Nano-granular FePt-Ag Composite Film – Its Magnetic and Magnetotransport Properties

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ABSTRACT

FePt/Ag multiplayer films are fabricated by laser ablation deposition technique onto quartz substrate and ex-situ annealed in vacuum with annealing temperature in the range of 400 – 630 °C. Face centered tetragonal (fct) FePt nano grains are developed in annealed films. With changing in FePt layer thickness and annealing temperature, the FePt grain size can be controlled from below 10 nm to around 20 nm. Correspondingly, the film magnetic coercivity increases from 4.7 to 15 KOe. Giant magnetoresistance effect (GMR) is found in this composite film system. The GMR ratio is sensitive to the film microstructure and the variation is interpreted based on the spin dependent scattering of conduction electrons at the interface between FePt and Ag grains.

Keywords: FePt nano grains, magnetic, GMR

1 INTRODUCTION

Thermal relaxation of tiny magnetic grains limits approaching ultra-high magnetic recording density in currently used Co-based hard disk recording medium. It was argued that to achieve acceptable signal to noise ratio, the K_uV/K_BT, where K_u is anisotropy energy density; V is magnetic switching volume; K_BT is thermal energy at room temperature, should be ≥ 50-70 [1]. Because smaller gain size is favored to get high recording resolution, to overcome this physical intrinsic obstacle, higher K_u materials will be desirable.

$L1_0$ phase face centered tetragonal (fct) $Fe_{50}Pt_{50}$ alloy has a high magnetic crystalline anisotropy with the K_u in the range of $6.6 - 10 \times 10^7$ erg/cc, which is much higher than that of presently used recording media. Recently, employing FePt/Ag multiplayer films, high perpendicular anisotropy and small switching volumes were obtained after annealing the multilayer films in vacuum at a high temperature [2]. It was found that Ag is a good material to isolate the FePt grains because of its high diffusivity during annealing and low solubility between FePt and Ag.

In present work, focus is on controlling the FePt grain size by varying the FePt layer thickness and annealing temperature, which is critical for recording medium application. With changing in grain size, both the film magnetic and magnetotransport properties were altered.

2 EXPERIMENTAL

Multilayer $[Fe_{50}Pt_{50}$ (x nm)/Ag (1 nm)$]_{\times 10}$ films were deposited onto quartz substrate, with the x varying from 0.5 to 2 nm, by laser ablation system. The base and deposition pressures were 2×10^{-7} Torr and 5×10^{-7} Torr, respectively. The deposition rate is 0.2 Å/S for Ag and 0.05 Å/S for FePt. The substrate temperature was kept at ambient temperature during deposition. As deposited films were annealed in vacuum of 1×10^{-7} Torr in the temperature range 400 – 630 °C with the annealing time ranging from 15 min to 1 hour. The film structure was characterized by x-ray with Cu-Kα radiation. Magnetic properties were measured using an alternating gradient force magnetometer (AGFM) with the maximum field of 20 KOe. Standard four-probe method was used to measure film resistance under a magnetic field. The maximum field is 15 KOe and the field was applied in film plane. The electrical current direction was either perpendicular or parallel to magnetic field in film plane, transverse or longitudinal being called for these two configurations, respectively. During measuring GMR transfer curve, the magnetic filed scanned from +15 KOe to -15 KOe, then reversed to +15 KOe. The definition of GMR ratio in this work is $GMR = [R(H)-R(Hs)]/R(Hs)$, where the Hs is the saturation field.

3 RESULTS AND DISCUSSION

3.1 FePt layer Thickness Effect

As deposited FePt/Ag multilayer films show a layered structure, evidenced by the peaks in small angle x-ray diffraction pattern [2]. With annealing, the layered structure was broken due to atomic diffusion to combine into FePt and Ag grains [3]. Fig. 1 shows the x-ray diffraction patterns for three samples with different FePt layer thickness annealed at 630 °C for 15 min. For 2 nm – FePt samples, the superlattice FePt (001) peak is clearly demonstrated, indicating that after annealing ordered fct FePt phase was developed. For the other two samples, although no obvious superlattice diffraction peak appears, the FePt (111) peaks are thought coming from the fct FePt grains rather than disordered fcc FePt grains

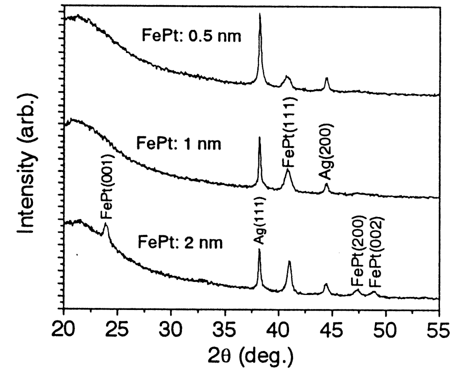

Figure 1: x-ray diffraction patterns for three samples with different FePt layer thickness.

