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A study on the macroscopic properties of hard/soft bilayers

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Abstract

The dependence of the macroscopic properties of the soft layer on the hard-layer magnetization and microstructure in exchange spring bilayers is studied. The exchange bias field experienced by the soft layer varies proportionally with magnetization as well as magnetic hardness of the hard layer. On the other hand, there is an inverse relationship between the coercivity of the soft layer and the hard layer magnetization, as well as between the coercivities of the two layers. Domain wall and interface processes offer a qualitative explanation of the results. A vector Preisach-type model for exchange spring bilayers is used to investigate the above.

Keywords: Exchange spring bilayers; Magnetic recording; Preisach modeling

1. Introduction

Exchange spring media [1,2] have recently been proposed as a means to satisfy the conflicting media design constraints of writability and thermal stability required for the development of ultra-high density recording media. These media consist of a soft spring layer ferromagnetically coupled to a hard layer. Similarly, to antiferromagnetically coupled (AFC) bilayers [3–6], they may have a two-phase hysteresis characteristic (Fig. 1). The soft layer switches first, at a field H_{ex}–H_{1c}, followed by the switching of the hard layer at a much higher field H_{2c}. H_{ex} is the exchange bias field responsible for the shifting of the soft layer loop; it is negative for exchange spring media and positive for AFC media. H_{1c} is the coercivity of the soft layer or the half-width of the soft layer (minor) loop, and H_{2c} is the coercivity of the bilayer, which is considerably less than the coercivity of the hard layer alone. These structures allow for a lower $M_r t$ product with respect to conventional thin films and tip the balance between thermal stability and higher density towards the latter [5,6]. The magnetic behavior of these structures is a function of the soft and hard layer magnetic properties and depends sensitively on the interlayer coupling. The coupling length, defined as the soft layer thickness beyond which a two-phase behavior is observed, the roughness of the interface and the existence or not of a non-magnetic spacer between the hard and the soft layer, all, affect the macroscopic magnetic properties of the bilayers.

The assumption that the onset of nucleation in the soft phase occurs when the Zeeman energy of the applied field overcomes the domain wall energy of the soft phase [7] yields a rough estimate of $H_{ex} \simeq H_{1N} = -2\sqrt{A_1 K_1}/M_{1s} t_1$ but cannot explain its dependence on the hard-layer properties observed experimentally.

If the domain wall nucleated in the soft phase at H_{1N} is allowed to propagate in the hard phase through the interface, the field required to overcome the pinning of the wall against the interface [8–10] H_{dw} can be obtained. If $H_{1N} > H_{dw}$, the two layers switch together and the two-phase characteristic is not observed.

The one-dimensional atomic model used in Ref. [11] corroborated the above results and showed that magnetic moments in the soft layer rotate more further away from the interface because the pinning by the hard layer is less. As the applied field increases, the spins at the interface start rotating and the domain wall is introduced in the hard

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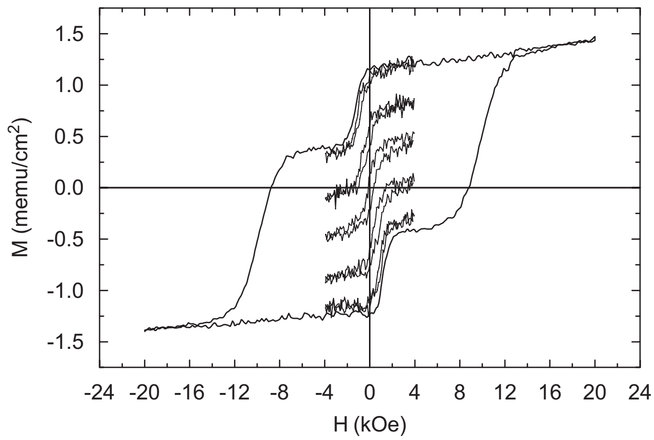

Fig. 1. Major loops of hard layer and bilayer with minor loops.

layer. A rough estimate of the switching field for the hard layer is obtained; $H_{sw} = A_2K_2/A_1M_{1s}$, which is in agreement with the experimental observation that the coercivity of the bilayer is less than the coercivity of the hard phase alone.

The above treatments assume negligible anisotropy in the soft layer which is governed solely by reversible processes while all the irreversible processes are taking place in the hard phase due to its multidomain structure. Measurements, however, have shown that soft-layer minor loops exhibit coercivities of a few hundred Oersteds and that both the exchange bias, H_{ex}, and the coercivity, H_{1c}, depend on the hard-layer properties.

