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COERCIVITY AND MICROSTRUCTURE OF NANO-SCALE FePtCr-SiN THIN FILMS

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Abstract. Nano-scale FePtCr-SiN thin films were fabricated on natural-oxidized silicon wafer. Thickness of the films was kept at 10 nm in order to examine the possibility for applying in high-density magnetic recording media. The as-deposited film was annealed in vacuum at various temperatures to obtain hard magnetic fct γ_1-FePt phase ($L1_0$ phase). Increasing SiN content in the film postponed the initial temperature required for obtaining high coercivity. The transmission electron microscopy (TEM) observation indicated that the FePtCr particles were dispersed in non-magnetic SiN matrix. The average grain size of the magnetic particles was decreased as Cr content of the film was increased. Average grain size of the $[(FePt)_{90}Cr_{10}]_{85}$-$[SiN_x]_{15}$ film is about 9.5 nm and its in-plane coercivity was about 3.7 kOe.

1. INTRODUCTION

FePt alloy thin film is suitable for high density magnetic recording media due to its high magnetocrystalline anisotropy ($Ku \sim 7 \cdot 10^7$ erg/cm^3) [1-3]. However, it still has some disadvantages to be improved for high density recording media application, such as large grain size and high exchange coupling between FePt grains. High density recording media require ultrafine grains of about 10 nm or less. Previous investigations have shown that the grain size of the FePt can be reduced by adding Cr into FePt film [4] or dispersing magnetic FePt grains into an amorphous non-magnetic SiN matrix [5]. Although granular FePt–Si_3N_4 thin film has good magnetic properties for high density recording application, the magnetic grain size of FePt-SiN film is still larger than 10 nm. In this work we add Cr into the FePt-SiN film to reduce its grain size and investigate the influences of Cr and SiN contents on the coercivity and of the FePtCr-SiN thin film.

2. EXPERIMENT

$[(FePt)_{100-x}$-$Cr_x]_{100-\delta}$-$(SiN_x)_\delta$ nanocomposite films (where x = 0 ~ 25 at.% and δ= 0 ~ 30 vol.%) with thickness of 10 nm were produced on natural-oxidized silicon wafer substrates at room temperature by co-sputtering $Fe_{50}Pt_{50}$, Cr, and Si_3N_4 targets. The as-deposited film was encapsulated in a quartz tube and annealed in vacuum between 350 ~ 750 °C for 30 minutes then quenched in ice-water in order to get ordered FePt $L1_0$ phase. A thin SiN cape layer of 5 nm was deposited on the magnetic film in order to protect the film from oxidizing. Magnetic properties were measured by vibrating sample magnetometer (VSM) and superconducting quantum interference device (SQUID) with maximum applied fields of 13 kOe and 50 kOe, respectively. Average grain size of the film was calculated from transmission electron microscopy (TEM) images. Composition and the homogeneity of the film were determined by energy disperse spectrum (EDS) and the film thickness was measured by atomic force microscopy (AFM).

