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Control of the exchange coupling in granular CoPt/Co recording media

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In order to control the exchange coupling between the grains in a perpendicular recording media, a simple method is to totally decouple the grains using a thick oxide and apply a continuous magnetic capping layer to improve the uniformity of the coupling. In this paper, a system of CoPt grains coupled with a Co layer is investigated using an atomistic spin model. We show that the exchange coupling between the CoPt grains and the Co layer has an impact on the reversal process of the grains, as well as causing a reduction in the coercivity of the whole system. Further, we have studied the coercivity of the whole system as a function of the exchange coupling parameter between the grains and the exchange layer, and have found a sharp decrease in the coercivity. The coercivity as a function of the exchange layer thickness is also studied for different exchange coupling parameters. © *2011 American Institute of Physics*. [doi:10.1063/1.3561446]

I. INTRODUCTION

In recent years, CoPt granular materials have attracted much attention because of their strong (perpendicular) magnetic anisotropy and their application in magnetic recording media.[1–6] The magnetic properties of CoPt films are affected by the exchange coupling between the grains, which is generally controlled by varying the thickness of the oxide that is applied as a spacing between the grains. Along with the rapidly increasing density of magnetic recording at present, the CoPt grain size decreases, which makes it harder to control the thickness of the oxide spacing between the grains. This can lead to fully coupled and decoupled grains, which creates a wider dispersion of magnetic properties and worsening of the signal-to-noise ratios. One possible solution to this problem is to totally decouple the grains with a very thick oxide and apply an exchange capping layer to achieve uniform exchange coupling. So far, experimental work has been carried out in granular CoPt/Co (Ref. 7) and FePt/Fe (Refs. 8–10) bilayers with perpendicular anisotropy, which has also reported the impact of exchange coupling on coercivity and reversal processes. In particular, theoretical work has been done by Goto *et al.*[11] and Asti *et al.*[12] by micromagnetic calculation. In this paper we study the granular CoPt/Co bilayers using an atomistic spin model, which is able to show the detailed reversal processes of the system, focusing on the impact of the exchange coupling on the reversal processes and the coercivity of the system.

II. METHODS

The system studied consists of seven CoPt grains coupled by a continuous Co thin layer to achieve uniform intergranular coupling. Two systems with different grain sizes have been studied: for the larger system, the grain size is 5 nm with 1 nm spacing; whereas for the smaller system, the grain size is 3 nm with 0.5 nm spacing, visualizations of which are included as insets in Fig. 1. The crystal structure of both CoPt and Co is assumed to be fcc, with a lattice spacing of 3.54 Å. The system is simulated using an atomistic spin model with the Heisenberg form of exchange, which describes the interaction between two spins on neighboring atomic sites.[13] For both systems, the CoPt grains are assumed to have no direct exchange coupling with each other. The classical spin Hamiltonian describes the energetics of the system and takes the following form:

$$\mathscr{H} = -\sum_{ij} J_{ij} \boldsymbol{S}_i \cdot \boldsymbol{S}_j - \sum_i K_u S_{iz}^2 - \sum_i \boldsymbol{S}_i \cdot \boldsymbol{H}_{\rm app}, \quad (1)$$

where J_{ij} is the exchange coupling parameter between the spin i and its neighboring spin j, and S_i and S_j are the spin moments. K_u is the uniaxial anisotropy constant, and $H_{\rm app}$ is the externally applied field.

The dynamical motion of the magnetization is described by the Landau–Lifshitz–Gilbert (LLG) equation,[14] taking the form

$$\frac{\partial \boldsymbol{S}}{\partial t} = -\frac{\gamma}{(1+\lambda^2)}[\boldsymbol{S} \times \boldsymbol{H}_{\rm eff} + \lambda \boldsymbol{S} \times (\boldsymbol{S} \times \boldsymbol{H}_{\rm eff})]. \quad (2)$$

The first term describes the precession of the normalized spin moment around the effective field, $H_{\rm eff}$. The second term is the spin relaxation, which is controlled by the Gilbert damping parameter $\lambda = 0.1$ in our system.[15] The spin moments for CoPt and Co are set at 1.5 Bohr magnetons (μ_B). Thermal effects are taken into account by using Langevin dynamics, which introduces an effective thermal field, $H_{\rm th}$, into the LLG equation.[16,17] All the calculations are performed at room temperature (300 K). The impact of the exchange coupling on the granular system has also been studied by varying the exchange coupling parameters.

