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Effects of rapid thermal annealing on nanostructure, texture and magnetic properties of granular FePt:Ag films for perpendicular recording (invited)

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We report effects of rapid thermal annealing on nanostructure, texture, and magnetic properties of granular FePt:Ag films. It was found that the orientations of FePt grains were dependent strongly on the as-deposited multilayer structure and the annealing processes. Through the control of the annealing processes, (001) textured $L1_0$ granular FePt:Ag films were obtained. Magnetic measurements revealed that saturation magnetization M_s , perpendicular coercivity H_c , and remanence ratio M_r/M_s , were also dependent on the annealing temperature, annealing time and Ag content. Perpendicular H_c values increased from 1.5 to 15 kOe when the annealing temperature changed from 400 to 600 °C for 600 s. Perpendicular H_c values remained about 11 kOe when the annealing time changed from 5 to 600 s. The effect of Ag content on magnetic properties is reported.

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INTRODUCTION

In recent years, dramatic improvements have been made in high-density magnetic storage media. The areal density of magnetic recording has made rapid increases yearly in laboratory demonstrations and now approaches 100 Gbit/in².¹ Such a high magnetic recording density requires media to have high coercivity and a grain size of less than 10 nm.² With such small grain size, the particle magnetization becomes thermal instability. In order to overcome the thermal instability and continue the growth of the areal density, recent studies have been focused on high anisotropy, $L1_0$ phased FePt and CoPt alloy thin films.³⁻⁵ Usually, a heated substrate or a post-thermal annealing is needed for obtaining the ordered structure. However, one of the side effects of annealing is relatively high processing temperature, which may adversely affect grain growth. One way to solve this problem is to use nanocomposite films, in which the grain growth can be suppressed by nonmagnetic matrix.^{6,7} For example, the studies of CoPt:C,^{8,9} FePt:B₂O₃,^{10,11} and CoPt:B₂O₃¹² films have been reported. In this study, rapid thermal annealing processing conditions and the nanostructural and magnetic properties of FePt:Ag films are presented.

EXPERIMENT

A series of (FePt)_{100-x}Ag_x ($x=0,3,11,20$) films were prepared by magnetron sputtering with multilayered structure of Fe/Pt/Ag. The thickness of single layer Fe and Pt

were 7.6 and 8 Å, respectively. The total thickness was about 100 Å. The substrate used was Corning 7059 glass substrate. The chamber base pressure and the Ar sputtering pressure were 3×10^{-7} Torr and 4×10^{-3} Torr, respectively. The composition of Fe, Pt, and Ag was controlled by adjusting the thickness ratio of Fe, Pt, and Ag layers. All as-deposited films were annealed in a rapid thermal annealer. The ramp rate was 100 °C/s. The annealing temperatures were varied from 400 to 600 °C. The annealing times were varied from 5 to 600 s. The structural properties were analyzed by x-ray diffraction (XRD) with Cu $K\alpha$ radiation. The magnetic properties were measured with an alternating gradient force magnetometer and Quantum Design MPMS XL superconducting

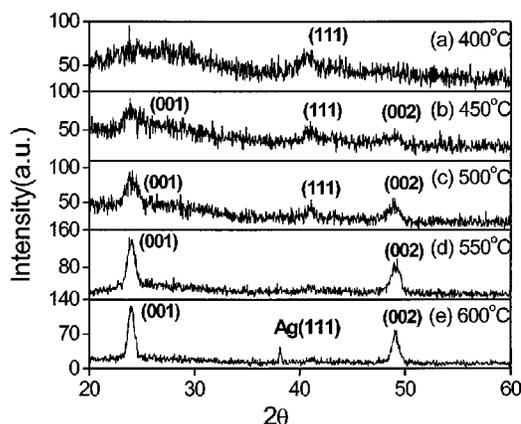


FIG. 1. XRD patterns of (FePt)_{100-x}Ag_x ($x=20$) films annealed at (a) 400, (b) 450, (c) 500, (d) 550, and (e) 600 °C for 600 s.

