



Original Article

Coercivity in Annealed Fe₅₇Pt₄₃ Thin Films

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Abstract: Fe₅₇Pt₄₃ thin films have been prepared by RF sputtering. As-deposited films were formed in a disordered face-centered cubic (fcc) phase. Upon annealing, the films transformed into the ordered face-centered tetragonal (fct) L1₀ phase. The effect of annealing temperature on magnetic properties of the films has been studied. The magnetic coercivity was governed by the degree of atomic order of the ordered phase in Fe₅₇Pt₄₃ film.

Keywords: L1₀ structure, coercivity, FePt.

1. Introduction

The L1₀ ordered FePt thin films have attracted much attention as a promising candidate for use in advanced recording media and high-performance permanent magnets applications because they possess high magnetocrystalline anisotropy ($K_u \sim 7 \times 10^7$ erg/m³) and good chemical stability [1-3]. The ordered face-centered tetragonal (fct) L1₀ FePt materials are normally obtained from the disordered face-centered cubic (fcc) materials via a disorder-order transition by annealing. First principle calculations show that the large K_u of L1₀ FePt is attributed to the large spin-orbit coupling of the Pt atoms and hybridization between the Fe-d and Pt-d states [4].

One of the issues of considerable interest in the FePt thin films is the effect of annealing temperature on the order parameter (S) which quantifies the degree of tetragonal ordering. Some works have been performed to investigate this effect, for example, Mahalingam et al. [5] on Fe-Pt thin films of various composition (Pt = 15, 24, 46 and 78 at%), Sun et al. [6] on Fe₅₂Pt₄₈ thin films, Chun et al. [7] on the

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$\text{Fe}_{49.5}\text{Pt}_{50.5}$ film. In this work we study the effect of annealing temperature on the order parameter in the thin film of $\text{Fe}_{57}\text{Pt}_{43}$ composition.

2. Experimental

FePt films are deposited on thermally oxidized silicon substrates by RF magnetron sputtering as also described in [8]. We use a target consisting of high-purity (99.99%) Pt pieces placed on a high-purity (99.99%) Fe disk. After high-purity Ar gas was introduced, sputter pressure was fixed at 0.266 Pa. The RF power was 100 W. The substrate temperature was kept at room temperature. The chemical composition of our sample was $\text{Fe}_{57}\text{Pt}_{43}$ as revealed from using energy dispersion spectrometer (EDS) included in the scanning electron microscope 5410 LV, Jeol. The structure of as-deposited and annealed films was studied by Bruker X-ray diffractometer D5005. The films are annealed under a high vacuum at high temperatures between 600 °C and 700 °C for 1 h. Magnetic properties of the films are measured by the vibrating sample magnetometer DMS 880 under a maximum in-plane field of 13.5 kOe.

3. Results and Discussion

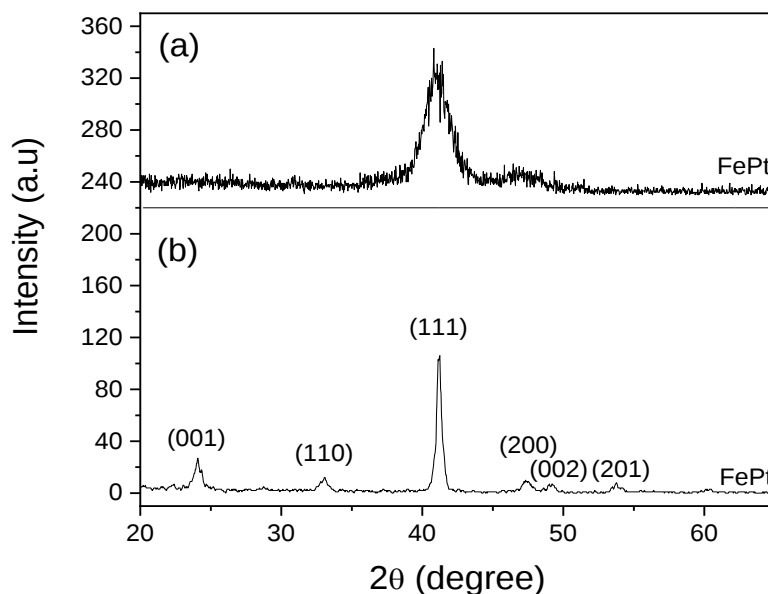


Figure 1. X-ray diffraction patterns of $\text{Fe}_{57}\text{Pt}_{43}$ films (a) as-deposited and (b) after annealing at 650 °C for 1 h.