III. RESULTS

Figure 1(a) shows typical hysteresis loops of the larger system with 5 nm grain size and 1 nm spacing. The dark-color line presents the exchange coupled case, with the

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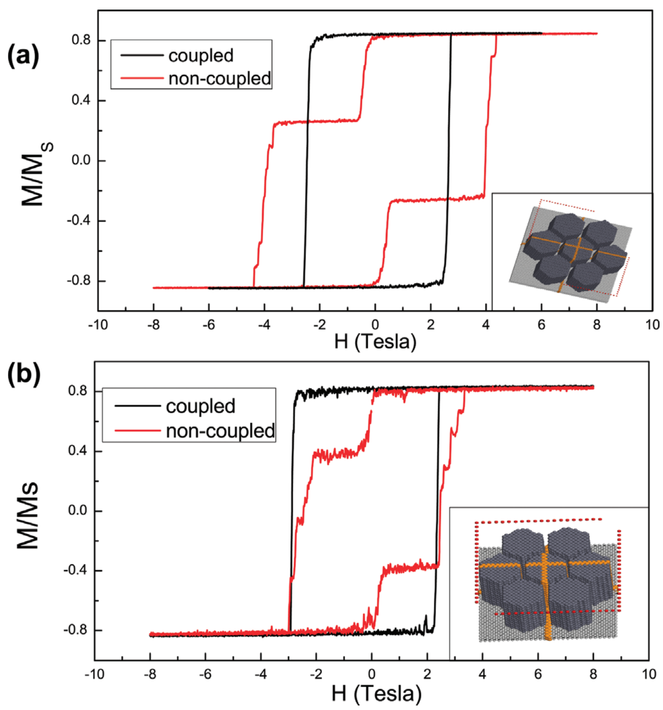

FIG. 1. (Color online) The hysteresis loops with and without exchange coupling between the CoPt grains and the exchange layer. The insets are the 3D schematic figures of the systems with (a) grain size = 5 nm and (b) grain size = 3 nm.

interface exchange coupling parameter $J_{ij} = 2.2 \times 10^{-21}$ J/atom. As a comparison, the light-color line shows the nonexchange coupled case where the interface exchange coupling parameter is zero. For the nonexchange coupled case, two obvious steps and also several smaller steps can be observed, whereas for the exchange coupled case, there are no such obvious steps. The first large step in the nonexchange coupled case originates from the reversal of the Co layer. The remaining smaller steps demonstrate the independent reversal of the CoPt grains, which have no exchange coupling between each other or the Co layer. Further, a reduction in the coercive field has also been found in the exchange coupled case.

Hysteresis loops of the smaller system have also been calculated, in Fig. 1(b). More steps can be observed in the nonexchange coupled case and the coercivity has also been reduced, although the reduction in coercivity is not as large as in Fig. 1(a). This result shows the impact of thermal effects on the reversal processes and coercivity: the thermal energy reduces the coercivity of the whole system and increases the dispersion of the reversal field of each single grain.

Figure 2 shows visualizations of the smaller system, showing the reversal process of the coupled and decoupled cases. It can be clearly observed in Figs. 2(Ia)–2(Id) that the Co layer reverses first and then the CoPt grains reverse independently without exchange coupling between the grains and the Co layer. For the exchange coupled case Figs. 2(IIa)–2(IId), the grains reverse almost simultaneously and domain walls also appear in the Co layer. This phenomenon shows that the exchange coupling between one grain and the Co layer can be transmitted to its neighboring grains, which also results in a reduction of the coercivity of the whole system.

