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# FePt:$SiO_2$ granular thin film for high density magnetic recording

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# FePt:$SiO_2$ granular thin film for high density magnetic recording

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Nanocomposite FePt:$SiO_2$ thin films consisting of high anisotropy FePt particles embedded in a $SiO_2$ matrix have been successfully fabricated by annealing the as-deposited FePt/$SiO_2$ multilayers. By adjusting the annealing temperatures and compositions, films were obtained with coercivity of 3.8 kOe and grain size of 10 nm, which are suitable for high-density magnetic recording. Magnetic activation volumes were measured and thermal stability is discussed.  [S0021-8979(00)46608-9]

## I. INTRODUCTION

The growth and microstructure of FePt thin films with the $L1_0$ ordered structure have received extensive attention due to their high anisotropy energy[1] and potential applications as high density longitudinal recording media,[2,3] magneto-optical recording media,[4] and high energy magnets.[5] It is expected that future 100 Gb/in.$^2$ recording media require higher anisotropy energy than current conventional Co alloys media because such high-density magnetic recording requires media with grain sizes of 10 nm or less, which is approaching the superparamagnetic limit of current media. Therefore, higher anisotropy energy is needed to retain thermal stability.[6,7] It also requires that the magnetic particles must be isolated to reduce intergrain interactions, which leads to lower media noise. In this research we studied the potential of FePt:$SiO_2$ granular thin films, which consist of high anisotropy FePt particles embedded in a $SiO_2$ matrix, for high-density media.

## II. EXPERIMENT

FePt/$SiO_2$ multilayers were deposited on 7059 glass substrates by dc- and rf-magnetron sputtering. The base pressure of the deposition chamber was $2\times10^{-7}$ Torr and high pure Ar was used for deposition at a pressure of 5 mTorr. The compositions of the films were adjusted by changing the FePt- and $SiO_2$-layer thickness. The as-deposited films were annealed in vacuum for 30 min in a temperature range from 500 to 650 °C. The structures of the films were investigated by x-ray diffraction (XRD) with Cu $K\alpha$ radiation. Magnetic properties were measured with a superconducting quantum interference device (SQUID) and an alternating gradient field magnetometer (AGFM). Domain pictures were taken by a magnetic force microscope (MFM).

## III. RESULTS AND DISCUSSION

As shown in Fig. 1(a), the as-deposited multilayers have a disordered face-centered-cubic (fcc) structure, which is magnetically soft with coercivity less than 100 Oe. When annealed in vacuum at temperatures of 500 °C and above, FePt films undergo a phase transition from the disordered fcc phase to the ordered face-centered-tetragonal (fct) phase $(L1_0)$.[2] A highly ordered fct structure, characterized by the (001) and (002) superlattice peaks, was obtained after annealing at 650 °C for 30 min, as shown in Fig. 1(b). The long-range order parameter,[8] which quantifies the order–disorder transition, is determined by the integral intensity of the superlattice peaks. The ordered fct phase is magnetically hard, as shown by the hysteresis loop in Fig. 2. Very similar loops were measured with applied field in the film plane and perpendicular to the film plane. A large coercivity of 8 kOe was obtained. The long-range order parameter, grain size, and coercivity of the films are sensitive to the annealing temperatures, as discussed elsewhere.[9]

High-density recording requires media with a coercivity of 3–4 kOe and grain size of 10 nm or less. We can adjust the coercivities and grain size of FePt:$SiO_2$ nanocomposite films by controlling the film composition, annealing temperature, and time. Under certain annealing temperatures and times, coercivities and grain sizes decrease as $SiO_2$ concentration increases, as shown in Fig. 3(a). The perpendicular grain sizes were estimated by the Scherrer formula[10] from the (111) peak width of XRD scans. When annealed at 600 °C for 30 min, the sample with 24 vol % of $SiO_2$ shows a coercivity of 3.8 kOe and a grain size of 10 nm, which is suitable for high-density magnetic recording. Since the $SiO_2$ matrix hinders the growth of FePt particles, the grain size decreases to well below 10 nm as $SiO_2$ concentration increases to over 50 vol %. However, the coercivity also de-

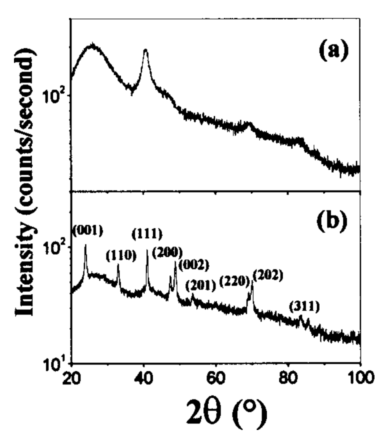


FIG. 1. XRD scans of $(\mathrm{FePt}38\,\text{Å}/\mathrm{SiO_2}12\,\text{Å})_{10}$ thin film. (a) as-deposited: (b) annealed at 650 °C for 30 min.

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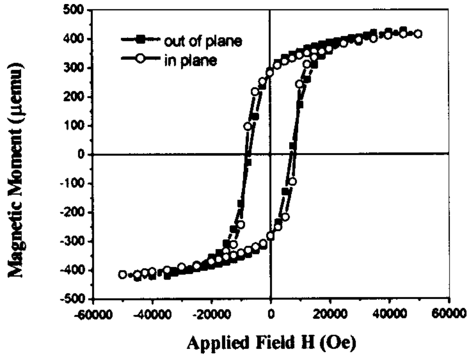


FIG. 2. Hysteresis loop of $(\mathrm{FePt38\ Å/SiO_2 12\ Å})_{10}$ annealed at 650 °C for 30 min.

creases rapidly. The decrease of coercivity may be due to smaller grains and the incomplete transition from fcc to fct phase.