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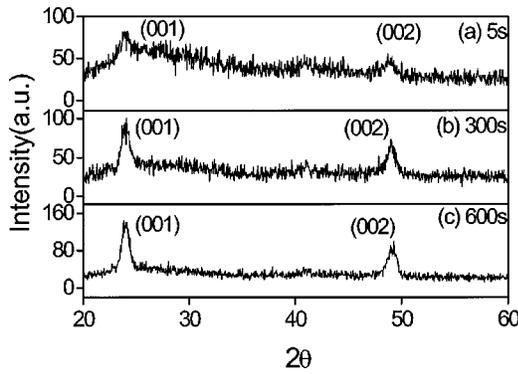


FIG. 2. XRD patterns of $(\text{FePt})_{100-x}\text{Ag}_x$ ($x=20$) films annealed at $550\text{ }^\circ\text{C}$, for (a) 5, (b) 300, and (c) 600 s.

quantum interference device magnetometer. The field is applied both in the plane and normal to the plane of the film.

RESULTS AND DISCUSSION

Shown in Fig. 1 are x-ray diffraction patterns of $(\text{FePt})_{100-x}\text{Ag}_x$ ($x=20$) films annealed at various temperature ranging from 400 to $600\text{ }^\circ\text{C}$ for 600 s. Figure 1(a) shows only (111) peak when the film is annealed at $400\text{ }^\circ\text{C}$. No superlattice peak is observed, indicating that the fcc phase has not transformed to fct structure. Figures 1(b) and 1(c) show that upon annealing the films to $450\text{ }^\circ\text{C}$, (001) and (002) superlattice peaks of FePt emerge. It implies that the order-disorder transformation in the FePt films starts. Upon further annealing to $550\text{ }^\circ\text{C}$, (001) and (002) diffraction peaks intensities increase [Fig. 1(d)], and become predominant and the (111) peak finally disappears, which results in a (001) texture. Only the dominant (001) and (002) peaks appear, indicating that the FePt grains are (001) oriented with the c axis along the film normal direction. When the sample is annealed at $600\text{ }^\circ\text{C}$, fcc Ag and $L1_0$ FePt phases coexist as seen in Fig. 1(e). This suggests that the FePt atoms dissolve into the Ag grains.

Figure 2 shows the XRD patterns of $(\text{FePt})_{80}\text{Ag}_{20}$ films annealed at $550\text{ }^\circ\text{C}$ for various annealing time. The annealing time in Fig. 1(a) is 5 s. Though the annealing time is relatively short, there is the presence of (001) superlattice peak,

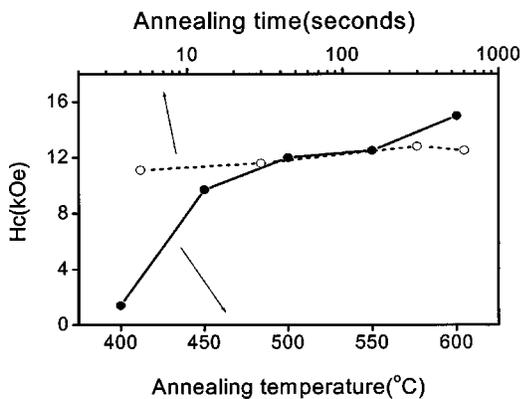


FIG. 3. Dependence of coercivity on the annealing time and annealing temperature. H_c was measured in perpendicular direction.

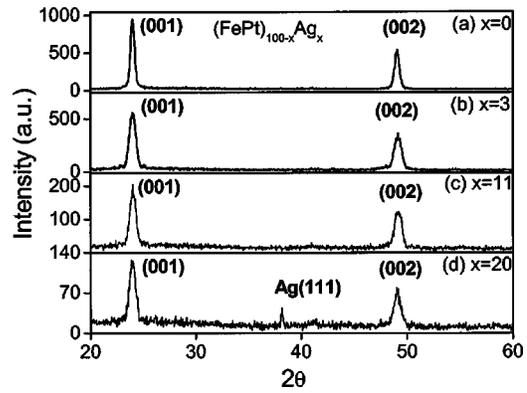


FIG. 4. XRD patterns of $(\text{FePt})_{100-x}\text{Ag}_x$ films annealed at $600\text{ }^\circ\text{C}$ for 600 s with $x=(a)0$, (b) 3, (c) 11, and (d) 20.

indicating the formation of the fct structure. With the annealing time increasing from 300 to 600 s [Figs. 1(b) and 1(c)], (001) and (002) superlattice peaks of FePt become stronger, indicating the development of (001) texture and formation of $L1_0$ tetragonal structure.

