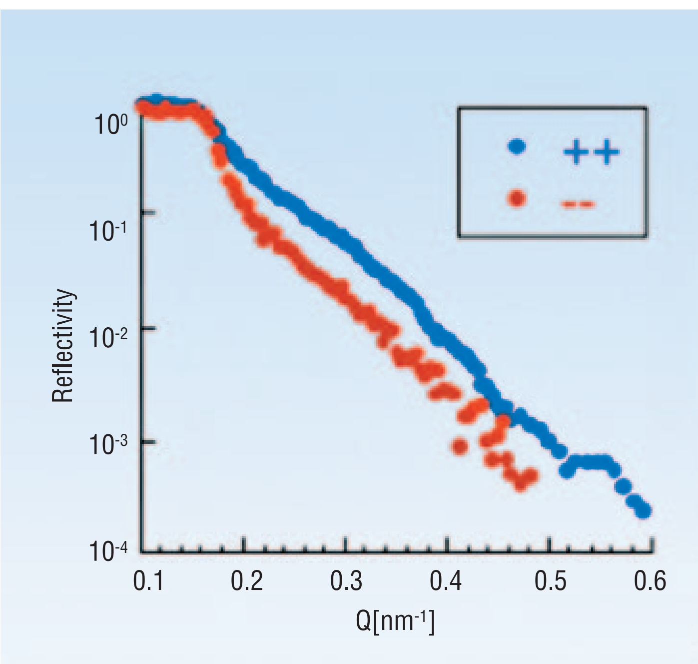

FIGURE 3. Reflectivity of scattered neutrons experiencing no flip in spin (++ and - -) versus *Q*. These data were taken at the coercive field on the (b) side of the loop in Fig. 1. No spin-flip scattering was observed, indicating magnetization reversal via domain nucleation and growth.

the twinned microstructure. Furthermore, field cooling provides an additional unidirectional asymmetry. Therefore, field reduction from positive saturation results in magnetization rotation rather than domain nucleation. This is due to the intrinsic unidirectionality that hinders formation of domains with magnetization anti-parallel to the cooling field direction. As the field is reduced from negative saturation, formation of domains with magnetization parallel to the initial cooling direction is favored. Hence reversal occurs by domain nucleation and propagation.

For the case of samples with single crystalline (untwinned) AF's, frustration is lacking; consequently, there is no anisotropy axis parallel to the cooling field with which unidirectional anisotropy can be established. In this case, magnetization rotation is always favored (as evidenced by SF scattering on both sides of the ferromagnetic hysteresis loop). We note the exchange bias for the single crystal sample is always small. A clear correlation was observed: samples with an asymmetric magnetization reversal process exhibit large exchange bias, while those with symmetric magnetization reversal process exhibit small exchange bias.

By identifying the mechanisms involved in the asymmetry favoring large exchange biasing in this system, these and related neutron reflectivity studies point out a direction for the design of next generation GMR sensors having substantial improvements in magnetic field sensitivity.

This work was supported by the U.S. Department of Energy, BES-DMS under Contract No. W-7405-Eng-36, grant DE-FG03-87ER-45332, and funds from the University of California Collaborative University and Laboratory Assisted Research.

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