The thickness of the prepared $\text{Fe}_{57}\text{Pt}_{43}$ film, as revealed by small-angle X-ray measurements, is 105 nm. The X-ray diffraction pattern of the as-deposited FePt film (Fig. 1a) shows that the pattern is characteristic of the chemically disordered fcc structure. The X-ray diffraction result shows that there are two broad peaks appeared: one strong peak located at about 41° which is presented for the fundamental (111) reflection of disordered fcc phase and one weak peak located at 47° - 49° which is

presented for another fundamental (200) reflection. It indicates that the as-deposited films are of disordered fcc phase. After annealing, the (111) peak becomes narrower and other peaks appear. The films transformed to the $L1_0$ structure, as indicated by the appearance of the (001) and (110) superlattice peaks and the splitting of the (200) peak into (200) and (002) peaks (Fig. 1b). Thus, through the disorder-order transition, the formation of the fct ordered phase starts upon annealing. In the annealed samples, the lattice parameters ratio c/a became less than 1, indicating the partial disorder-order structure transformation from fcc to fct. The observed (001) and (110) peaks are also considered a chemical order signature of the ordered $L1_0$ phase of FePt. Ratio c/a is derived to be 0.990, 0.973, 0.961 for annealing temperature (T_{an}) of 600 °C, 650 °C, and 685 °C, respectively. Ratio c/a of 0.961 is close to that of the perfectly ordered FePt. It indicates that the formation of fct phase expands with increasing annealing temperature and at an annealing temperature of 685 °C the fct phase formation is almost completed.

