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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 $H_{\max}$, (ii) reducing the field to a return value $H_r < H_{\max}$, (iii) increasing H to $H_{\max}$ again and measuring the magnetization, and (iv) repeating steps (ii) and (iii) for decreasing values of H_r where $H_r > -H_{\max}$. The FORC distribution may then be defined in terms of the magnetization $M(H_r, H)$ by the mixed second-order derivative $\rho(H_r,H) = -\frac{1}{2}\frac{\partial^2 M(H_r,H)}{\partial H_r \partial H}$ 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 nm ≤ *x* ≤ 30 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.

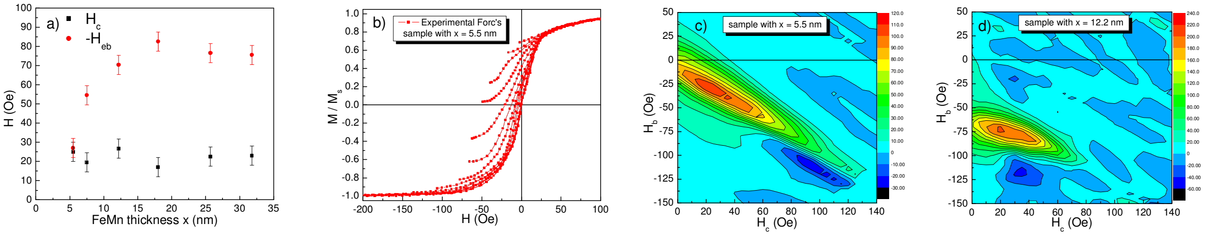

Figure 1: a) exchange-bias field and coercivity behavior as a function of the FeMn thickness at room temperature. **b)** First-order reversal curves of the sample prepared with *x* = 5.5 nm of FeMn thickness. Finally, contour plots of FORC distributions obtained for two different samples: **c)** 5.5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

References

[1] C.R. Pike, Phys. Rev. B 68 (2003) 104424, and C.R. Pike, C.A. Ross, R.T. Scalettar, G. Zimanyi, Phys. Rev. B 71 (2005) 134407.