Microstructure and magnetic properties of the $(FePt)_{100-x}Cr_x$ thin films

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The $(FePt)_{100-x}Cr_x$ alloy thin films with $x=0-16$ at. % were fabricated on natural-oxidized Si(111) substrate by dc magnetron sputtering. The as-deposited films were annealed between 300 and 750 °C in order to transform the soft magnetic fcc γ-FePt phase to the hard magnetic fct γ_1-FePt phase. The addition of Cr in the FePt thin films will reduce its saturation magnetization and coercivity, however, it could inhibit the grain growth during annealing of the samples. The optimum condition for high-density magnetic recording purpose of the $(FePt)_{100-x}Cr_x$ alloy films was found with $x=5$ at. %, annealing at 650 °C for 15 min, and ice water quench cooling. According to the transmission electron microscopy study, the average grain size in the annealed $(FePt)_{100-x}Cr_x$ alloy thin films decrease from 60 to 5 nm with increasing x from 0 to 16. [S0021-8979(00)52408-6]

I. INTRODUCTION

In recent years, the FePt thin films have received significant attention owing to their potential applications in magnetic and magneto-optic recording.[1–4] In the thin film recording media, high coercivity and small grain size are required for high-density longitudinal magnetic recording. The ordered equiatomic FePt phase with tetragonal $L1_0$ structure has very high magnetocrystalline anisotropy constant ($K_u \sim 7\times10^7$ ergs/cm^3), high coercivity, good corrosion resistance, and large energy products $(BH)_{max}$.[5–8] It suits for the application in magnetic recording media and various micromagnetic devices. Previous investigations have shown that the magnetic properties of the FePt films are sensitive to process parameters.[9,10] In this work, the effects of annealing temperature and doping concentration of Cr on the magnetic properties and grain size of the FePt thin film were investigated.

II. EXPERIMENT

The $(FePt)_{100-x}Cr_x$ alloy thin films with $x=0-16$ at. % were fabricated on natural-oxidized Si(111) substrate by dc magnetron sputtering. 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 Cr, respectively. The deposition rate is about 0.6 Å/s. The base pressure in the vacuum system was under 5×10^{-7} Torr, and after the high purity argon gas (99.9995%) was introduced, the sputter pressure of 5 mTorr was used in this study. The $(Fe_{50}Pt_{50})_{100-x}Cr_x$ film thickness was fixed at 10 nm in order to examine the possibility of applying these films in high-density magnetic recording media. The as-deposited film was sealed in a quartz capsule and then postannealed in vacuum at a temperature between 300 and 750 °C. The annealing time was 15 min, and the film was quenched in ice water after annealing.

The magnetic properties of the film at room temperature were measured with a superconducting quantum interface device (SQUID). Microstructure of the film was characterized by x-ray diffractometer. The average grain size of the film was measured by the transmission electron microscopy (TEM) bright-field image. Composition and homogeneity of the film were determined by energy disperse spectrum (EDS).

III. RESULTS AND DISCUSSION

The structure and magnetic properties of the pure FePt films have been reported before.[9,10] In this investigation, the influence of Cr addition on the structure and magnetic properties of the FePt thin films is reported. The addition of Cr in the FePt thin films from 0 to 16 at. % reduces its saturation magnetization roughly from 700 to 400 emu/cm^3, and its coercivity roughly from 10 to 4 kOe. From the x-ray diffraction pattern studied, we find that all as-deposited $(FePt)_{100-x}Cr_x$ alloy thin films with $x=0-16$ at. % are polycrystalline fcc γ-phase structure. The γ-FePt phase is magnetically soft in bulk form, however, due to the contribution of large internal stresses introduced by sputtering process, it has higher coercivity in the thin film form than in the bulk form. These internal stresses may produce some microcracks in the as-deposited FePt film for thicker films (e.g., 200 nm).[1,9] However, we found that these microcracks disappeared for the 10 nm film. It indicates that the internal stress of the film was decreased as film thickness decreased.

