Composition influence on the microstructures and magnetic properties of FePt thin films*

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The Fe_xPt_{100-x} (10 nm) ($x = 31$–51) thin films are fabricated on Si (100) substrates by using magnetron sputtering. The highly ordered $L1_0$ FePt phase is obtained after post-annealing at 700 °C in $Fe_{47}Pt_{53}$ thin film. The sample shows good perpendicular anisotropy with a square loop and a linear loop in the out-of-plane and the in-plane direction, respectively. The variations of the magnetic domains are investigated in the films when the content value of Fe changes from 31% to 51%.

Keywords: FePt, coercivity, composition, magnetic domain

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1. Introduction

With ever-increasing areal density of magnetic recording medium, storage space allocated to each bit is correspondingly reduced, and recording grains smaller than 5 nm are required to realize a density higher than 1 Tb/in^2. However, the magnetization of such small grains may become thermally unstable due to superparamagnetic effect.[1,2] This superparamagnetic behavior can be suppressed by using the medium with large magnetocrystalline anisotropy. Thus the $L1_0$ FePt thin film with large magnetocrystalline anisotropy ($Ku \approx 7 \times 10^7$ erg/cc) is considered to be a promising candidate as an ultrahigh density recording medium, and it has attracted great attention to its microstructure and magnetic properties.[3–6] It is well known that the composition and the film thickness affect the microstructure and magnetic properties of the thin film. The microstructures and coercivity values of FePt thin films with various compositions were investigated by several groups. It was found that when the composition changed from $Fe_{36}Pt_{64}$ to $Fe_{70}Pt_{30}$, the coercivity first increased and then decreased with the content of Fe increasing.[7] Another work reported that that $L1_0$ $Fe_{38}Pt_{62}$ film exhibits the largest uniaxial magnetic anisotropy.[8] The effects of composition on magnetic properties were also studied in FePt nanoparticles fabricated by the chemical method in a composition range from $Fe_{41}Pt_{59}$ to $Fe_{60}Pt_{40}$.[9] The study on the composition effects of Fe_xPt_{100-x} films ($x = 36 \sim 58$) each with an Fe/Pt multilayer structure showed an obvious promotion of the phase transformation in each of the films with slightly Pt-rich off-stoichiometric compositions.[1] However, the effect of composition on structure and magnetic properties of 10-nm-thick FePt film has not been reported. In this paper, the structures and magnetic properties of 10-nm-thick Fe_xPt_{100-x} ($x = 31 \sim 51$) films are investigated systematically.

2. Experiments

The Fe_xPt_{100-x} (10 nm) thin films were deposited on Si (100) substrates by using magnetron sputtering. The base pressure of the sputtering system was less than 2.3×10^{-5} Pa and the working pressure was 0.67 Pa under high purity argon gas. The FePt layers were deposited by co-sputtering from pure Fe and Pt targets. The compositions of the films were controlled by adjusting the sputtering power of each target. After deposition, the films were annealed at 700 °C for 1 h in a vacuum furnace. The microstructures of the films were characterized by using X-ray diffractometry (XRD) with Cu Kα radiation. The magnetic hysteresis loops were measured at room temperature by using a vibration sample magnetometer (VSM) with a maximum magnetic field of 1.6 T. The magnetic domain structures of the films were detected by using an Asylum research magnetic force microscopy (MFM) in AC mode.

3. Experimental results

Figure 1 shows the θ–2θ XRD patterns of Fe_xPt_{100-x} (10 nm) ($x = 31 \sim 51$) samples. There are no obvious (001) and (002) diffraction peaks of the $L1_0$ FePt film observed in the films with 31% Fe content revealing that the face-centered tetragonal (fct) FePt phase is not formed. The (001) peak increases with the Fe content increasing, and then decreases when it reaches 51%. At about 48.2°, a diffraction peak is observed for each of the samples with the Fe content values ranging from 31% to 46%, which correspond to the overlap of (200) and (002) diffraction peaks of the fct ordered FePt. It is

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also worth noting that the overlap of (200) and (002) diffraction peaks shifts toward a larger angle with the increase of Fe content, and reaches a maximum in the sample with an Fe content of 47%, accompanied by the disappearance of (111) peak. All these results suggest that the good (001) textured $L1_0$ FePt phase has been formed in $Fe_{47}Pt_{53}$ thin film.