2. Experimental results and discussion

Co–Pt hard–soft bilayers with (1 1 1) texture have been prepared through sputtering. The hard layer has been heat treated at various temperatures in order to investigate the effect of the hard-layer microstrusture on the soft-layer properties. Table 1 summarizes the properties of two typical samples (1 and 2) whose hard-layers were previously annealed at 710 and 600 °C, respectively. Fig. 1 shows minor loops of the soft layer measured at different levels of the hard-layer magnetization. The sample was initially brought to positive saturation. Then the field was decreased to a certain negative value and removed to obtain the respective DC demagnetized state. A loop of the soft layer was measured at that state and the process was repeated for a larger negative field until negative saturation was reached. The half-width, H_{1c}, of each minor loop and the offset from zero, H_{ex}, have been determined for each DC demagnetized state. The dependence of H_{1c} and H_{ex} on the hard-layer magnetization, M_2, for the two samples of Table 1 are shown in Fig. 2.

In both cases, H_{ex} increases and H_{1c} decreases with M_2. A similar behavior has been observed in AFC media [3]. As far as the dependence of H_{ex} on M_2 is concerned, only the exchange bias was positive. This direct relationship between H_{ex} and M_2 is expected since it is an interface effect and the interface changes with the hard-layer magnetization state facilitating the coupling between the two layers as more domains are magnetized in one direction.

Table 1
Sample properties

	Sample 1 ($T_{anneal} = 710\,°C$)		Sample 2 ($T_{anneal} = 600\,°C$)	
	Hard layer	Bilayer	Hard layer	Bilayer
H_{2c} (kOe)	13.15	10.85	8.15	4.90
M_r (memu/cm^2)	0.96	1.45	0.80	1.14
$H_{1c,max}$ (kOe)		0.32		0.53
$H_{ex,max}$ (kOe)		0.97		1.33

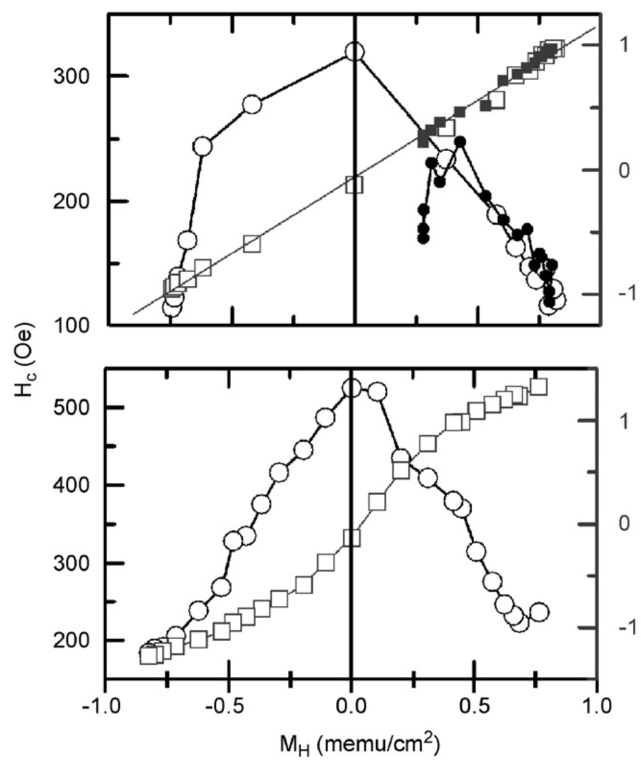

Fig. 2. Coercivity and exchange bias field of the soft layer vs the hard-layer magnetization: (a) sample1 and (b) sample2.

Contrary to AFC media, the soft-layer coercivity, H_{1c}, decreases with M_2. A possible explanation is that at lower M_2 levels, the misaligned hard layer spins near the interface introduce a "magnetic roughness" across the interface increasing the pinning of the domain wall in the soft phase. The decrease of H_{1c} along with the decrease in the soft-layer loops' squareness as a function of M_2 may also suggest the existence of exchange anisotropy [12] proportional to the exchange bias field H_{ex} which introduces an effective field at an angle to the applied field resulting in loops that are not "easy axis" loops anymore.

H_{ex} and H_{1c} also decrease with the increasing anisotropy of the hard layer. Coupling between the two phases is