The $M_r/M_s$ ratio also decreases as $SiO_2$ concentration increases, as shown in Fig. 3(b). The decrease of $M_r/M_s$ ratio may be due to the reduced exchange interactions between grains. $\delta M$ plots shown in Fig. 4 indicate that exchange coupling has been reduced as $SiO_2$ concentration increases. For films with $SiO_2$ more than 50 vol % only dipole interactions were observed. At the same time the $M_r/M_s$ ratio decreases to near the value of 0.5 for noninteracting Stoner–Wohlfarth particles. This suggests that the high anisotropy FePt particles were randomly distributed and isolated by the $SiO_2$ matrix.

Figure 5 shows the domain pattern of the film with 24 vol % of $SiO_2$. The domain pattern consists of segmented stripes with an average domain width of 60 nm.

As recording density approaches 100 Gb/in.,[2] the bit size and grain size become smaller and smaller in order to retain a reasonable signal-to-noise ratio. As grain size approaches the superparamagnetic limit, thermal fluctuations become very important. Thermal stability is usually determined by the activation volume $V^*$, which can be determined by measuring the viscosity coefficient $S$ and the irreversible susceptibility $\chi_{\mathrm{irr}}$:[11]

$$V^* = k_B T \chi_{\mathrm{irr}} / M_s S,$$

where $S$ is measured by the time decay of magnetization:

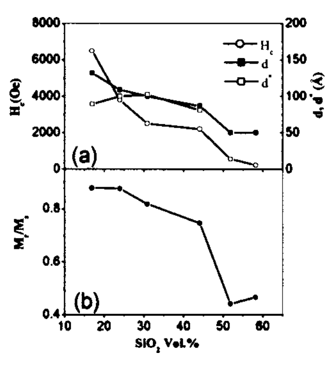


FIG. 3. The dependence of $H_c$, grain size $d$, magnetic grain size $d^*$, and $M_r/M_s$ ratio on $SiO_2$ concentration.

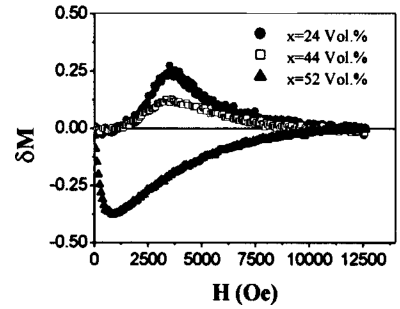


FIG. 4. $\delta M$ plots of $(\mathrm{FePt38\ Å/SiO_2}x\ \mathrm{Å})_{10}$ annealed at 600 °C for 30 min.

$$M(H,t) = M_0 - S(H)\ln(t/t_0),$$

where $M_0$ and $t_0$ are constants independent of time. Figure 6 shows the linear dependence of magnetization on $\ln(t/t_0)$, which allows the determination of the magnetic viscosity coefficient $S$. The activation volume is on the order of $1\times10^{-18}\,\mathrm{cm}^3$, and does not does not change much with composition. The magnetic grain size $d^*$, defined as $(V^*)^{1/3}$, was found very close to the physical grain size $d$ for most samples, as shown in Fig. 3(a). This, along with the $\delta M$ results, suggests that the particles reverse as units which are only weakly exchange coupled. The $K_u V^*/k_B T$ value is about 850 (assuming $K_u = 3.5\times10^7$ erg/cc for the FePt phase[12]), much above the required value of 60 for thermally stable media.[13]

## IV. SUMMARY

FePt:$SiO_2$ nanocomposite films were successfully synthesized with controlled grain sizes and magnetic properties by varying film compositions and annealing temperatures. These films consist of high anisotropy FePt particles isolated by a $SiO_2$ matrix. Films were obtained with desired magnetic properties ($H_c \sim 3.8$ kOe) and grain size ($\sim$10 nm) which are suitable for high-density magnetic recording. Magnetic viscosity studies indicate that these films have excellent thermal stability. Altogether the results suggest that FePt:$SiO_2$ nanostructured films are promising candidates for future high-density recording media.

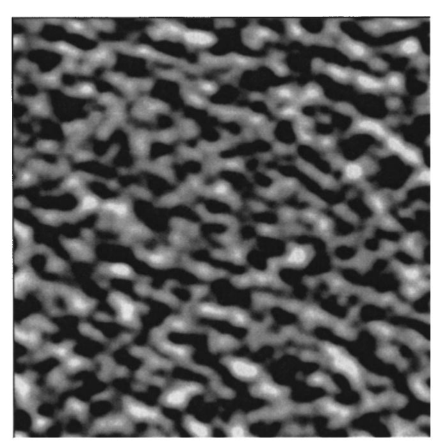

FIG. 5. MFM image of the FePt:$SiO_2$ nanocomposite film with 24 vol % of $SiO_2$. The size of the image is 2 μm.

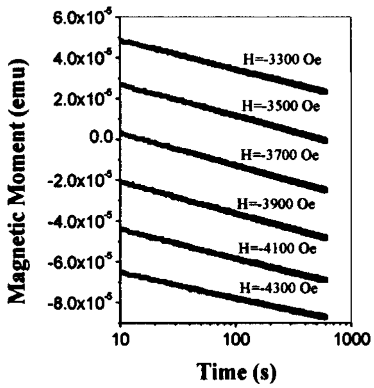


FIG. 6. The dependence of magnetization on ln $t$.

## ACKNOWLEDGMENTS

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