Magnetic domain structure in thin CoPt perpendicular magnetic anisotropy films

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Abstract. The relation between thickness and domain structure of Co₈₀Pt₂₀ perpendicular magnetic anisotropy films was investigated through experiments and micromagnetic simulation. The films with thickness over 10 nm exhibited clear maze domain structure, while for the films thinner than 10 nm the domain structure abruptly changed from maze domain to irregular and large domain as the thickness became thinner. The irregular domain had narrower domain wall width than maze domain.

1 Introduction

CoPt-based films with high perpendicular magnetic anisotropy are suited to the recording layer of hard disks [1-3]. It is important to elucidate magnetic domain structure of the films because it directly relates to SN ratio [4-6]. And it was reported that the domain structure of L₁ CoPt films changed from maze domain to irregular and larger one as the film thickness became thinner [7]. However, the relation between thickness and domain structure for Co₈₀Pt₂₀ films has not been discussed yet in detail, and relation between domain structure and magnetization state has not been mentioned yet. In this study, we investigated the influence of thickness on domain structure of Co₈₀Pt₂₀ films especially in thin film thickness region with experiment, and analyzed magnetization state with micromagnetic simulation.

2 Experimental procedure and simulation method

Co₈₀Pt₂₀ / Ru (thickness of 20 nm) / Pt (100 nm) films were deposited on glass substrate using an RF-magnetron sputtering system. Thickness was varied from 3 to 50 nm. No substrate heating was carried out during each deposition process. The Ar pressure during film deposition was 2×10^{-3} Torr for all films. Magnetic properties were measured with a vibrating sample magnetometer (VSM). Domain structure was evaluated using a magnetic force microscope (MFM).

In order to investigate the influence of CoPt film thickness on domain structure and size, micromagnetic simulation was carried out. The equilibrium magnetization distribution of CoPt films was solved by Landau-Lifshitz-Gilbert (LLG) equation, which was

Table 1. Magnetic parameters of CoPt film.

Saturation magnetization M_s (emu/cm ³)	c-axis distribution $\Delta \theta_{50}$ (deg.)	Exchange constant A ($\times 10^{-6}$ erg/cm)
1300	5	1 (for 5 nm thick film) 3 (for 10, 20, 50 nm thick films)

Table 2. Averaged anisotropy field H_k for CoPt films with various thickness.

Thickness (nm)	5	10	20	50
H_k (kOe)	17	16	15	11

originally coded by us [8]. The calculation region is 600 nm $\times$ 600 nm $\times$ δ_{CoPt} nm and was divided into 5 nm $\times$ 5 nm $\times$ 5 nm cubic cells, where δ_{CoPt} is the film thickness and was varied from 5 to 50 nm. The magnetic parameters which were used for the simulation are shown in Table 1. It was reported that the magnetic anisotropy K_u increased as the film thickness decreased, and K_u was related to a lattice deformation [9-11]. From the reports, anisotropy field H_k was set to increase as the thickness decreased in the simulation. Table 2 shows the averaged H_k for CoPt films with various thickness.

3 Results and discussion

3.1 Experimental results

Fig. 1 shows perpendicular hysteresis loops of CoPt films with various thickness. Saturation magnetic field H_s and nucleation field H_n obtained from the perpendicular hysteresis loops are summarized in Fig. 2 as a function of

Fig. 1. Perpendicular hysteresis loops of CoPt films with different thickness.

film thickness. From Figs. 1 and 2, it is found that the H_s decreases as the thickness decreases and that for thicker films, H_n is positive and reduces with decrease in thickness down to a thin film thickness of about 10 nm and for thinner films H_n becomes more and more negative. Origins of the decrease of H_s and H_n with decrease of film thickness are considered to be due to the increase of perpendicular magnetic anisotropy and an increasing impedance of domain wall motion with decrease in film thickness [7, 9–12].

Fig. 3 shows MFM images of the CoPt films shown in Fig. 1. Samples for the MFM observation were prepared as follows. After perpendicular field of 15 kOe was applied to the films, the field was changed to the remanent coercivity, then the field was removed. The MFM images after DC-demagnetization, AC-demagnetization and virgin state exhibited similar domain structure. The films with thickness of 10 and 20 nm exhibit maze domain structure, while the 5 nm thick film shows large and irregular domain [7]. The

Fig. 2. Dependence of H_s and H_n on thickness of CoPt films.

