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Effects of W and Ti on the grain size and coercivity of $Fe_{50}Pt_{50}$ thin films

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Abstract

Polycrystalline $(Fe_{50}Pt_{50})_{95}X_5$ (X = W or Ti) alloy thin films were prepared by DC magnetron sputtering on natural-oxidized silicon wafer substrates, then postannealed in vacuum at various temperatures. The film thickness was 10 nm. The effects of sputtering argon pressure, annealing temperature and doping element on the grain size and in-plane coercivity of the FePt thin film were investigated. We found that the addition of W or Ti all can reduce the grain size of the annealed film, but coercivity of the film was decreased. Maximum coercivity of all the doped films could reach about 8 kOe, which was obtained by annealing the film at 650°C for 15 min. The grain size was about 10 nm. These films may be a promising candidate for high-density magnetic recording media. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Thin films; Sputtering; Coercivity

1. Introduction

In thin film recording media, high coercivity and small grain size are required for high-density longitudinal magnetic recording. FePt alloy has very high magnetocrystalline anisotropy constant ($Ku \cong 7\times10^7$ ergs/cm^3), high coercivity, good corrosion resistance and large energy products $(BH)_{max}$ [1]. Early investigations are mostly concerned with the improvement of the energy product and phase transformation temperature of the FePt bulk alloy [2]. Literature about magnetic properties of FePtX alloy thin film (where X is the third element other than Fe and Pt) and application for magnetic recording media is rare. In this work, the effects of sputtering argon pressure, annealing temperature and doping element on the grain size and in-plane coercivity of the FePt thin film were investigated. The film thickness was kept at 10 nm in order to examine the possibility of applying these doped films in high-density magnetic recording media.

2. Experimental

Polycrystalline $(Fe_{50}Pt_{50})_{95}X_5$ (X = W or Ti) alloy thin films were produced by DC magnetron sputtering on a natural-oxidized silicon wafer substrate at room temperature. A mosaic target consisting of high purity iron disk (99.99%) overlaid with high purity platinum pieces (99.99%) was used. Two separated DC magnetron guns were used for co-sputtering FePt and doping element, respectively.

The applied DC power was 40 W for 2-in diameter sputtering gun. The base pressure in the vacuum system was under 5×10^{-7} Torr, and after the high purity argon gas (99.9995%) was introduced, sputter argon pressures P_{Ar} between 3 and 10 mTorr were used in this study. The deposition rate of the film is about 0.6 Å/s. The film thickness was fixed at 10 nm. The as-deposited film was sealed in a quartz capsule and then postannealed in vacuum at various temperatures. The annealing time t_{an} was 15 min and the film was quenched in ice-water after annealing.

The magnetic properties of the film parallel to the film plane were measured with a superconducting quantum interference device (SQUID) at room temperature, and the maximum applied field was 50 kOe. The microstructure of the films was identified by transmission electron

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microscopy (TEM). The average grain size of the film was measured by the TEM bright-field image. Composition and homogeneity of the film were determined by energy disperse spectrum (EDS). Thicknesses of the films were measured by an α-step.

3. Results and discussion

Fig. 1 shows the relations between the in-plane coercivities H_c of the various as-deposited films and sputtering argon pressures at room temperature. It can be seen that most of the as-deposited films' H_c values increase with increasing P_{Ar}. The H_c value is lower than 40 Oe as X = W or Ti. From TEM analysis, we find that these as-deposited films are all polycrystalline structures, and they are all FCC γ-phase. The grain size of all as-deposited $(Fe_{50}Pt_{50})_{95}X_5$ films are similar, about 5 nm. Fig. 2 is a typical TEM bright-field image and diffraction pattern of the as-deposited $(Fe_{50}Pt_{50})_{95}X_5$ film.

From Fig. 1, we can see that the addition of the third element will affect the coercivity of the as-deposited FePt film. The γ-FePt phase is magnetically soft in bulk form, however, due to the contribution of large internal stresses that were introduced by the sputtering process; it has higher coercivity in the thin film form than in the bulk form. The internal stress of the film was varied with the doping element because the lattice parameter of an $Fe_{50}Pt_{50}$ alloy will be changed and the crystalline lattice of $Fe_{50}Pt_{50}$ film is distorted when the third element is doped.