The dependence of perpendicular coercivity H_c on annealing temperature for 600 s and annealing time at $550\text{ }^\circ\text{C}$ are shown in Fig. 3. When the films are annealed for 600 s, the coercivity H_c increases with the rise of annealing temperature. After annealing at $400\text{ }^\circ\text{C}$, a relatively low coercivity H_c , 1.5 kOe is obtained. With the annealing temperature increasing to $450\text{ }^\circ\text{C}$, the coercivity increases very rapidly and reaches a high value of 10 kOe, indicating that the disordered fcc structure transforms to the ordered fct structure. Below $450\text{ }^\circ\text{C}$, the coercivity is small. After raising the temperature to $600\text{ }^\circ\text{C}$, H_c increases up to 15 kOe with the same heat treatment. When these films annealed at $550\text{ }^\circ\text{C}$ with the annealing time increasing from 5 to 600 s, coercivity about 11 kOe is obtained. Though the annealing time has been prolonged, the degree of ordering of the films has not become better. This result may be caused by the Ag matrix, which constrains grain growth. Comparing these two results, we find that H_c mostly depends on annealing temperature but not on annealing time.

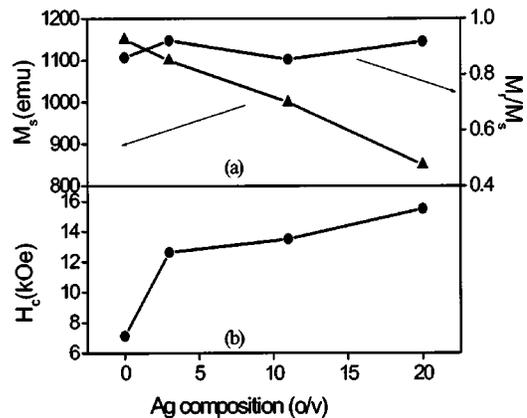


FIG. 5. Dependence of perpendicular coercivity, remanence ratio M_r/M_s , and saturation magnetization M_s on the Ag composition annealed at $600\text{ }^\circ\text{C}$ for 600 s.

We also prepared a series of $(\text{FePt})_{100-x}\text{Ag}_x$ films with variable Ag atomic ratio from 0 to 20 at. %. Figure 4 shows the XRD patterns of films annealed at 600 °C for 600 s. All the samples clearly show the (001) superlattice peak of FePt, so the ordered $L1_0$ tetragonal structure has been formed independent of the Ag content. The Ag content has relatively small affection on orientation. The dependence of perpendicular coercivity H_c , remanence ratio M_r/M_s , and saturation magnetization M_s on Ag composition are shown in Fig. 5. The data show clearly that by controlling Ag content one can obtain H_c with values in the range of 7 to 16 kOe. As shown in Fig. 5(b), the perpendicular remanence ratio M_r/M_s of the loop ranges from 0.85 to 0.92. M_r/M_s remains almost unchanged as the Ag content increases from 0% to 20%. M_s decreases from 1150 to 850 emu with increasing Ag content. These results show that Ag content controls the magnetic properties and is a useful parameter for optimizing media properties for high-density recording.

CONCLUSION

In summary, we prepared $L1_0$ phased FePt:Ag thin films. By varying the annealing temperature and time and relative FePt:Ag composition, a high perpendicular coercivity (>10 kOe) can be obtained. It increases with a rise in the annealing temperature and Ag content. The perpendicular magnetic anisotropy is a result of the (001) orientation of

FePt grains. As a matrix material, Ag content has little effect on orientation. The nanostructural and magnetic properties of these films show that they may have a magnificent potential for application in high density, perpendicular magnetic recording media. Further studies including grains size, exchange coupling and read/write testing are underway.

ACKNOWLEDGMENTS

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