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Physica B 372 (2006) 328–331

PHYSICA B

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Multiscale modelling of hysteresis in FePt/FeRh bilayer

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Abstract

The switching field reduction of the FePt layer due to the coupling to FeRh layer has been investigated in systems of different geometries and different coupling strengths. The atomistic and multiscale (atomistic at the interface and micromagnetic far from it) models have been considered for an isolated grain and thin film geometries, respectively. It has been shown that a considerable reduction of the switching film in FePt could be achieved even for small interface exchange value. The decrease of the coercive field value in hard material has been investigated as a function of thickness of both hard and soft medium.

Keywords: Micromagnetic modelling; Exchange spring; Magnetic bilayers; Multiscale modelling

The FePt/FeRh magnetic bilayer has been recently proposed by Thiele et al. [1] as a potential medium for heat-assisted magnetic recording. FeRh belongs to the class of materials with a metamagnetic transition: at room temperature FeRh is antiferromagnetic, undergoing a transition to the ferromagnetic state at temperatures around 450 K. The advantage of this medium is that the antiferromagnetic character of FeRh at room temperature could provide additional thermal stability while the coupling between FePt and FeRh after the metamagnetic transition has occurred could be used to lower the switching field via an exchange spring mechanism. From a general point of view, the system represents a soft–hard magnetic structure, in which the understanding of the reversal mechanism has a fundamental nature.

The switching field of the FePt (recording magnetic medium) could depend on various microscopic and morphological parameters such as the saturation magnetization of FeRh, the exchange parameter on the interface or the thickness of soft and hard phases. For the exchange spring formation, the thickness of the FeRh should be larger than that of the exchange correlation length in this material [2]. A different situation arises in the case when the soft magnetic material is thin, which corresponds to the composite magnetic medium discussed in Refs. [3–5]. The intrinsic and extrinsic parameters of this composite medium could be optimized to get a reasonable decrease of the coercivity and more remarkably, even to get an increase of the thermal stability [5]. The aim of the present paper is to investigate the switching behavior of the composite media based on FePt/FeRh parameters as a function of the interface exchange parameters and thicknesses of both soft and hard phases. For this purpose, we have developed two different models.

Our first model represents a grain of 6 nm × 6 nm × L nm comprising an FePt grain above FeRh one with exact grain matching. This model is atomistic rather than micromagnetic and consists of atomistic localized magnetic moments of FePt or FeRh placed on the Fe sites with the exact implementation of FePt and FeRh lattice structure. The Heisenberg form of exchange is used. The arrangement of the FeRh lattice with respect to FePt one was taken from Ref. [6] so that the fct FePt lattice is rotated 45° with respect to bcc FeRh lattice and displaced half a FeRh lattice constant. The *c*-axis of the FePt lattice is parallel to the grain long axis. The localized magnetic moments are coupled by the Heisenberg exchange which has an anisotropic character due to different distances in different atomic planes. We consider only Fe sites possessing the

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doi:10.1016/j.physb.2005.10.078

total magnetic anisotropy in a similar way to the effective one-ion Hamiltonian presented in Ref. [7]. To consider the possible deterioration of exchange at the interface, we model the interface properties with the reduced Heisenberg exchange parameter J_s. The following intrinsic parameters were used: anisotropy constant $K^{\mathrm{FePt}} = 7 \times 10^7\,\mathrm{erg/cm^3}$, $K^{\mathrm{FeRh}} = 0$, saturation magnetization $M_s^{\mathrm{FePt}} = 1100\,\mathrm{emu/cm^3}$, $M_s^{\mathrm{FeRh}} = 1270\,\mathrm{emu/cm^3}$, exchange constant $J = 7.7 \times 10^{-14}\,\mathrm{erg}$ in both FePt and FeRh.

Fig. 1 represents a hysteresis cycle of FePt/FeRh magnetic grain calculated via atomistic approach for two different thicknesses of FePt. The nucleation process starts in FeRh grain which is softer but has an additional shape anisotropy due to the elongated form of the grain. The domain wall (exchange spring) of the Neel-type propagates and gets pinned at the FePt/FeRh interface. An additional field is necessary to push the center of the domain wall into the FePt (see Fig. 2). Associated with that there is a change of the domain wall width illustrated in Fig. 3. For a thinner (3 nm) FePt layer, the domain wall could not be formed in the hard magnetic material (with a domain wall thickness of 4 nm). Once the center of the domain wall penetrates inside the hard medium, this produces the complete magnetization reversal in FePt. Fig. 4 represents a coercivity reduction in the case of the "exchange spring medium" as a function of the FePt thickness. The remarkable reduction of the switching field (more than 5 times) than that of the pure FePt grain could be obtained even with small interfacial exchange value for thin FePt layer.