As seen in Figs. 1 and 2, the exchange coupling between the CoPt grains and the Co layer has an impact on the coercivity of the whole system and the reversal processes of the grains. However, a detailed analysis of the effect of the exchange coupling parameter on the coercivity is still lacking. Therefore, in order to study the impact of exchange coupling thoroughly, the coercivities of both the larger and smaller systems as a function of the exchange coupling parameter J_{ij} between the grains and the Co layer were calculated. The interface exchange coupling parameter between the CoPt atoms and the Co atoms J_{ij} varies from 0 to 2.2×10^{-21} J. The results are shown in Fig. 3(a) for both systems. Consider first the larger grain system. A very sharp decrease in coercivity is found for relatively small values of the exchange leading to a minimum in the coercivity, which increases to a constant value as J_{ij} tends to the bulk value. Similar behavior was observed by Garcia-Sanchez *et al.*[18] in studies of soft/hard layers. The soft Co layer is too thin to support a perpendicular domain wall, and as a result an exchange-spring mechanism is unlikely.[19] This is supported by the fact that the coercivity minimum seen in Ref. 18 is also predicted by two-spin models such as that of Victora and Shen.[20] In our case the reversal starts with the nucleation of an in-plane domain that propagates causing reversal of the CoPt grains. At higher values of the exchange the propagation of this domain wall is inhibited by the CoPt grains, and

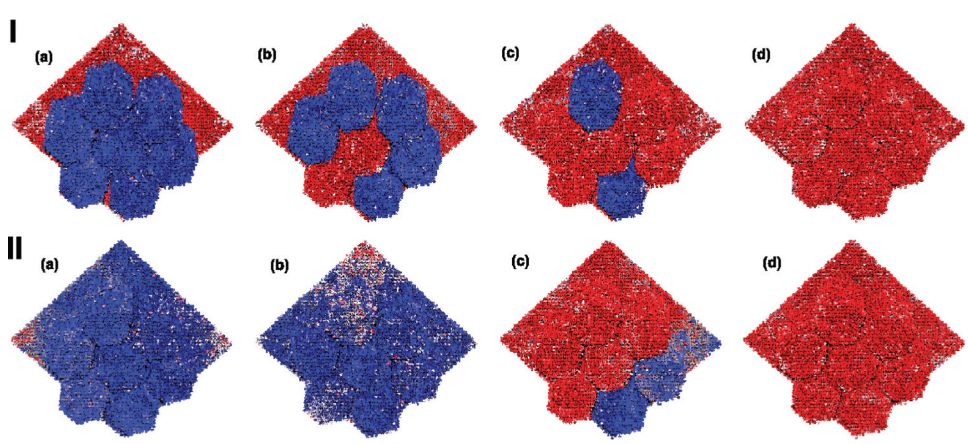

FIG. 2. (Color online) Visualizations of the smaller system both without (I) and with (II) exchange coupling. The applied fields are the same order as the coercive field.