For annealed films, small amount of FeCr phase was observed for all the doped films; and the fct γ_1-FePt phase is dominated for samples with annealing temperature roughly above 500 °C. As an example, Fig. 1 shows the x-ray diffrac-

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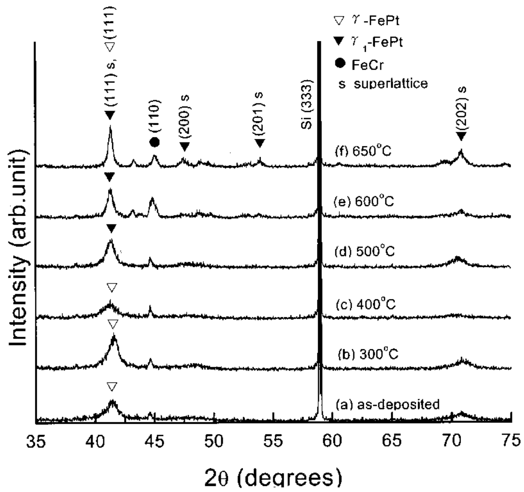

FIG. 1. X-ray diffraction patterns of the $(FePt)_{88}Cr_{12}$ alloy thin films with (a) as-deposited, and annealed at (b) 300, (c) 400, (d) 500, (e) 600, and (f) 650 °C for 15 min.

tion patterns of the $(FePt)_{88}Cr_{12}$ thin films with (a) as-deposited and (b) to (f) annealed between 300 and 650 °C for 15 min. It is clear that the fcc γ-FePt phase is dominated in the as-deposited films and the fct γ_1-FePt phase increases with increasing the annealing temperature. For the two films annealed at the highest temperatures, there are a few unidentified lines in the x-ray spectra. It may be due to the reaction of the films with their substrates during high temperature annealing. Figure 2 is a typical TEM bright-field image and diffraction pattern of a $(Fe_{50}Pt_{50})_{95}Cr_5$ film annealed at 650 °C for 15 min. It shows that the average grain size is roughly 12 nm. The fcc γ-FePt, fct γ_1-FePt, and FeCr phases

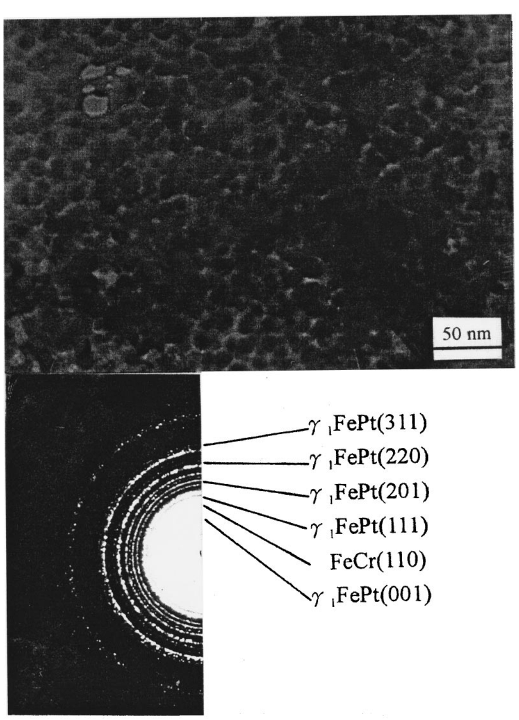

FIG. 2. TEM bright-field images and diffraction patterns of the $(FePt)_{95}Cr_5$ film annealed at 650 °C for 15 min.

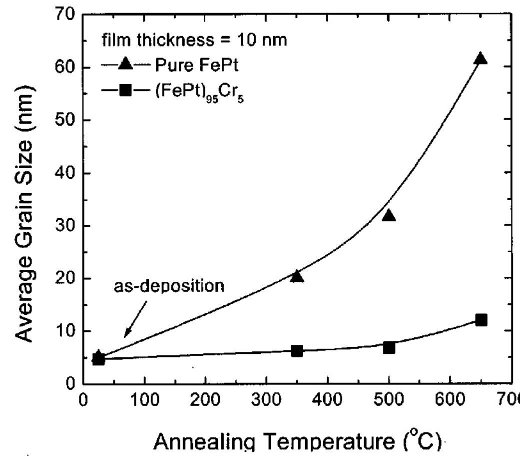

FIG. 3. Average grain size as a function of annealing temperature for the pure FePt and $(FePt)_{95}Cr_5$ films.

were observed, however, from our experimental data, it was not sufficient to clarify the extent of Cr in the FePt phase.

