Magnetic and Structural Properties of Fe₃Pt Thin Films

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The hcp ordered phase of Fe₃Pt alloy thin films is for the first time successfully synthesized onto Al₂O₃(00·1) substrates by electron beam evaporation technique. It exhibits the basal-plane 6-fold magnetic anisotropy of the order of 10⁵ erg/cc. The magnetic anisotropy varies with deposition temperature in the similar way as the intensity of hcp (00·1) superlattice peak changes. This result implies the close correlation between the basal-plane magnetic anisotropy and the occurrence of the hcp structure. The in-plane magnetic anisotropy constant decreases with temperature from 2.0×10⁵ erg/cc at 80K to 1.4×10⁵ erg/cc at 300K.

Keywords: hcp Fe₃Pt, 6-fold magnetic anisotropy (K_{in}), superlattice.

1. Introduction

Recently, the hcp phase of Co₃Pt alloy thin film was reported to be stabilized through the epitaxial growth by electron beam evaporation onto Al₂O₃(00·1) substrate, although such an hcp phase of Co₃Pt does not exist in bulk form^{1), 2)}. The hcp Co₃Pt alloy thin films are found to possess the high magnetic anisotropy of the order of 10⁷ erg/cc at room temperature. On the other hand, Fe₃Pt, which is of the L1₂ structure (fcc) in bulk form, is known to exhibit very little magnetic anisotropy. Until now, there has been very little report in literature on hcp phase of Fe₃Pt thin film. Therefore, a systematic study of both magnetic properties and crystal structure as a function of deposition temperature (T_s) of Fe₃Pt films has been carried out and this paper presents the results and discussions.

2. Experimental

Thin films of Fe₃Pt were fabricated onto MgO(100) and Al₂O₃(00·1) substrates by electron beam evaporation using Fe and Pt targets of purity of 99.99%. Vacuum during deposition was better than 10⁻⁸ Torr. Substrate deposition temperature (T_s) was varied from the ambient temperature (~30°C) to about 550°C. The film thickness for all the samples was kept about 550Å. The evaporation rate was about 0.7 Å/s (Fe:0.48 Å/s, Pt:0.22 Å/s). Measurements of the magnetic properties were carried out using a vibrating sample magnetometer and a torque magnetometer (max field:15kOe). The torque measurement for the in-plane magnetic anisotropy was performed in a temperature range from -200°C to room temperature. The structural analysis was carried out by X-

ray diffraction ($\theta/2\theta$ scan and ϕ scan) using the CuK α , β radiation.

3. Results and Discussion

Figure 1 shows the X-ray spectra of the Fe₃Pt thin films grown onto (a) MgO(100) and (b) Al₂O₃(00·1) substrates at $T_s=500^\circ\text{C}$. Here only the CuK α radiation was used for measuring the sample grown onto MgO(100), while the CuK $\alpha+\beta$ radiation was used for the case of Al₂O₃(00·1). The structure of the film grown onto MgO(100) was found to be L1₂ (fcc) with the lattice constant of $a=3.79\text{\AA} \pm 0.01\text{\AA}$, which is 2% higher than the bulk value. This expansion is believed to be due to the substrate effect since the misfit of the substrate is 9%. On the other hand, the structure of the film fabricated onto Al₂O₃(00·1) is found to be not fcc. A careful analysis of identifying the diffraction spectrum reveals that the diffraction lines (designated as A and B) are assigned to be (00·1) and (00·3) of the hcp structure. The diffractions (00·2) and (00·4) are believed to be overlapped with the diffraction line of the Al₂O₃ substrates. The peaks found at around 39-40° and 85-86° are coming from the substrate, which was confirmed by X-ray diffraction of the substrate only.

Fig. 1 XRD spectra of the Fe₃Pt thin films deposited onto (a) MgO(100) and (b) Al₂O₃(00·1) substrates at $T_s=500^\circ\text{C}$.

The peak width of (00·1) in Fig. 1(b) is much smaller than that of (100) in Fig. 1(a). The reason for this may be as follows. The misfit of Fe₃Pt with MgO substrate is larger (9%) than that (4%) with Al₂O₃ substrate, which is rotated by 30° with respect to <10·0> Fe₃Pt. (That is to say <10·0>Fe₃Pt || <11·0> Al₂O₃) as shown in Fig.2. Therefore, lower lattice strain is present at the sample grown on Al₂O₃ substrate, which may yield the sharper

peak as shown in Fig. 1(b). One may safely conclude that the structure of the film deposited at $T_s = 500^\circ\text{C}$ is a partially ordered hcp structure with the c axis along the film normal. The atomic arrangement of hcp Fe_3Pt phase is believed to be similar to the ordered hcp Co_3Pt phase which was first proposed by Harp et al³⁾. Figure 3 shows the proposed structure of hcp Fe_3Pt thin films. However a further careful analysis is necessary to identify the structure.

Fig. 2 Epitaxial relationship of a Fe_3Pt thin film with $\text{Al}_2\text{O}_3(00.1)$ substrate.

Fig. 3 The proposed hcp structure of Fe_3Pt in similar to hcp Co_3Pt ³⁾.

In order to examine the effect of the substrate deposition temperature T_s on crystal structure, a systematic experiment was performed for the films deposited at the various T_s (Figure 4).

