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Magnetic properties and structure of Fe/Pt thin films

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Magnetic Properties and Structure of Fe/Pt Thin Films

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Abstract—The structural transformation from fcc to fct and relevant magnetic properties of initially multilayered Fe/Pt films were studied. When the as-deposited Fe/Pt films were annealed at the temperature of 300°C and up, the fct-phase was formed. Rather square hysteresis loops and large coercivities were measured from the annealed films. The films annealed at 300°C retain a layered structure.

I. Introduction

Fe-Pt thin films have recently received much attention owing to their potential applications in magnetic and magneto-optic recording. FePt alloy films with large in-plane coercivity, prepared by magnetron DC-sputtering , were studied by Yung et al. [1]. Lairson reported a technique for producing the ordered FePt intermetallic compound with perpendicular anisotropy [2]. Earlier studies showed the properties of FePt films were affected greatly by processing [3-4]. In this paper the magnetic properties and relevant structure of initially multilayered Fe/Pt films are reported.

II. Experiment

Fe/Pt multilayers were deposited by RF- and DC-sputtering on microscope cover glasses. The base pressure of the sputtering system was 2×10^{-7} Torr, the sputtering process was conducted at room temperature under 5 mTorr Ar pressure, and the deposition rates were about 1Å/s for both Pt and Fe. The as-deposited samples were sealed in quartz capsules and then subjected to vacuum annealing at temperatures ranging from 200-400°C. The magnetic properties of the as-deposited and annealed films were measured by a Micromag-2900 alternating gradient force magnetometer in which an alternating magnetic field gradient was used to produce an alternating force on a sample with a net magnetic moment [5]. The structure and phases were determined by x-ray diffraction (XRD) with Cu-K_α radiation.

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III. Results and discussion

The layered structure of the Fe/Pt multilayers was studied by small-angle XRD. Figure 1 shows the small-angle XRD patterns of the as-deposited and the 300°C annealed films. The first, second and third-order superlattice peaks were observed in the XRD scan of the as-deposited film. Besides the superlattice peaks there are several small peaks which are due to the multi-reflection effect. After annealing the as-deposited sample in vacuum at 300°C for 15 minutes, the first order superlattice peak and traces of the second and the third order peaks were still observed. That is, the film remains a layered structure after the annealing.

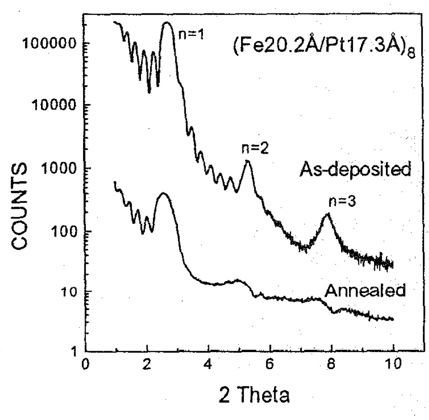

Fig.1 The small-angle XRD scans of Fe/Pt film

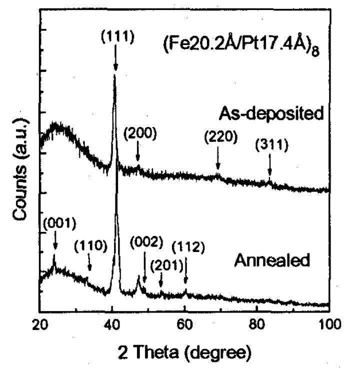

Fig.2 The large angle XRD patterns of Fe/Pt film

The large-angle XRD patterns of the as-deposited and annealed Fe/Pt multilayers are shown in Fig.2. The as-deposited film has a disordered fcc structure (γ-Phase). It grows along the [111] direction and a well-defined (111) peak appears at $2\theta=39.5°$. After annealing at 300°C for 15 minutes, the position of the (111) peak was found to shift a little toward higher angle, and several new diffraction peaks were found belonging to the fct phase (CuAuI structure). The shift of the (111) peak is due to the smaller c-axis lattice parameter of the fct structure. A c/a value of 0.963 was reported for $Fe_{50}Pt_{50}$ alloy by Men'shikov et al [6]. The new peaks were indexed as (001), (110), (002), (201) and (112) respectively, as shown in Fig.2. Thus, after annealing above 300°C, the structure increasingly transforms to compositionally modulated fct structure.

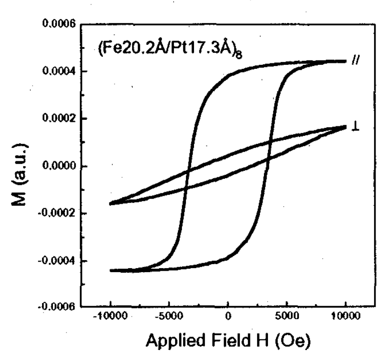

Fig.3 The hysteresis loops of (Fe20.2Å/Pt17.3Å) film annealed at 300°C for 15 minutes

According to the hysteresis loops of the as-deposited and annealed FePt films, the magnetic easy axis is found to lie in the film plane. The coercivities of the as-deposited films are small. After annealing, square loops and large coercivities were obtained. Fig.3 shows the hysteresis loops of the 300°C annealed Fe/Pt film with applied field both parallel and perpendicular to the film plane. An in-plane coercivity (H_c) of 3.2kOe was obtained. A minor loop was obtained along the perpendicular direction since the film was not saturated with the maximum 10kOe applied field.