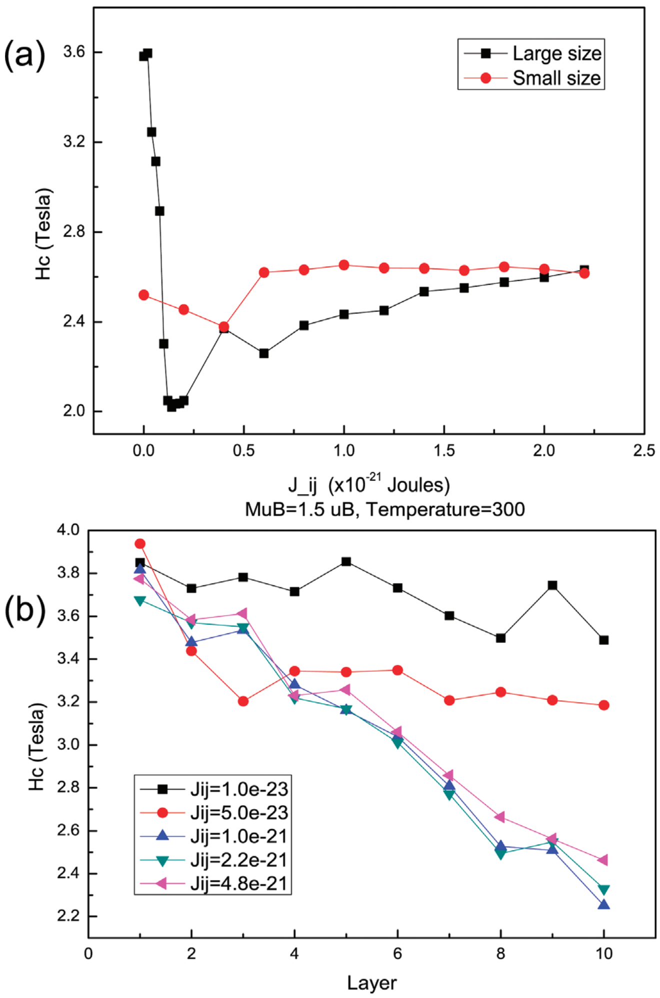

FIG. 3. (Color online) (a) The coercivity as a function of interface exchange coupling parameter J_{ij}, for both the larger grain-size system and the smaller one. (b) The coercivity as a function of the thickness of the Co layer, with different interface exchange coupling parameters, the grain size is 5 nm.

so the coercivity reduction is less pronounced. In the case of the smaller grain-size system, the change of coercivity with J_{ij} is much less pronounced. This is attributed to the effects of thermal activation, which is not considered in the previous models. Even for $J_{ij} = 0$, H_c is reduced relative to the larger grain system due to thermal effects. As J_{ij} increases the behavior tends to that of the larger grain system, presumably because the stronger exchange coupling is increasing the energy barrier to thermally activated reversal.

Although the magnetic properties of a granular CoPt/Co bilayers can be controlled by varying the interface exchange coupling parameters, in practice it is not so easy to change the exchange coupling parameter. It is much easier to control the thickness of the exchange coupling layer (Co layer in our system). Therefore, studying the impact of the thickness of the exchange layer also becomes important. The coercivity as a function of the layer thickness of Co has also been calculated for different values of J_{ij} for the larger system, as shown in Fig. 3(b). For larger values of the exchange coupling, the decrease in the coercivity as a function of layer thickness converges to a maximum rate. For weaker exchange coupling, the effects are generally weaker, with a smaller overall reduction in the coercivity and the reduction reaching a plateau at a thickness of four layers. The reversal mechanism involves the nucleation of a perpendicular domain wall, followed by a propagation of the reversed volume. For weak interlayer exchange coupling the insertion of a domain wall does not significantly contribute to a coercivity reduction in the hard layer. Given sufficient interfacial exchange any reversed domain in the capping layer can penetrate the hard layer and initiate the reversal. The contribution of the layer thickness to the reversal process is therefore determined by the ease with which a domain wall is inserted into the capping layer. Given the low coercivity and domain wall width of 20 nm (56 monolayers), this explains the limited reduction seen in our calculations. We would expect a high-exchange plateau in the coercivity reduction at the intrinsic coercivity of the soft layer (0.5 T). Nevertheless, one would not expect an increase in the coercivity for larger layer thicknesses, as once the capping layer thickness is greater than the DW width, the noncollinear reversal will show a further reduced coercivity. For the strongly coupled case, it is intriguing that the coercivity of the system can be so easily controlled simply by varying the thickness of the capping layer.

IV. CONCLUSION

In summary, an atomistic model has been used to simulate the effects of a soft capping layer on the reversal process of CoPt grains. We have found that the addition of a coupling layer reduces the coercivity of the system, and that smaller grain sizes show a lesser decrease of the coercivity due to greater thermal fluctuations. Further, we have demonstrated the effect of capping layer thickness on the coercivity of the system, and its ability to easily control the coercivity of the system.

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