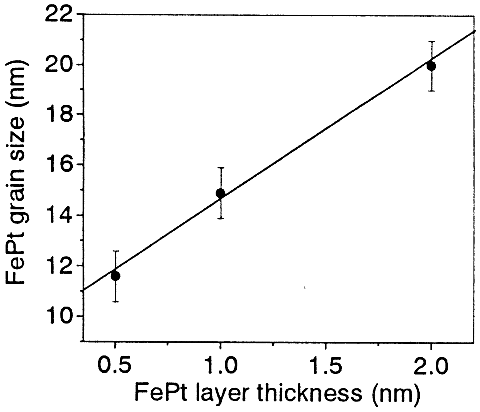

Figure 2: FePt grain size versus FePt layer thickness

considering the big coercivity (Hc) of these films (discussed in the following). Based on the FePt (111) diffraction peaks of these three samples, the FePt grain size was estimated out using Scherrer formula, as shown in Fig. 2. It is unambiguous that with increasing the FePt layer thickness the obtained FePt grain size increases, which provides an easy way to control grain size.

Fig. 3 shows coercivity values measured from in plane M-H hysteresis loops. As FePt layer thickness increases from 0.5 to 2 nm, in other words, as the FePt grain size increases from around 11 nm to around 20 nm, the film coercivity increases from 4.7 KOe to 15 KOe. This huge coercivity value is certainly a result of very high uniaxial anisotropy of fct FePt grains. From the coherent rotation Stoner-Wohlfarth (SW) model, the Hc = 2 K_u/Ms for orientated FePt grain assembles if applied field along easy direction, which gives a value of 20 KOe if we take a Ku = 10^7 erg/cc and Ms = 1000 emu/cc . The decease of coercivity with reduction in grain size is possibly due to thermal relaxation effect. The K_u value in these films is not expected to be as high as that of bulk FePt alloy because some fcc FePt phase still exists in these films,

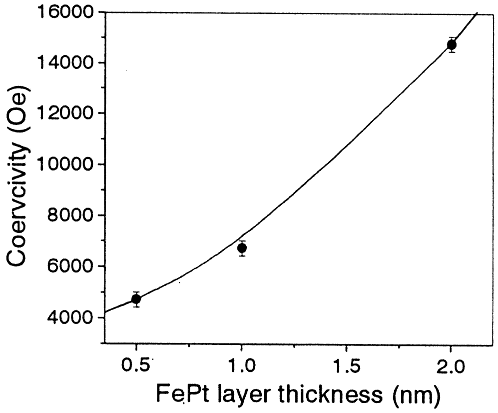

Figure 3: Coercivity versus FePt layer thickness

as revealed by fcc FePt (200) diffraction peak of 2 nm-FePt sample. Thermal relaxation effect in 0.5 and 1 nm – FePt samples has a noticeable effect on the magnetization reversal process due to much smaller grain volumes of these two samples than that of 2 nm - FePt sample.

Figure 4 presents the magnetotransport measurement results for these three samples. The resistivity of FePt-Ag composite films shows a dependence on applied magnetic field — so called magnetoresistance effect (MR). This MR effect was ascribed to be giant magnetoresistance effect (GMR), supported by its features of negative sign, isotropic in film plane and $(M/Ms)^2$ dependence for MR ratio [3]. The GMR effect in granular metallic composite films was pointed out to originate from the spin dependent conduction electron scattering at the interface between magnetic entities and non-magnetic matrix [4]. In FePt-Ag films, the electron scattering at the interface between FePt and Ag grains should be responsible for the found GMR effect. To get high GMR ratio in this system, large amounts of tiny FePt grains are preferred

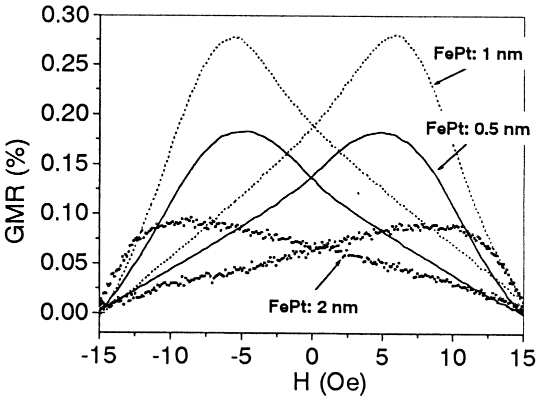

Figure 4: GMR transfer curves for three samples with different FePt layer thickness

in order to enhance the spin dependent scattering probability. 1 nm-FePt sample gives the maximum GMR effect among these three samples. With 2 nm-FePt, the GMR effect becomes very weak, which is because the increased grain size decreases the specific grain surface area; with 0.5 nm – FePt, the reduced magnetic scattering center concentration is responsible for the reduced GMR effect.

3.2 Annealing Temperature Effect

Another way to effectively control grain size is through changing the annealing temperature. Fig. 5 shows the x-ray diffraction patterns for [FePt 1.6 nm/Ag 1nm]$_{x10}$ multilayer film of as deposited, consecutively annealed at 450 °C and 500 °C for 1 hour, respectively. Almost no trace of FePt in as deposited diffraction pattern can be found because of the extremely fine microstructure of FePt in as deposited state.