Figure 2 shows the M–H loops of the Fe_xPt_{100-x} (10 nm) ($x = 31$–51) samples. For the thin films with small Fe content values (31% and 34%), the in-plane hysteresis loop and the out-of-plane loop are almost the same, indicating an isotropic magnetization behavior, which results from the mixture of different textured grains. The results are consistent with the results of XRD patterns in Fig. 1. An obvious perpendicular anisotropy is found with the increase of Fe content, and it is optimized in the sample with 47% Fe, as illustrated in Fig. 2(d). With Fe content increasing further, the film shows small coercivity and isotropic behavior again, as shown in Fig. 2(e).

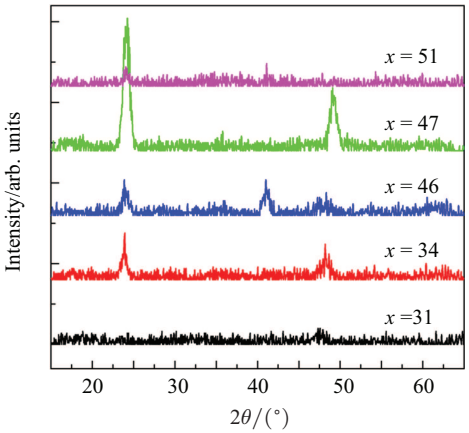


Fig. 1. (color online) XRD patterns of the 700 °C annealed 10-nm thick Fe_xPt_{100-x} films with different values of x ($x = 31$–51).

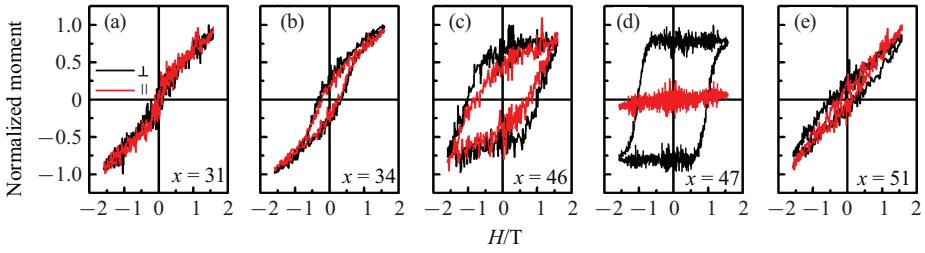


Fig. 2. (color online) Magnetic hysteresis loops of samples with different content values of Fe ($x = 31$–51).

Figure 3 indicates the variations of coercivity and squareness of Fe_xPt_{100-x} thin films with Fe content. In Fig. 3(a), the coercivity values of both out-of-plane and in-plane of the $Fe_{31}Pt_{69}$ film are very small and close to the same value 0.7 T. The out-of-plane coercivity values of the films increase when x varies from 31 to 47 and then decreases. The variation of in-plane coercivity has the same trend as that of out-of-plane, but it starts to decrease earlier (at 46% Fe content). The $Fe_{47}Pt_{53}$ film shows a large out-of-plane coercivity value of 1.02 T and the relative minor in-plane coercivity 0.37 T. Figure 3(b) illustrates that the squareness of out-of-plane hysteresis loop increases to a maximum value of 0.99 when Fe content is 47 %. These results suggest that a strong perpendicular anisotropy is obtained in the $L1_0$ $Fe_{47}Pt_{53}$ thin film.

