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Space and thickness influence on magnetization reversal in periodic cylinder shaped exchange spring

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ABSTRACT

Magnetization reversal in periodic cylinder shaped exchange spring with soft layer Fe_3Pt and hard layer FePt has been studied. Coercive field increases with the increase of space between periodic cylinders due to dipole effect in exchange spring Fe_3Pt/FePt. Critical field of magnetization reversal decreases with the increase of thickness in soft layer in Fe_3Pt/FePt system. This phenomenon is caused by the competition between exchange coupling effect and demagnetization effect. Moreover, from the status of magnetization in different field, magnetization in central region of the periodic cylinders starts to reverse first in periodic cylinder Fe_3Pt/FePt exchange spring. The reversion of magnetization from center to boundary is caused by the competition between demagnetization field and magnetic field in periodic cylinder exchange spring.

Exchange spring is composed of hard magnet and soft magnet. It has attracted much attention for strong exchange coupling between interfaces of hard and soft layers [1]. Due to the interaction between hard and soft layers, exchange spring magnets have advantage of both decreasing coercive field and keeping good thermal stability [2,3]. These kinds of properties have potential application in magnetic recording devices [4–7]. There are many studies on continuous film exchange spring systems for their ferromagnetic resonance property [8], coercive field, anisotropy [9–13], but far fewer ones on special shapes, such as cylinder shape. Studying cylinder shaped nanostructure exchange spring is crucial for patterned data storage and recording.

In this paper, cylinder shaped periodic exchange spring with soft layer Fe_3Pt (thickness t from 4 nm to 8 nm) and hard layer FePt (thickness 4 nm) has been studied. By OOMMF [14] simulation, we find that coercive field increases with the increase of space in periodic cylinders, which is due to the variation of dipole effect between periodic cylinders. And coercive field deceases with the increase of thickness of Fe_3Pt. This is caused by the competition between exchange coupling effect and demagnetization effect. Moreover, with the increase of applied magnetic field, magnetization in soft layer of periodic cylinder exchange spring Fe_3Pt/FePt does not reverse simultaneously for all cylinders but has a tendency of reversion from central regions of periodic cylinders to boundary ones. From the demagnetization field distribution we find that demagnetization field has a maximum value in the center and decreases gradually to the boundary in each one of cylinder. Due to the competition between demagnetization field and applied magnetic field, magnetization in the central region of periodic cylinder exchange spring reverses first. The detailed description for this will be discussed in the following.

In the first part, simulation method and parameters has been described in detail. In our simulation, OOMMF software package is used. The structure is cylinder shape, which is composed of soft magnet Fe_3Pt and hard magnet FePt. In OOMMF simulation, finite difference method is used, which means cell size being regular and rectangular (square). Due to the rectangular (square) shape in cell size, smaller size is more accurate for simulating cylinder shape. Thus, cell size 1 nm × 1 nm × 1 nm is used in our simulation. The thickness of FePt is 4 nm and that of Fe_3Pt varies from 4 nm to 8 nm. The parameters we used here are: saturation magnetization $Ms(FePt)=0.70\times10^6$ A/m and $Ms(Fe_3Pt)=0.86\times10^6$ A/m, uniaxial anisotropy $K_1(FePt)=2\times10^5$ J/m^3 and $K_1(Fe_3Pt)=0$. The exchange coupling constant we used here is $A(FePt)=20\times10^{-12}$ J/m for the hard magnet, $A(Fe_3Pt)=13\times10^{-12}$ J/m and $A(Fe_3Pt/FePt)=17\times10^{-12}$ J/m. The schematic figure of the cylinder structure is shown in Fig. 1. The top of Fig. 1 is side view of periodic cylinder exchange spring. Z direction is shown here. In the figure, we can see that the bottom material is hard magnet FePt with z in range [0, 4 nm] and the top one is soft magnet Fe_3Pt with z range [4 nm, 12 nm]. It is a 5 × 5 periods of cylinder structure. The bottom of Fig. 1 is top view of periodic cylinder exchange spring. The cylinder radius is denoted by r, which is 5 nm in our simulation. D represents the distance between two cylinders, which are 10 nm,

