Magnetic interaction in exchange-biased bilayers: a first-order reversal curves analysis

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Abstract – Thin films of Si[100]/Cu/NiFe/FeMn/Ta were produced via dc magnetron sputtering and their magnetic behavior were studied by first-order reversal curves (FORC) analysis. The FORC distributions display a reversible contribution, corresponding to permalloy particles unaffected by the presence of FeMn and a major irreversible contribution, clearly asymmetric and inclined. This inclination evidenced the presence of mean-field effects on the Py layer as a function of the exchange-bias field.

First-order reversal curves (FORC) analysis is a phenomenological approach that has been topic of renewed interest in magnetic systems [1]. A set of FORC is usually obtained by: (i) saturating the sample by applying a field $H_{\text{max}}$, (ii) reducing the field to a return value $H_r < H_{\text{max}}$, (iii) increasing $H$ to $H_{\text{max}}$ again and measuring the magnetization, and (iv) repeating steps (ii) and (iii) for decreasing values of $H_r$ where $H_r > -H_{\text{max}}$. The FORC distribution may then be defined in terms of the magnetization $M(H_r,H)$ by the mixed second-order derivative $\rho(H_r,H) = \frac{1}{2} \frac{\partial^2 M(H_r,H)}{\partial H \partial H_r}$ which is plotted in a rotated system of coordinates $\{H_c = \frac{1}{2}(H - H_r), H_b = \frac{1}{2}(H + H_r)\}$. In these coordinates, $\rho(H_c,H_b)$ can be seen as a distribution of single-domain particles with coercivity $H_c$ under the effect of an interaction field of intensity $H_b$. The FORC diagram provides a detailed characterization of the hysteretic response of a system because it evidences dominant magnetic interactions, possible magnetic aftereffects and the annihilation of memory during the demagnetization process. In this work, the FORC analysis was applied to a set of exchange-biased ferro/antiferromagnetic bilayers of composition Ni_{0.8}Fe_{0.2}(10 nm)/FeMn ($x$ nm), with $5 \text{nm} \leq x \leq 30 \text{nm}$. The samples were deposited by dc magnetron sputtering onto a 20 nm Cu buffer layer on Si[100] and capped with a 10 nm Ta layer. The samples exhibit a clear dependence of the exchange-bias field $H_{eb}(x)$ with the thickness $x$ of the antiferromagnetic layer (Fig. 1a) but the coercivity is practically independent of this parameter. First-order reversal curves were measured for each sample as explained above (Fig. 1b is an example for the sample with $x = 5.5$ nm). Figures 1c and 1d display contour plots of the FORC distributions $\rho(H_c,H_b)$ for samples fabricated with $x = 5.5$ nm and $x = 12.2$ nm, respectively. It is important to keep in mind that the FORC distribution represents the magnetic behavior of the ferromagnetic Py layer, whose thickness and preparation is nearly identical in all our bilayers. Then, the differences observed between distributions of different samples reflect the effects produced by the antiferromagnetic FeMn in contact with the Py layer. We have observed in all samples a significant reversible contribution, corresponding to particles with $H_c \approx 0$, i.e. permalloy particles unaffected by the presence of FeMn. But the principal contribution, the irreversible, displays a strong dependence with the exchange-bias field of sample. Indeed, the irreversible distributions are inclined respect to the horizontal line $H_b = 0$ and this inclination is an indicative of mean-field effects. This inclination (and the dispersion of coercivities) decreases with the increase of the $H_{eb}$ field. A new Preisach model with exchange-bias was successful applied in order to simulate the experimental FORC’s and the behaviors observed.

![Image](image_url)

Figure 1: a) exchange-bias field and coercivity behavior as a function of the FeMn thickness at room temperature. b) First-order reversal curves of the sample prepared with $x = 5.5$ nm of FeMn thickness. Finally, contour plots of FORC distributions obtained for two different samples: c) 5.5 nm and d) 12.2 nm of FeMn thickness.

References