Fig. 3 is the relationship between the in-plane coercivity H_c and the annealing temperatures T_{an} of Pure FePt and various annealed $(Fe_{50}Pt_{50})_{95}X_5$ films. We can see that the coercivity increases with the annealing temperatures as $T_{an} < 650°C$, and the tendencies of X = W and X = Ti curves are similar. The coercivity is increased slowly with increasing T_{an} as $T_{an} < 500°C$, and it increases rapidly as $T_{an} > 550°C$. The coercivity decreases rapidly as $T_{an} > 650°C$ except in the case of pure FePt film, the H_c of which is decreased as $T_{an} > 600°C$. The

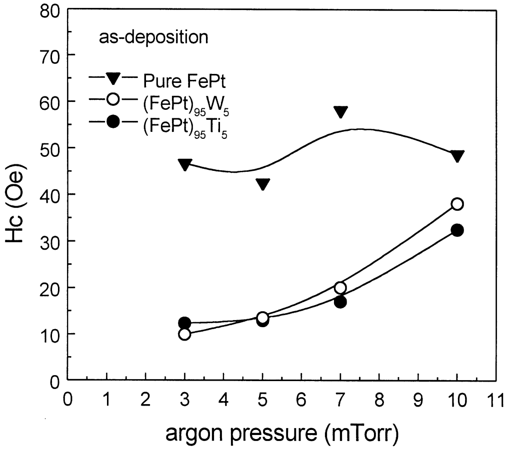

Fig. 1. Variations of in-plane coercivity with sputtering argon pressure of as-deposited pure FePt and various $(FePt)_{95}X_5$ films.

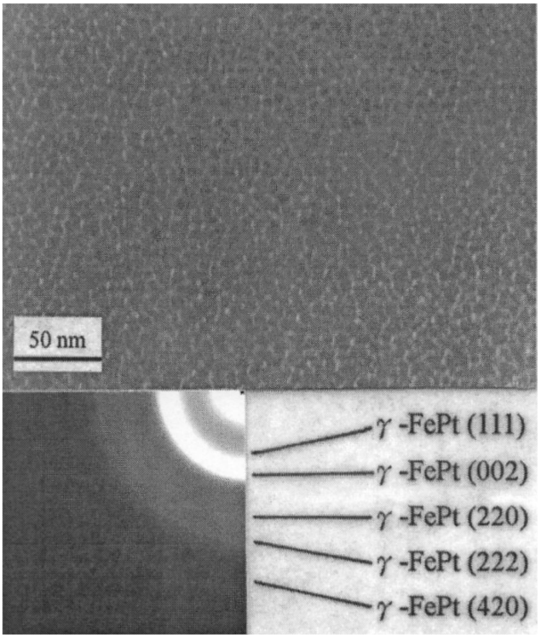

Fig. 2. TEM bright images and diffraction patterns of the as-deposited $(FePt)_{95}W_5$ film. It has FCC γ-FePt phase structure.

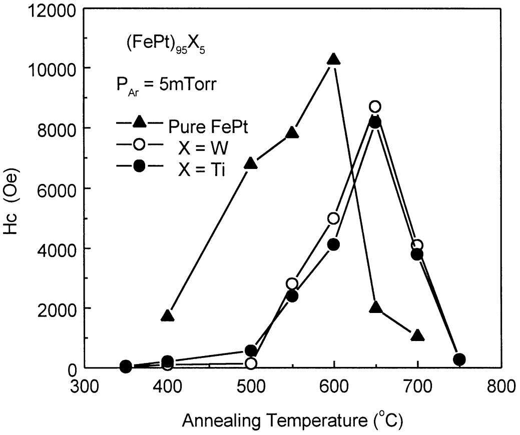

Fig. 3. Variations of in-plane coercivity with annealing temperature of post-annealed pure FePt and various $(FePt)_{95}X_5$ films. The sputtering argon pressure is 5 mTorr.

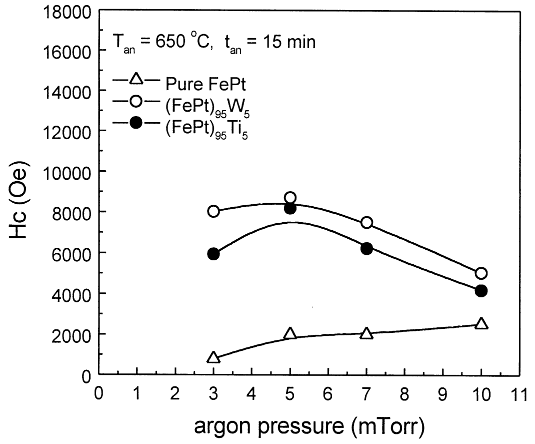

Fig. 4. Variations of in-plane coercivity H_c with sputtering argon pressure of post-annealed pure FePt and various $(FePt)_{95}X_5$ films that were annealed at 650°C.