Fig. 3. MFM images of CoPt films with thickness of (a) 5 nm, (b) 10 nm, and (c) 20 nm.

Fig. 4. Stripe half period as a function of film thickness.

squareness ratio of the perpendicular hysteresis loops of the films having irregular domain structure such as Fig. 3 (a) was 1.0. Fig. 4 shows averaged stripe half period (SHP) estimated from MFM images as a function of film thickness. For the films less than 13 nm the SHP becomes smaller as film thickness becomes thicker, while for the films more than 13 nm the SHP becomes slightly larger as the thickness becomes thicker. It has been shown that the increasing SHP with increase of thickness can be expressed as follows [13].

$$\text{SHP} \propto \sqrt{t \times D_0} \quad \text{for } t \geq D_0, \quad (1)$$

where t is film thickness, D_0 is dipolar length which is a balance between domain wall energy and demagnetizing energy, and is defined as

$$D_0 = \sigma_w / 2\pi M_s^2, \quad (2)$$

where σ_w is wall energy density. The tendency of the SHP more than 13 nm shown in Fig. 4 is consistent with Eq. (1). On the other hand, Kaplan and Gehring [14] derived an expression for films with thickness below D_0 as

$$\text{SHP} \propto t \times e^{\pi D_0 / 2t} \text{ for } t \leq D_0. \quad (3)$$

From Eq. (3), it is found that the SHP becomes smaller as the thickness becomes thicker in thin thickness region. The tendency of the SHP less than 13 nm is in agreement with Eq. (3). It is inferred that D_0 for the films shown in Fig. 4 is around 13 nm.

3.2 Simulation and discussion

Fig. 5 shows simulated perpendicular hysteresis loops of CoPt films with various thickness. Each shape of hysteresis loops almost coincides with the experimental

Fig. 5. Simulated perpendicular hysteresis loops of CoPt films with different thickness.

one shown in Fig. 1. H_s and H_n increase as the thickness increases. Because the simulated hysteresis loops almost coincide with the experimental ones, it seems to be appropriate to make consideration on domain structure obtained from the experiment by using the simulation with the parameters shown in Tables 1, 2.

Fig. 6 shows simulated magnetization distribution of CoPt films with various thickness after DC-demagnetization. White areas represent $M_z/M_s = 1$ and black areas represent $M_z/M_s = -1$. Magnetization distribution of the 20 nm thick CoPt film exhibits maze domain structure, while the 5 nm thick film shows large and irregular-like domain. Fig. 7 shows averaged SHP estimated from simulated magnetization distribution as a function of film thickness. For the films less than 20 nm the SHP becomes smaller as film thickness becomes thicker, while the 50 nm thick film has larger SHP than the 20 nm thick film. The domain structure and the tendency of the SHP are almost in agreement with the experimental results shown in Figs. 3 and 4. Fig. 8 shows cross section of the simulated magnetization distribution near domain wall. In Fig. 8, the length of the magnetization vector is expressed as $(M_z^2 + M_x^2)^{1/2}$, so short magnetization vector indicates that the magnetization inclines to y-direction. From Fig. 8, it is found that the film with thickness of 5 nm which exhibits irregular-like domain has narrower domain wall width than the films exhibiting maze domain.

Fig. 6. Simulated magnetization distribution of CoPt films with thickness of (a) 5 nm, (b) 10 nm, and (c) 20 nm.

Fig. 7. Simulated stripe half period as a function of film thickness.

Fig. 8. Cross-sectional view of simulated magnetization distribution of CoPt films with thickness of (a) 5, (b) 10, and (c) 20 nm.

4 Conclusion

In this study, we investigated the influence of thickness on domain structure of $\text{Co}_{80}\text{Pt}_{20}$ films with experiment, and analyzed magnetization state with micromagnetic simulation. As a result, for the films with thickness thinner than 10 nm, the domain structure abruptly changed from maze domain to irregular domain. The simulation showed irregular-like domain has narrower domain wall width than maze domain.

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