From the observations of TEM images, Fig. 3 shows the variation of the average grain size as a function of annealing temperature (T_{an}) for the pure FePt and $(Fe_{50}Pt_{50})_{95}Cr_5$ films. The average grain size of all the unannealed films are about the same (~5 nm). After annealing, the average grain size of the $(FePt)_{95}Cr_5$ film grows slower than that of a pure FePt film. At $T_{an}=650$ °C, the average grain size of a pure FePt film is 60 nm, and it is only about 12 nm for a $(FePt)_{95}Cr_5$ film. From the TEM bright-field image and coercivity studies, we found that the effect of Cr addition is not only reducing the film's magnetic hardening but also limiting the grain growth of the magnetic FePt phase during annealing. Figure 4 shows the average grain size as a function of Cr concentration for the $(FePt)_{100-x}Cr_x$ films annealed at 650 °C for 15 min. The average grain size decreases very fast for films containing a few percent (<5 at. %) of Cr. For films containing Cr between 5 and 16 at. %, they decrease slowly from 12 to 5 nm.

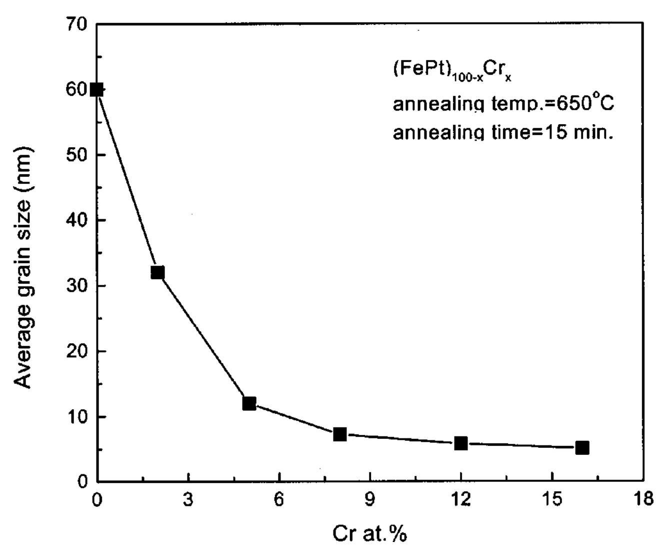

FIG. 4. Average grain size as a function of the Cr concentration for the $(FePt)_{100-x}Cr_x$ films.

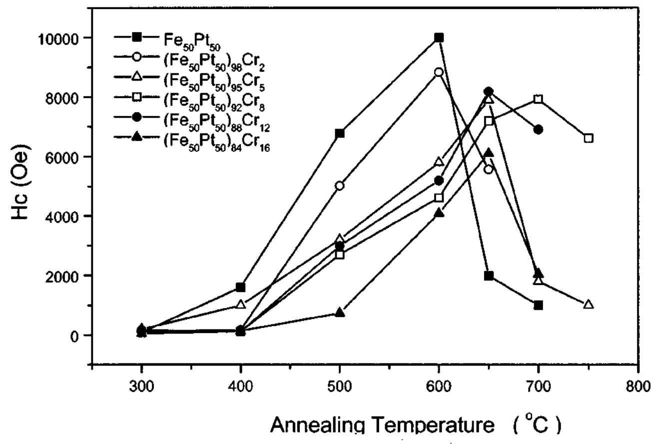

FIG. 5. Coercivity as a function of annealing temperature for the $(FePt)_{100-x}Cr_x$ alloy thin films with $x=0$, 2, 5, 8, 12, and 16 at. %.

Figure 5 shows the coercivity of the $(Fe_{50}Pt_{50})_{100-x}Cr_x$ alloy thin films as a function of annealing temperatures. In general, for films annealing between 600 and 650 °C, the saturation magnetization is between 400 and 700 emu/cm^3, and the coercivity between 4 and 10 kOe can been achieved. The coercivity increases monotonously with the annealing temperature before reaching its maximum value. This is due to the gradual transform of the fcc γ-FePt phase to the fct γ_1-FePt phase. After reaching its maximum value, the coercivity drops rapidly with increasing T_{an}. This is due to the chemical reaction of the thin film with Si substrate.

In conclusion, we have observed that the addition of Cr in the FePt thin films will reduce its saturation magnetization and coercivity, however, it could inhibit the grain growth during annealing of the samples. The optimum condition for high-density magnetic recording purpose of the $(FePt)_{100-x}Cr_x$ alloy films was found with $x=5$ at. %, annealing at 650 °C for 15 min, and ice water quench cooling. According to the TEM study, the average grain size in the annealed $(FePt)_{100-x}Cr_x$ alloy thin films decrease from 60 to 5 nm with increasing x from 0 to 16.

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