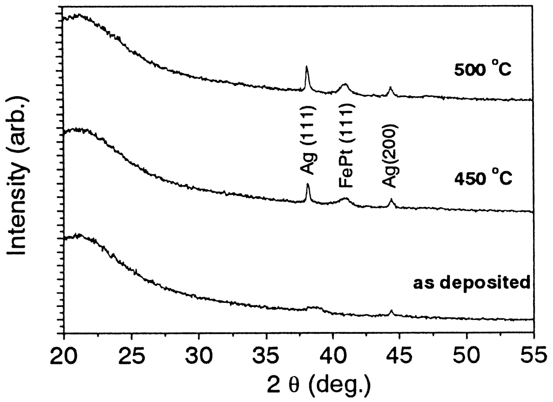

Figure 5: x-ray diffraction patterns for [FePt 1.6 nm/Ag 1 nm]$_{x10}$ annealed at different temperatures.

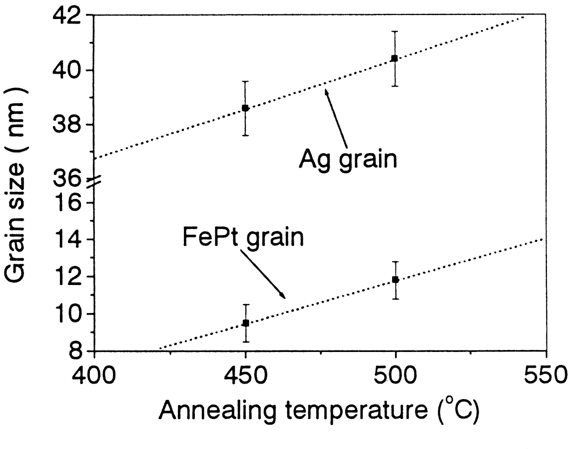

Figure 6: FePt and Ag grain size as a function of annealing temperature.

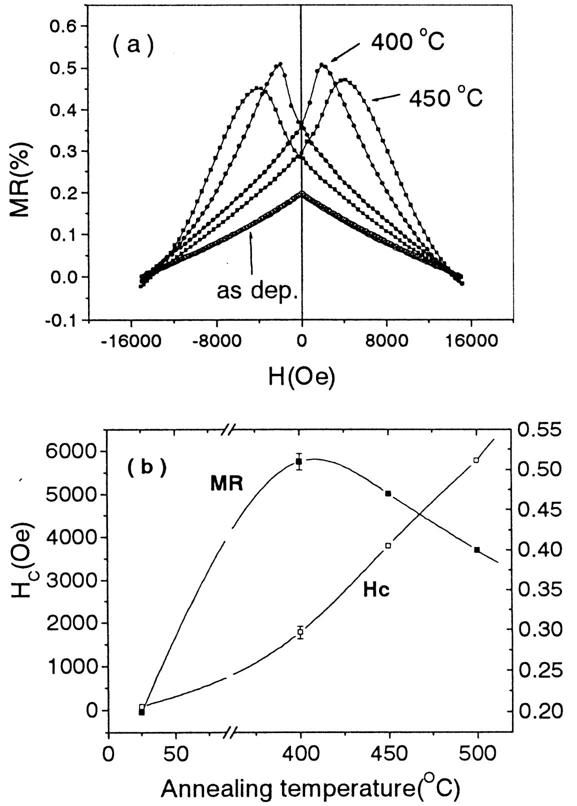

Figure 7: (a) MR transfer curves for the sample annealed at different temperatures. (b) MR ratio and Hc as a function of annealing temperature.

With increasing annealing temperature, Ag (111) and FePt (111) peaks are gradually developed. Based on these two peaks, the corresponding Ag and FePt grains were calculated out, shown in Fig. 6. Ag grain size is much bigger than FePt grain size, which is reasonable because the melting point of Ag is much lower than that of FePt and so higher diffusivity leads to bigger grain. With increase in annealing temperature by 50 °C, both grains get bigger.

Figure 7 (a) shows the MR transfer curves for the sample annealed at different temperatures and (b) shows the MR ratio and Hc as a function of annealing temperature. The film coercivity monotonically goes up within this temperature range, which is clearly a result of increased ordering of fct FePt phase with higher temperature. The as deposited MR effect comes from the spin-disorder scattering effect in alloy film and usually it is a much weaker effect than GMR effect. With occurrence of GMR effect, the MR ratio jumps to 0.5 % from as deposited 0.2 % and then goes down. The decrease of GMR ratio for higher temperature annealed sample is evidently due to the grain size growing.

4 CONCLUSIONS

In conclusion, by controlling FePt layer thickness and annealing temperature, the fct FePt grain size is effectively controlled, which gives an effect both on magnetic and on magnetotransport properties. Smaller grain size and larger magnetic scattering center concentration are helpful to get higher GMR effect.

ACKNOLEDGEMENT

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