Fig. 5 represents the coercive field reduction as a function of the thickness of FeRh. It is clearly seen that the exchange spring formation (thick soft layer) is more efficient in decreasing the coercive field value than that the thin soft layer. Fig. 6 represents the coercivity reduction as a function of interfacial exchange in grains with different thicknesses. Substantial reduction of the switching field could be achieved with interfacial exchange of the order of 10% of the bulk value. However, more interfacial exchange is necessary for thicker FePt layer as compared to a thinner one to get the same reduction.

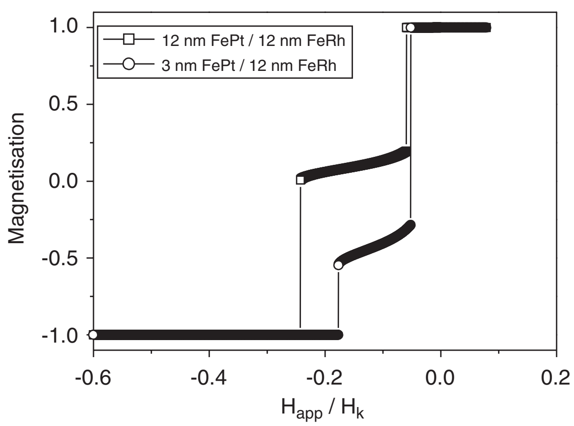

Fig. 1. Magnetization as a function of applied field for a singular grain of FePt/FeRh and two FePt thicknesses with $J_s/J = 0.4$.

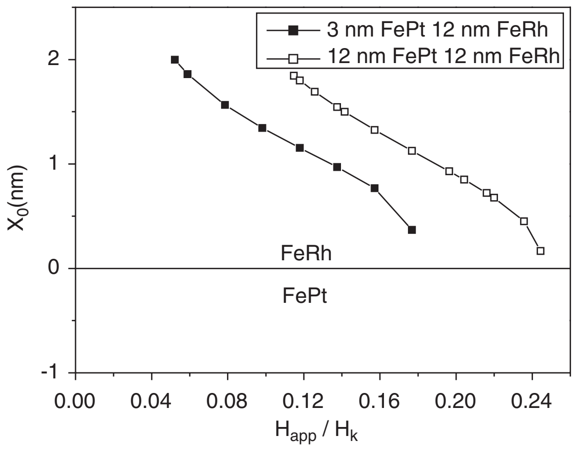

Fig. 2. Domain wall center position as a function of the applied field for $J_s/J = 0.4$. The solid line represents the interface between FePt and FeRh.

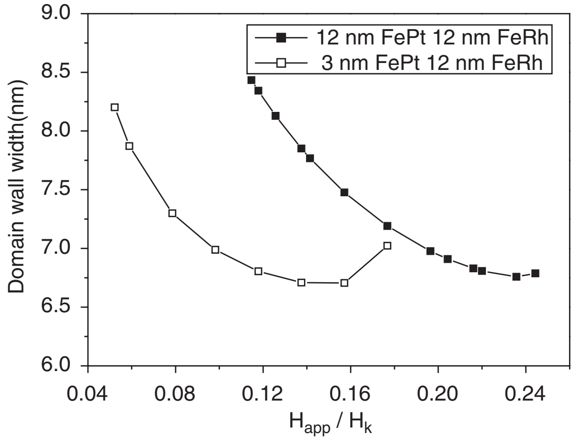

Fig. 3. Domain width as a function of the applied field for $J_s/J = 0.4$.

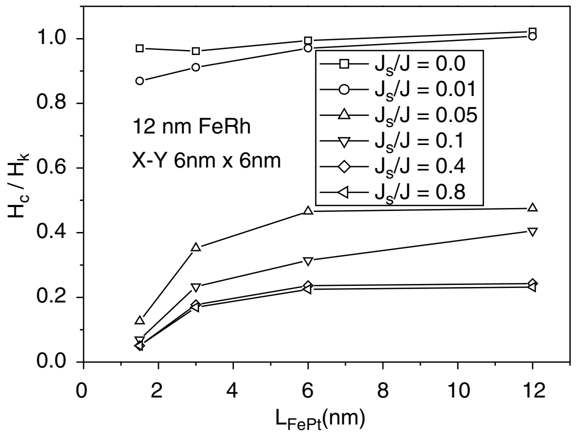

Fig. 4. Coercivity reduction in "exchange spring" medium with 12 nm FeRh, calculated in one-grain model as a function of FePt thickness for different reduced interfacial exchange parameters.

A second model represents a thin film with granular structure for FePt and continuous or granular one of the