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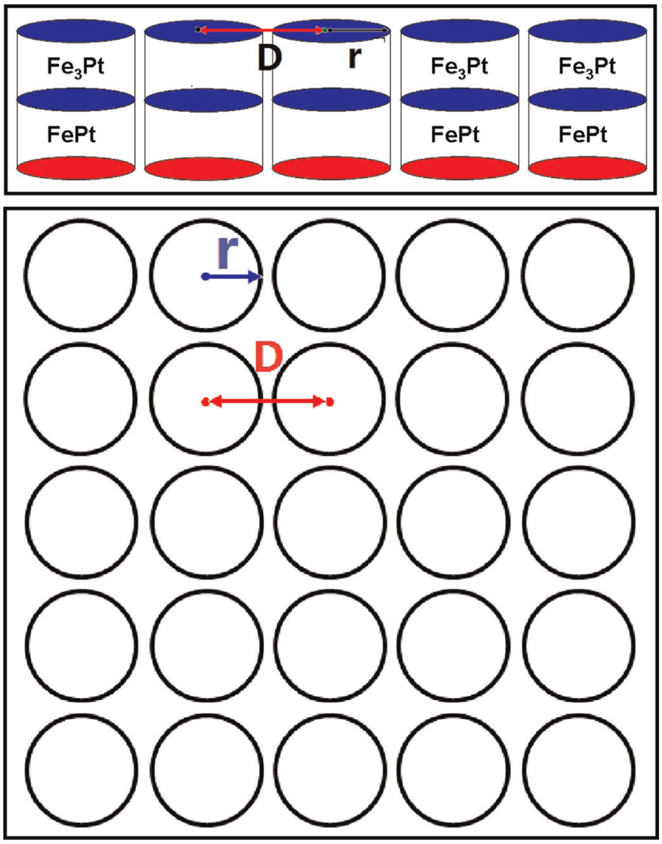

Fig. 1. Schematic figure of the cylinder exchange spring structure. Top one: Side view of the periodic cylinder exchange spring, *Z* direction is denoted here; Bottom one: top view of periodic exchange spring with periods 5×5. *r* denotes the radius of cylinder structure and *D* means the distance between nearest two cylinders. *X*, *Y* directions have been given in the figure.

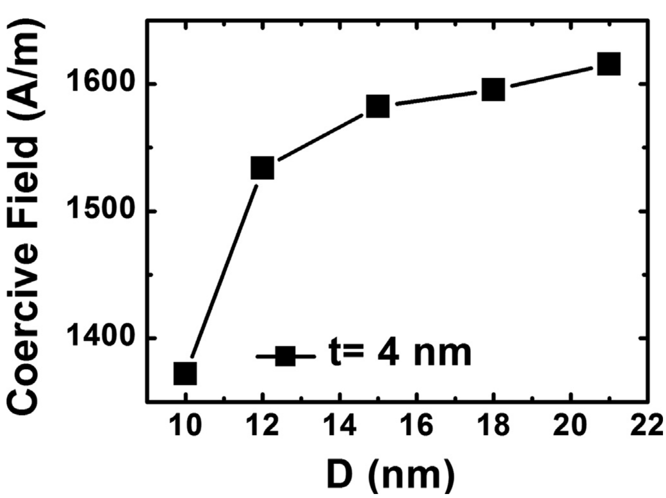

Fig. 2. Coercive field dependence on space between periodic cylinders in Fe_3Pt/FePt with soft layer Fe_3Pt thickness t=4 nm.

12 nm, 15 nm, 18 nm and 21 nm here. The period of cylinder exchange spring is *D*. Here, *X* and *Y* mean the directions in plane. In our simulation, *X* and *Y* are both in the range of [0, $D \times 5$ nm]. By OOMMF simulation, coercive field, exchange energy and demagnetization field distribution for periodic cylinder exchange spring Fe_3Pt/FePt have been given in the following part and will be discussed in detail.