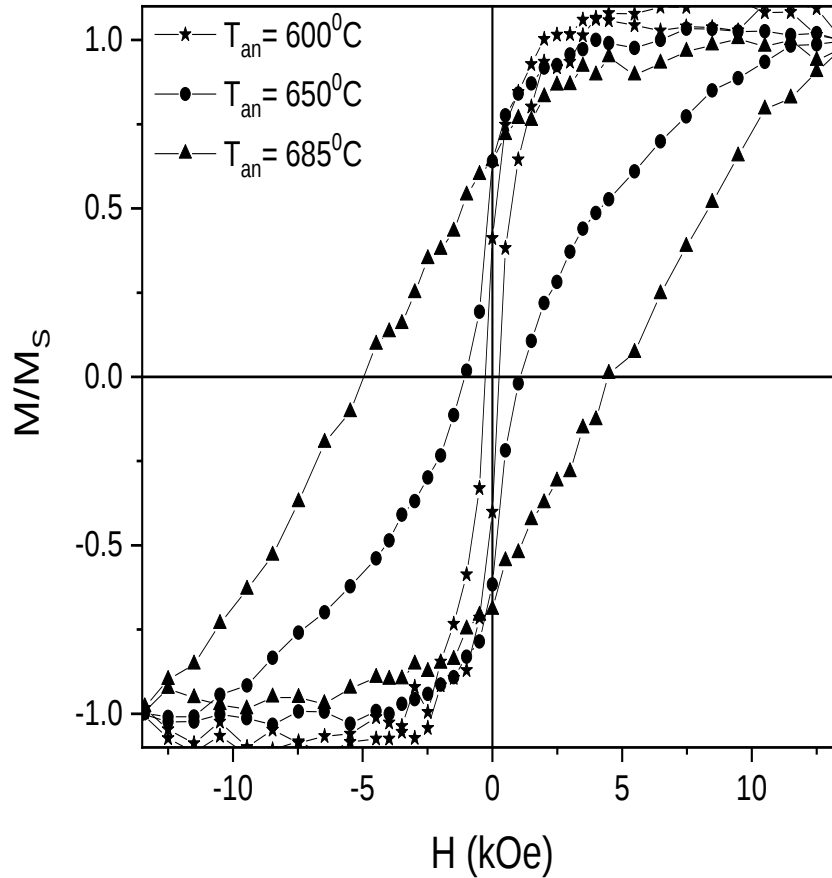


Figure 2. Room-temperature magnetization measurements of $\text{Fe}_{57}\text{Pt}_{43}$ films after annealing at different temperatures.

The as-deposited FePt film possesses coercive field of a few hundred Oe, indicating that it is slightly coercive. The same behavior has been reported by Mahalingam et al., [5] and Chun et al., [7]. After

annealing, the films show to have high coercivity (H_C). The room-temperature magnetization measurements of the FePt film annealed at temperature range from 600 °C to 685 °C are presented in Fig. 2 [8]. When the annealing temperature is 600 °C, the curve does not show significant difference compared to that of the as-deposited film. When T_{an} is 650 °C, the curve shows a two-phase behavior: one is associated with a low-coercivity phase which is similar to the as-deposited film and another one characteristic for a high-coercivity phase. Coercivity begins to develop at an annealing temperature higher than 600 °C, then it increases sharply and reaches 4.4 kOe at $T_{an} = 685$ °C. The annealing-temperature dependence of the coercivity (H_C) of Fe₅₇Pt₄₃ film is shown in Fig. 3a.

It is of high interest to describe the ordering process quantitatively by determining the order parameter S . There are conventionally two ways to calculate order parameter S in the sample [9]. The first one involves the measurement of the intensity of the superlattice peaks versus the fundamental ones obtained from X-ray diffraction patterns. The second way is deducing the order parameter directly from the c/a ratio where c and a are lattice parameters of the sample [9]. Here we calculate S directly from the c/a ratio using the equation [9].

$$S = \left[\frac{1 - \frac{c}{a}}{1 - \left(\frac{c}{a}\right)_{S_f}} \right]^{1/2}$$

where c/a is the measured value for the prepared FePt films and $(c/a)_{S_f}$ is the value for the tetragonality obtained from the fully ordered sample. $S = 1$ in this equation corresponds to the fully ordered phase. Using this equation, the value $(c/a)_{S_f} = 0.956$ reported by Chen et al., [10] for FePt film, we deduced the value of S for our sample. The obtained values for S are shown in Fig. 3a, together with the room-temperature coercivity as a function of annealing temperature. It can be seen that the variation in coercivity (H_C) with the annealing temperature follows that of the order parameter (S). Rhen and Coey [11] have pointed out that the coercivity dependence on the annealing temperature in FePt films can be understood in term of the phase transition from the disordered phase to the ordered phase. For low annealing temperatures, the phase formation is far from complete, accounting for the small coercivities, associated with the disordered FePt phase. As the annealing temperature increases, our Fe₅₇Pt₄₃ film transformed into the ordered fct L1₀ phase with coercivity reaching a value of 4.4 kOe at 650 °C. These results indicate that the annealing-temperature dependence of coercivity is indeed related to that of the order parameter, and the degree of atomic ordering is essential to understanding the origin of coercivity in FePt films, as also shown for FePd and CoPt nanostructures [12, 13].

Shih et al., [14] showed that magnetic hardening in FePt films is directly affected by the degree of atomic ordering. These authors also used the remanent magnetization (M_r) to saturation magnetization (M_s), M_r/M_s , ratio as a measure of chemical ordering degree of the L1₀ ordered phase for FePt films [14]. This method has been successfully applied to evaluate the annealing-temperature dependence of the order parameter by Luong et al., [12] for FePd nanoparticles and by Nam et al. for CoPt nanoparticles [13]. For our Fe₅₇Pt₄₃ sample we have plotted in Fig. 3b the squareness ratio (M_r/M_s) as a function of annealing temperature T_{an} . It is interesting to observe that the annealing-temperature dependence of the M_r/M_s ratio follows that of the order parameter in the annealing-temperature range investigated. The results presented in Fig. 3 suggest that coercivity is governed by the degree of chemical order of the fct ordered phase. This result is similar to that observed for the FePd nanoparticles [12] and CoPt nanoparticles [13].