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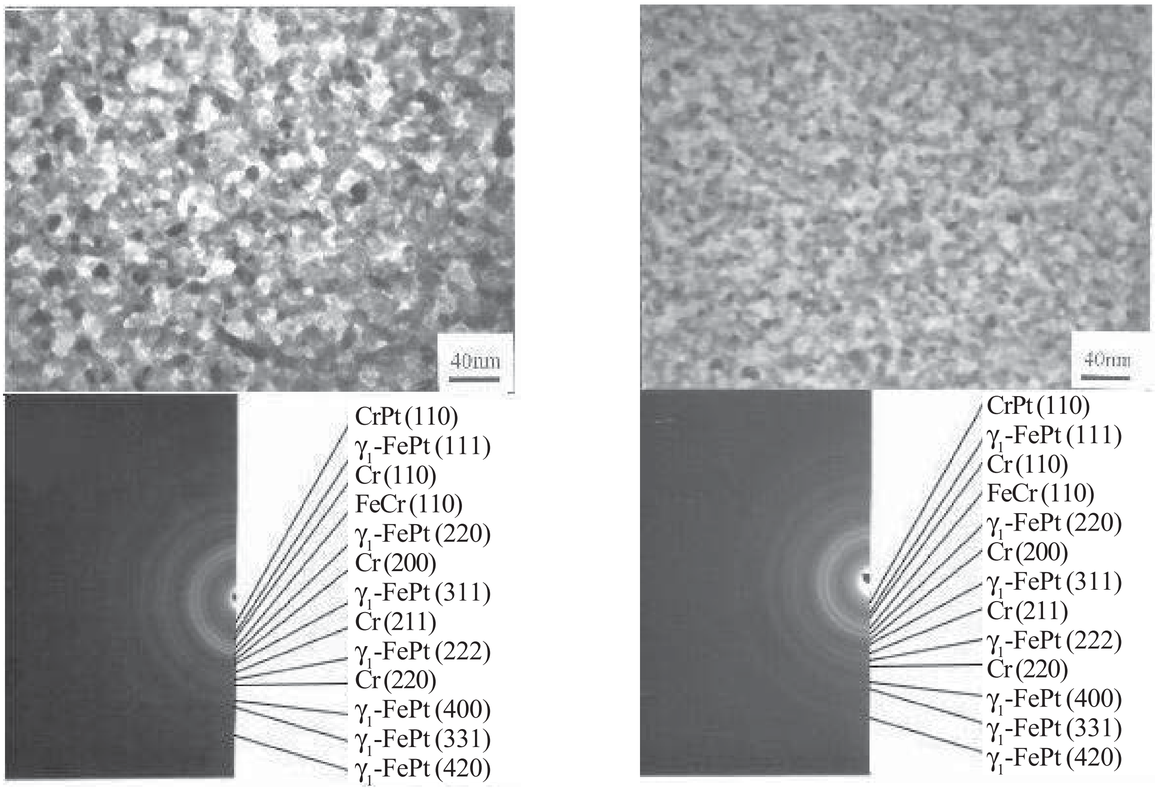

Fig. 1. TEM bright field images and the electron diffraction patterns of (a) the $[(FePt)_{94}Cr_6]_{85}$-$[SiN_x]_{15}$ film and (b) $[(FePt)_{75}Cr_{25}]_{85}$-$[SiN_x]_{15}$ film. The films were annealed at 600 °C for 30 min then ice-water quenched.

3. RESULTS AND DISCUSSION

Figs. 1(a) and 1(b) show the TEM bright field images and electron diffraction patterns of the $[(FePt)_{94}Cr_6]_{85}$-$[SiN_x]_{15}$ and $[(FePt)_{75}Cr_{25}]_{85}$-$[SiN_x]_{15}$ films, respectively. The γ_1-FePt, FeCr, CrPt, and Cr phases were observed in both annealed films. The SiN diffraction rings were not observed in the films, this means that the SiN was in amorphous state. Comparing Fig.1(a) with Fig.1(b), one can see that the grain size of the $[(FePt)_{75}Cr_{25}]_{85}$-$[SiN_x]_{15}$ film are smaller than that of the $[(FePt)_{94}Cr_6]_{85}$-$[SiN_x]_{15}$ film. Average grain size of the $[(FePt)_{94}Cr_6]_{85}$-$[SiN_x]_{15}$ film is about 14 nm and it will decrease to about 9.5 nm and 5 nm as Cr content is increased to 10 at.% and 25 at.%, respectively.

Fig. 2(a) is the relationship between in-plane coercivity, $Hc_{//}$, and annealing temperature, T_{an}, and Fig.2(b) is the relationship between out-of-plane coercivity, $Hc_{\perp}$, and T_{an} of various annealed $[(FePt)_{90}Cr_{10}]_{100-\delta}$-$[SiN_x]_{\delta}$ films with different SiN volume fractions. $Hc_{//}$ value of the $[(FePt)_{90}Cr_{10}]_{100-\delta}$-$[SiN_x]_{\delta}$ film rises rapidly as T_{an} > 350 °C. The rapid decrease of $Hc_{//}$ for T_{an} > 650 °C is due to the grain growth and the reaction of FePtCr with the silicon substrate [6]. $Hc_{\perp}$ value also has the same tendency as that of $Hc_{//}$ as shown in Fig. 2(b). The maximum $Hc_{\perp}$ value is about 3.6 kOe, which is much smaller than that of $Hc_{//}$. Therefore, magnetic anisotropy of these films is parallel to the film plane. It also indicates that the increase of SiN content in the film increases the annealing temperature required for obtaining highest coercivity. This is due to the fact that the amorphous SiN phase is a poor heat-conductor. It would postpone the initial temperature at which the fcc γ-FePt phase begins to transform to the ordered FePt $L1_0$ phase as SiN content of the film is increased. After annealing at 600 °C, the $Hc_{//}$ value of the $[(FePt)_{90}Cr_{10}]_{85}$-$[SiN_x]_{15}$ film is 3.7 kOe and its grain size is about 9.5 nm. This film would be suitable for magnetic recording application.