Fig. 2 shows coercive field dependence on space *D* between periodic cylinders in exchange spring Fe_3Pt/FePt. Here, the thickness of Fe_3Pt is 4 nm (as denoted by t). It can be seen that coercive field increases with the increase of space between two cylinders. The increase of space *D* in cylinders will lead to the increase of demagnetization energy near coercive field in Fe_3Pt/FePt system. Thus, dipole effect will be more and more obvious with the increase of space *D*. In order to reverse magnetization, larger magnetic field has to be applied. Therefore, with the increase of space *D*, coercive field increases.

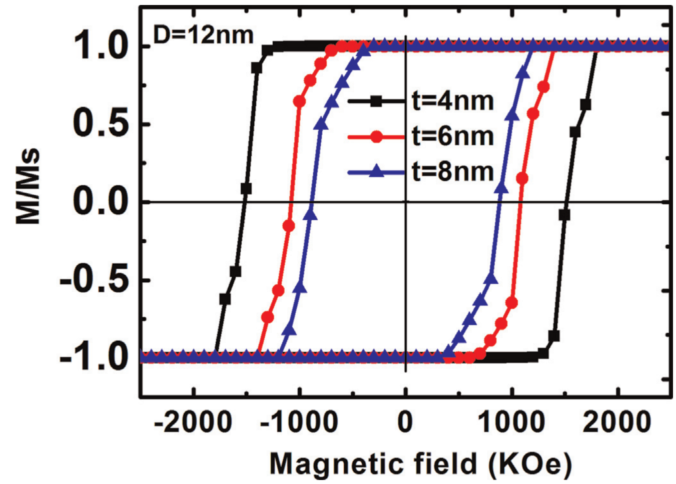

Fig. 3. Hysteresis loops for periodic cylinder Fe_3Pt/FePt exchange spring with space 12 nm in thickness of soft layer Fe_3Pt t=4 nm (Black Square), t=6 nm (Red circle) and t=8 nm (Blue triangle). (For interpretation of the references to color in this figure legend,the reader is referred to the web version of this article).

The hysteresis loops for periodic cylinder Fe_3Pt/FePt exchange spring with different thickness of Fe_3Pt has been given in Fig. 3. The thicknesses of soft layer Fe_3Pt are t=4 nm (Black square), t=6 nm (Red circle), and t=8 nm (Blue triangle). We can see from the hysteresis loop that it shows spring property in periodic cylinder exchange spring. Moreover, from this figure we can get the result that with the increase of thickness in soft layer Fe_3Pt, starting point of magnetic field for magnetization reversal decreases.

From the hysteresis loops in Fig. 3 we can see magnetization reversal in periodic cylinder exchange spring qualitatively. In order to see how the magnetization reverse with the increase of magnetic field vividly, we plot the magnetization status in given fields from −1.5 KOe to −1.8 KOe with soft layer thickness t=4 nm. In Fig. 4, the top view of magnetization status is plotted. On the left side of Fig. 4, magnetizations in field −1.5 KOe (a), −1.6 KOe (b), −1.7 KOe (c) and −1.8 KOe (d) are shown in OOMMF simulation. On the right side of Fig. 4, the corresponding schematic one is shown in order to see magnetization reversal clearly. From the evolution of magnetization with the increase of absolute value of magnetic field, it can be seen that the central regions of periodic cylinders starts to reverse first. The magnetization in boundary regions reverses too with the increase of magnetic field. Finally, the magnetization in soft magnet of periodic cylinder Fe_3Pt/FePt system reverses totally. In Fig. 3, thickness t=4 nm in Fe_3Pt has been given. For thickness t=6 nm and t=8 nm in soft layer, magnetization reversal has the same tendency which is from center to boundary cylinder but in different fields.

From Fig. 3 we can see that absolute value of magnetization reversal field decreases with the increase of thickness in soft layer. Magnetization reversal and its thickness dependence could be explained by exchange energy distribution and demagnetization energy as shown in Fig. 5.

Fig. 5 shows the magnetic field dependence on exchange energy (top one) and demagnetization energy (bottom one) of