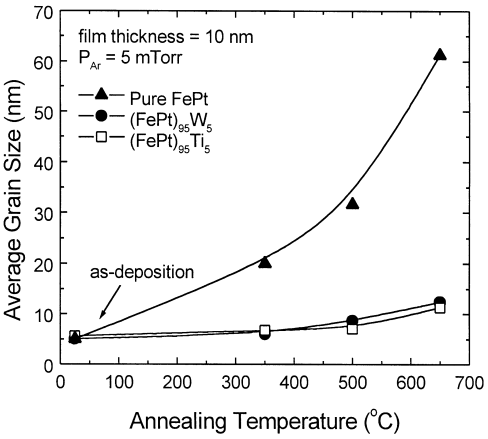

Fig. 5. Variations of average grain size with differing annealing temperatures of pure FePt and various $(FePt)_{95}X_5$ films.

maximum H_c value of pure FePt film is about 10 kOe, and it is about 8 kOe for doped films. In a previous study, we found that the FePt film would react with the silicon substrate as $T_{an} > 600°C$ [3]. However, when 5 at% W or Ti is added, the H_c value of the film will decrease at $T_{an} > 650°C$, which is higher than 600°C, as shown in Fig. 3.

The rapid increase of H_c of the doped films as $T_{an} > 500°C$ is due to the rapid increase of the amount of FCT γ_1-FePt phase, which is transformed from the FCC γ-FePt phase in the as-deposited film. The FCT γ_1-FePt phase has a high magnetocrystalline anisotropy constant. Rapid decrease of H_c of the doped films as $T_{an} > 650°C$ is due to the reaction of the film with silicon substrate.

Fig. 4 shows the relationships of H_c value with sputtering argon pressure of various post-annealed $(FePt)_{95}X_5$ films. The annealing temperature is 650°C. We find that the tendency of the curve of $(FePt)_{95}W_5$ film is similar to that of $(FePt)_{95}Ti_5$ film. Their H_c values all increase with P_{Ar} as $P_{Ar} < 5$ mTorr, then decrease as $P_{Ar} > 5$ mTorr. The maximum H_c value is about 8 kOe, which occurs at $P_{Ar} = 5$ mTorr. The low coercivity of pure FePt film at this annealing temperature (650°C) is due to the chemical reaction of the film with silicon substrate, as shown in Fig. 3.

W and Ti atoms are nonmagnetic atoms. The tendencies of the curves of $(FePt)_{95}W_5$ film and $(FePt)_{95}Ti_5$ film to be similar may be due to the fact that the atomic radii of W (2.02 Å) and Ti (2.00 Å) are similar; as a result, after the phase transformation of γ-FePt to γ_1-FePt structure at 650°C, the variations of the internal stress of these two films are similar. Therefore, the contribution of internal stress to the coercivity of these two films is about the same.

From the observations of TEM images, Fig. 5 shows the variations of average grain size with differing annealing temperatures of various $(FePt)_{95}X_5$ films. The sputtering argon pressure is 5 mTorr. We can see that the average grain sizes of all doped films grow much more slowly than those of pure FePt film when the annealing temperature is increased. This means that these doping elements will all inhibit the grain growth of the film. As $T_{an} = 650°C$, the average grain size of pure FePt film is about 60 nm, but it is only about 10 nm for all doped films.

4. Conclusion

The magnetic properties of sputtered polycrystalline $(Fe_{50}Pt_{50})_{95}X_5$ (X = W or Ti,) alloy thin films have been studied. The effects of sputtering argon pressure, annealing temperature and doping element on the grain size and in-plane coercivity of the FePt thin film were investigated. We found that the addition of W or Ti can all reduce the grain size of the annealed film, but coercivity of the film was decreased. Maximum coercivity of all the doped films could reach about 8 kOe, a result obtained by annealing the film at 650°C for 15 min. The reduction of grain size is helpful for increasing recording density of the film.

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