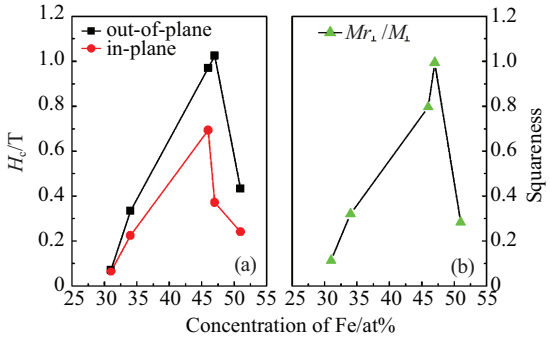


Fig. 3. (color online) Variations of (a) coercivity and (b) squareness of Fe_xPt_{100-x} (10 nm) with Fe content.

Figure 4 displays the MFM images of the Fe_xPt_{100-x} (10 nm) ($x = 31$–51) thin films in ac demagnetized state. In the $Fe_{31}Pt_{69}$ thin film, since the film is of in-plane magnetization, the MFM signal is only observed near the domain wall, as shown in Fig. 4(a). When the values of x are 34 (Fig. 4(b)) and 46 (Fig. 4(c)), the number of magnetic domains increases and the size of domain wall decreases. Hence the narrow transitions can be seen between antiparallel polarization domains, which originates from the perpendicular magnetic anisotropy of the film, which was discussed previously. As x increases to 47, an obvious particulate domain is observed as shown in Fig. 4(d), which is typical domain structure for the film with strong perpendicular anisotropy. Meanwhile, the domain size of the film becomes smaller than those of other samples. The sizes of the irregular domains are about 500 nm, and the relative round single domains with sizes of 100 nm–300 nm are observed. The size of domain wall is estimated to be about 3.9 nm in Fig. 4(d) according to the formula of

$L_h = \pi/(\mathrm{A/K})^{1/2}$, in which the parameters refer to the hysteresis loops in Ref. [10]. The broader transition appears again as in $Fe_{51}Pt_{49}$ thin film and it indicates that the perpendicular magnetic anisotropy reduces and the easy magnetic axis deviates from the normal direction of the film. The domain and domain wall are different from those in $Fe_{47}Pt_{53}$ thin film. Because the magnetization of the $Fe_{47}Pt_{53}$ with good perpendicular magnetic anisotropy is stronger than those of other samples in the out-of-plane direction, so the $Fe_{47}Pt_{53}$ possesses larger demagnetization energy than other samples, when detecting the magnetic domains in an ac demagnetized state, the demagnetization energy in the $Fe_{47}Pt_{53}$ film reduces greatly, hence more magnetic domains appear. Consequently, the magnetic domain size and domain wall are smaller than those of other samples.

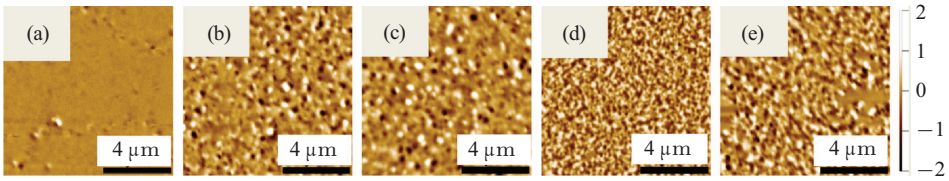


Fig. 4. (color online) AC-demagnetized state domain structures of the different content values of Fe ($x = 31$–51) samples.

4. Conclusions

The $L1_0$ ordered FePt thin film with a strong perpendicular anisotropy is obtained in $Fe_{47}Pt_{53}$ thin film. The XRD results indicate that the good (001) textured $L1_0$ FePt phase is formed in $Fe_{47}Pt_{53}$ thin film. The VSM results suggest that the $Fe_{47}Pt_{53}$ thin film has a strong perpendicular anisotropy. The magnetic domain size of the $Fe_{47}Pt_{53}$ thin film becomes smaller than those of other samples and the pattern of the domain is typical for film with perpendicular anisotropy.

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