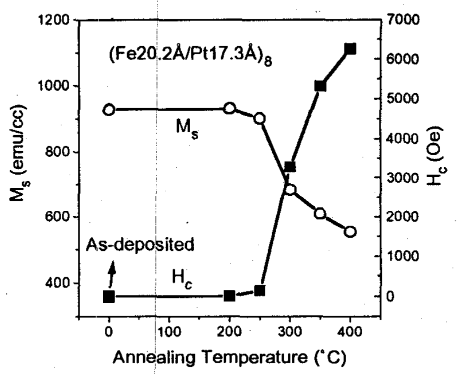

Fig.4 The dependence of M_s and H_c on annealing temperatures

Fig.4 shows the dependence of the in-plane coercivities (H_c) and saturation magnetization (M_s) of the $(Fe20.2Å/Pt17.3Å)_8$ multilayer on annealing temperature. When the annealing temperature (T_a) was below 300°C, no significant changes of H_c and M_s were observed. When T_a was raised to 300°C and above, H_c increased sharply and, at the same time, M_s decreased. The changes of H_c and M_s are due to the fcc to fct structural transition. The decrease of the saturation magnetization is due to the change of the ferromagnetic order of the fcc-structure to the ferrimagnetic order of fct-structure which involves a decrease of the mean atomic magnetic moment [6]. It is well known that the structural transformation of the fcc phase (cubic) to the fct phase (tetragonal) results in a high crystal magnetic anisotropy energy of up to 7×10^7 erg/cm^3 [7]. The high anisotropy energy results in the large coercivity. When the annealing temperature was raised to 400°C, an H_c as high as 7kOe was observed. The transformation temperature of fcc to fct phase was previously reported around 400°C in FePt alloy films [1]. In our Fe/Pt multilayers, this transformation temperature is about 300°C. Due to the low annealing temperature, a small grain size was obtained. It was found to be less than 15nm by transmission electron microscopy (TEM). A similar grain size of 17nm was reported for the 400°C annealed $Fe_{50}Pt_{50}$ alloy film [1].

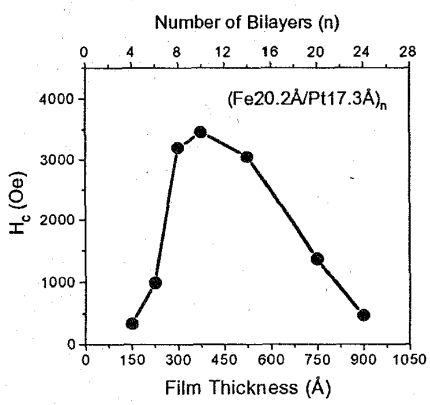

Fig.5 The dependence of H_c on film thickness

The coercivity also depends on the film thickness. (Fe20.2Å/Pt17.3Å) multilayers of different thickness were annealed at 300°C for 15 minutes. Large coercivities were found among the films with thickness between 300 and 600Å. When the film thickness t is more than 600 Å, the coercivity decreases sharply with the increase of t. When t is smaller than 300Å, the coercivity is also small. For ultra-high density recording media, large coercivity is required. Under the annealing conditions mentioned above, a film of 300Å thickness is necessary to obtain the coercivity of 3kOe. However, the M_r of such 300°C annealed film is about 600 emu/cm^3, and the M_rt is about 1.8 memu/cm^2. Larger H_c and smaller M_rt values have been obtained by increasing annealing temperature and annealing time. Fig. 6 shows the hysteresis loop of the $(Fe20.2Å/Pt17.3Å)_4$ multilayer annealed at 300°C for 30 minutes. A large coercivity of 3.21 kOe was obtained from the 150 Å thick film. The squareness (M_r/M_s) of the loop was 0.83. A smaller M_rt of 0.9 which is more suitable for high density magnetic recording has been obtained.

IV. Conclusions

The structural transformation temperature was found as low as 300°C in Fe/Pt multilayers.

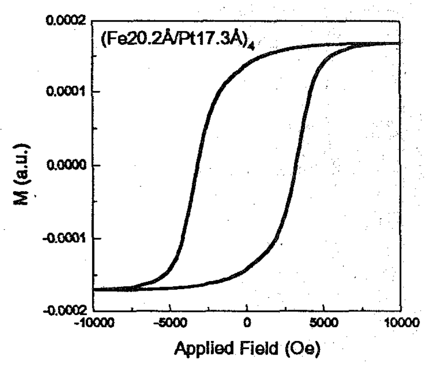

Fig. 6 The hysteresis loop of $(Fe20.2Å/Pt17.3Å)_4$ multilayer annealed at 300°C for 30 minutes.

Under this low annealing temperature, an average grain size smaller than 15nm was found by TEM. The coercivity can be adjusted by annealing temperature, annealing time and film thickness. Since large coercivity and fine grain size are required in ultra-high-density magnetic recording (10Gb/in^2), the present results suggest that further research on Fe/Pt including dynamic SNR tests will be worthwhile.

Acknowledgment

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