The sample fabricated at $T_s = 30^\circ\text{C}$ shows no obvious diffraction lines, implying that it is amorphous. Upon heating during the deposition, the $(00.1)_{\text{hcp}}$ line becomes appeared. The intensity of this line seems to be maximum at $T_s = 425^\circ\text{C}$. The broader diffraction lines of $\text{Al}_2\text{O}_3(00.6)$ and (00.12) observed at 300 – 550°C are due to overlap with $\text{Fe}_3\text{Pt}(00.2)$ and (00.4) lines, thus unable to estimate the degree of ordering in the present study.

In order to investigate further the structure, the so-called ϕ scan analysis by X-ray diffraction was performed for all the samples under consideration. Figure 5 shows a representative pattern of a sample made at $T_s = 550^\circ\text{C}$. The

Fig. 4 XRD spectra of the Fe_3Pt thin films at the various deposition temperatures.

X-ray was irradiated at a grazing angle 0.5° with respect to the film plane, and then was detected by a detector located at $2\theta = 71.2^\circ$ which corresponds to the Bragg diffraction condition of $(11.0)_{\text{hcp}}$ of Fe_3Pt .

Fig. 5 XRD profile (ϕ scan) of (11.0) plane of the Fe_3Pt thin film deposited onto $\text{Al}_2\text{O}_3(00.1)$ substrate at 550°C .

As seen in the figure, the six-fold pattern is clearly observed, indicating the high quality of single crystal film with the c-axis along the film normal. From the position of

20, one can estimate lattice constant a to be $2.65 \text{ \AA}$. The lattice constant a and c and the ratio c/a are plotted as a function of T_s , as shown in Fig 5(b). The lattice constants c and a are found to be $4.31 \text{ \AA} \pm 0.03 \text{ \AA}$, $2.65 \text{ \AA} \pm 0.07 \text{ \AA}$, and the ratio of c/a 1.63, all being nearly constant with T_s .

Figure 6(c) shows the saturation magnetization M_s at room temperature of Fe_3Pt thin films grown onto $\text{Al}_2\text{O}_3(00\cdot1)$ substrate. There is a trend that M_s decreases with increasing T_s , which should be compared with the bulk value of about $1,250 \text{ emu/cc}$ at room temperature⁴⁾.

Torque measurements indicate that Fe_3Pt thin films fabricated onto $\text{Al}_2\text{O}_3(00\cdot1)$ substrate exhibit very little perpendicular magnetic anisotropy. An effort has been made to determine the in-plane magnetic anisotropy. The samples with a diameter of 10 mm were made circular in shape. The samples of Fe_3Pt fabricated at T_s above 200°C exhibit the six-fold torque curves in fields up to 15kOe, whereas the ones made at $T_s=30^\circ\sim 100^\circ\text{C}$ shows very little in-plane magnetic anisotropy. A representative case of torque curves of the sample fabricated at $T_s=425^\circ\text{C}$ at the

Fig. 6 (a) Intensity of (00·1) peak (b) Lattice constant c , a and c/a (c) Magnetic anisotropy (K_{in}) and saturation magnetization (M_s) of the Fe_3Pt thin films at the various deposition temperatures.

various fields is given in Fig. 7. A significant rotational hysteresis loss is seen even at 15kOe. It is noted that a Al_2O_3 substrate did not exhibit any significant torque at all even at 15kOe as shown in Fig.8. Thus, one may conclude that the observed six-fold torque curves are from the Fe_3Pt samples examined. The 6-fold magnetic anisotropy constant (K_{in}) can be estimated from the torque data, using the relation $L_{in}(\alpha(\psi)) = 6K_{in}\sin 6\alpha(\psi)$, where L_{in} is the torque amplitude at $H=\infty$ and α is the angle between H and the easy axis in the basal plane. It is noted that the easy axis in the basal plane is found to be along $\langle 10\cdot0 \rangle$.

Figure 6(c) shows the magnetic anisotropy constant (K_{in}) at the various T_s . The maximum of K_{in} is found at nearly $T_s=425^\circ\text{C}$. It is noted that this dependence of K_{in} on T_s is very similar to that of $I_{00\cdot1}$ vs T_s as shown in Fig. 6(a).

Fig. 7 Torque curves at various fields of the Fe_3Pt sample grown onto Al_2O_3 substrate kept at 425°C .

Fig. 8 Torque curves of the Fe_3Pt thin films onto Al_2O_3 substrate and just only Al_2O_3 substrate at $H=15 \text{ kOe}$. (The easy axis (E.A.) in the basal plane is along $\langle 10\cdot0 \rangle$.)

Fig. 9 In plane 6-fold magnetic anisotropy (K_{in}) as a function of temperature for the Fe_3Pt thin film deposited onto Al_2O_3 substrate at $T_s=425^\circ\text{C}$.

Therefore, the hcp structure of Fe₃Pt alloy thin films possesses the basal plane magnetic anisotropy of the order of 10⁵erg/cc at room temperature. Figure 9 shows the temperature dependence of K_{in} of the sample made at T_s=425⁰C. The magnetic anisotropy constant K_{in} decreases with T from 2.0×10⁵erg/cc at about 80K to 1.4×10⁵erg/cc at room temperature. It is of interest to point out that this value K_{in} is much larger than that of hcp Co, which was reported to be of the order of 10² erg/cc⁵⁾.

4. Summary

For the first time, the ordered hcp structure of Fe₃Pt alloy thin films has been successfully synthesized onto Al₂O₃(00·1) substrates held at temperatures from 400~550⁰C. The films are to possess the c-axis along the film normal. The basal plane magnetic anisotropy is found to be of the six-fold symmetry, with the order of 10⁵erg/cc.

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