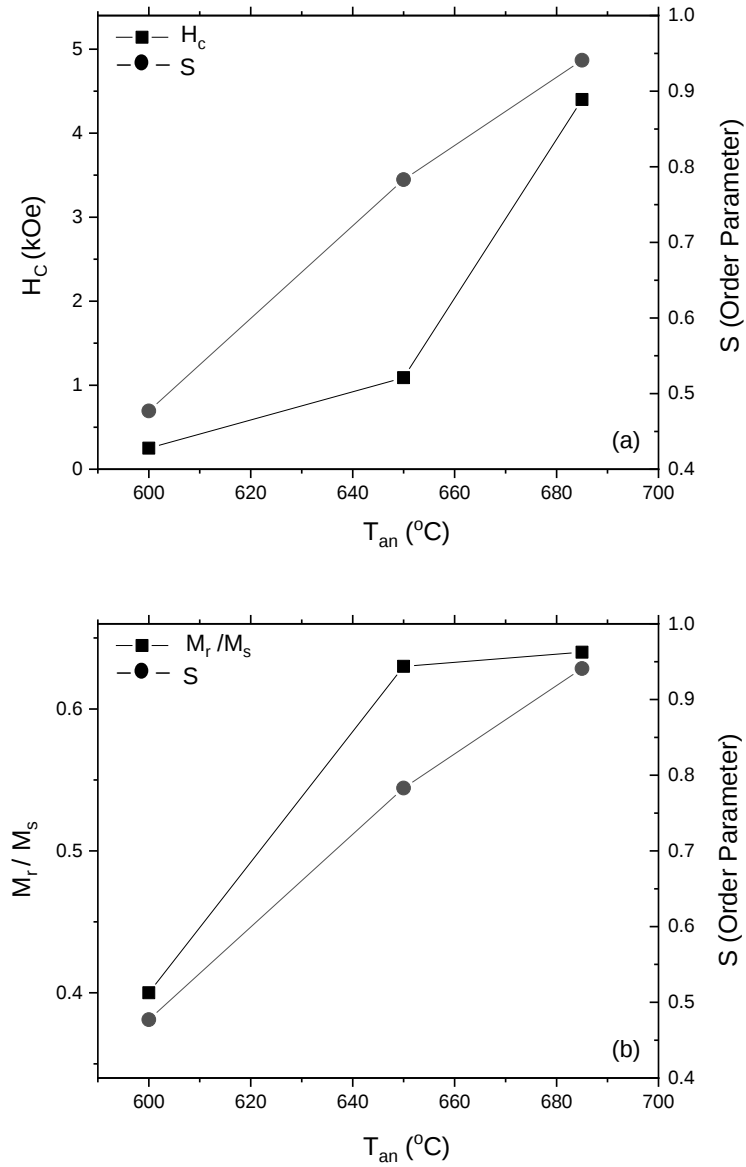


Figure 3. (a) Coercivity (H_c), (b) squareness ratio (M_r/M_s), and order parameter (S) versus annealing temperature for $\text{Fe}_{57}\text{Pt}_{43}$ film.

4. Conclusion

$\text{Fe}_{57}\text{Pt}_{43}$ films were prepared by RF magnetron sputtering. The effect of annealing temperature on magnetic properties of the obtained FePt films has been studied. The variation in the coercivity and the squareness ratio (M_r/M_s) with annealing temperature follows that of the order parameter. The magnetic hardening was governed by the degree of atomic order of the fct ordered phase in $\text{Fe}_{57}\text{Pt}_{43}$ films.

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