Fig. 3 shows the relationship between $Hc_{//}$ value and Cr content of the $[(FePt)_{100-x}Cr_x]_{100-\delta}$-$[SiN_x]_{\delta}$ film with different SiN contents. The annealing temperature was 600 °C. It indicates that the $Hc_{//}$ value decreases with increasing Cr and SiN contents. Since Cr is expected to segregate at grain boundaries of

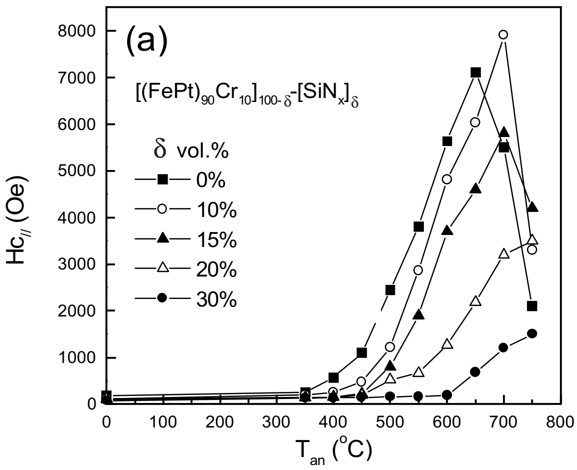

Fig. 2. The relationships between (a) $Hc_{//}$ and T_{an}, and (b) $Hc_\perp$, and T_{an} of the annealed $[(FePt)_{90}Cr_{10}]_{100-\delta}$-$[SiN_x]_\delta$ films.

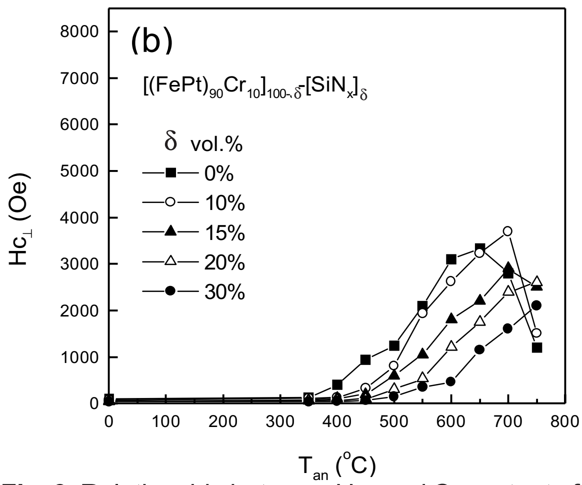

Fig. 3. Relationship between $Hc_{//}$ and Cr content of the $[(FePt)_{100-x}Cr_x]_{100-\delta}$-[$SiN_x]_\delta$ film.

FePt grains [7] and limit the grain growth of FePt, the grain size distribution would become large and some grains become superparamagnetic particles. On the other hand, the SiN matrix will surround FePt grains and increases the phase transformation temperature of γ-FePt to γ_1-FePt [5]. Therefore, the magnetocrystalline anisotropy constant of FePt films would be decreased at T_{an}=600 °C as SiN content is increased. Due to these two factors, the $Hc_{//}$ value would be decreased with increasing Cr and SiN contents as shown in Fig. 3.

4. CONCLUSION

The magnetic particle size in annealed FePtCr-SiN granular film was decreased with increasing Cr contents. The average grain size of FePt particles could be decreased to 5 nm as Cr content was increased to 25 at.%. The $[(FePt)_{90}$-$Cr_{10}]_{85}$-($SiN_x)_{15}$ film which annealed at 600 °C for 30 minutes would be a promising candidate for high-density magnetic recording medium application. Its $Hc_{//}$ was about 3.7 kOe and the average grain size of the FePtCr in this film was about 9.5 nm.

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