EFFECT OF SUBSTRATE HEATING ON PERPENDICULAR ANISOTROPY IN Co/Pt MULTILAYERED FILMS

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Abstract—Co/Pt multilayered films were prepared on heated glass slides by electron beam evaporation. It was found that perpendicular anisotropy K_1 increased with elevating substrate temperature T_s . Interface anisotropy K_s and volume anisotropy K_v were evaluated from the dependence of K_1 on bilayer period λ . In the range of T_s from 30 to 130°C, K_s increased with elevating T_s while K_v hardly depended on T_s . On the other hand, at $T_s=300^\circ\text{C}$, K_s was almost zero but K_v was positive and large, which made K_1 almost independent of λ . It was also found that substrate heating was quite effective to enhance coercive force H_{c1} . Though K_1 was hardly dependent on Pt buffer layer thickness, H_{c1} increased with thickening Pt buffer layer. There was no correlation between low angle X-ray diffraction intensity I_1 and K_s or between I_1 and K_1 . Though the dispersion of (111) orientation, $\Delta\theta_{50}$, decreased with elevating T_s , there was no clear correlation between $\Delta\theta_{50}$ and K_1 or between $\Delta\theta_{50}$ and H_{c1} . The films deposited on room temperature substrates were annealed in vacuum. With elevating annealing temperature T_a , K_s decreased while K_v slightly increased. Though $\Delta\theta_{50}$ was hardly changed by annealing, I_1 decreased with elevating T_a .

KEY WORDS: Co/Pt MULTILAYERED FILM, VACUUM EVAPORATION, SUBSTRATE HEATING, MAGNETIC ANISOTROPY, COERCIVE FORCE, ANNEALING, X-RAY DIFFRACTION

INTRODUCTION

Recent investigations have revealed that Co/Pt multilayered films have large perpendicular anisotropy [1] as well as the enhanced magneto-optical Kerr rotation at shorter wavelengths [2]. Co/Pt multilayered films are consequently regarded as one of the most promising candidates for future high-density magneto-optical recording media.

Perpendicular anisotropy in Co/Pt multilayered films has been attributed to interface anisotropy [2]. It is well known that an increase in the substrate temperature increases the surface mobility of the condensed atoms [3], which would cause the smoothing of layered structure. On the other hand, interdiffusion between adjacent layers increases with elevating substrate temperature, which would affect not only interface anisotropy but also volume anisotropy through the formation of CoPt alloy layers. Accordingly, it is quite interesting to investigate the effect of substrate heating on perpendicular anisotropy in multilayered films.

In this paper we report the effects of substrate heating, Pt buffer layer thickness and annealing in vacuum on magnetic properties of evaporated Co/Pt multilayered films.

EXPERIMENTAL

Co and Pt layers were alternately deposited by electron beam evaporation onto glass slides heated up to 300°C. The layer thickness was monitored using quartz monitors. The thickness ratio of Co layer to Pt layer is kept constant at 3:10. Though the bilayer period λ was varied from 1.3 to 6.5 nm, the total film thickness d was kept constant around 40 nm by adjusting the number of bilayers. The deposition was started from and ended with Pt layers in any film. In some films, the Pt layer deposited directly onto a substrate was thickened to 15 nm irrespective of λ in order to investigate the effect of buffer layer. The deposition rate was 0.4 nm/min for both Co and Pt layers. The pressure during deposition was 5×10^{-6} Torr.

Magnetic properties were measured using a vibrating sample magnetometer and a torque magnetometer. The effective perpendicular anisotropy constant K_1 was calculated for the total film volume except that of a 15 nm thick Pt buffer layer. Crystalline properties were investigated by X-ray diffraction (XRD). The bilayer period λ obtained by low angle XRD reasonably agreed with the designed value. The bilayer periods given below are designed ones.

Fig.1 Perpendicular anisotropy $K_{\perp}$ as a function of bilayer period λ and substrate temperature T_s .

RESULTS AND DISCUSSION

Figure 1 shows perpendicular anisotropy $K_{\perp}$ as a function of bilayer period λ and substrate temperature T_s . Without substrate heating or at $T_s=30^{\circ}\text{C}$, $K_{\perp}$ decreases with increasing λ , being negative in films with $\lambda \geq 2.6$ nm. As T_s is elevated, however, $K_{\perp}$ becomes larger. In films with $\lambda=1.3$ nm, $K_{\perp}$ reaches the maximum of 3×10^6 erg/cm³ at $T_s=130^{\circ}\text{C}$, which is three times larger than that at $T_s=30^{\circ}\text{C}$. In films prepared at lower T_s , $K_{\perp}$ decreases with increasing λ , which suggests that $K_{\perp}$ is mainly due to interface anisotropy. In films prepared at $T_s=300^{\circ}\text{C}$, however, $K_{\perp}$ never decreases with increasing λ , which suggests that $K_{\perp}$ is due to volume anisotropy rather than interface anisotropy.

Figure 2 shows the product of bilayer period λ and perpendicular anisotropy $K_{\perp}$, $\lambda K_{\perp}$, in films prepared at different substrate temperatures as a function of Co layer thickness t_{Co} . At lower T_s up to 130°C , $\lambda K_{\perp}$ decreases almost linearly with increasing t_{Co} , as reported previously[2]. The interface anisotropy K_s and volume anisotropy K_v were evaluated from the relation $\lambda K_{\perp} = K_v t_{\text{Co}} + 2K_s$. As shown in Tab.1, K_s increases with elevating T_s , which suggests that interface becomes smoother

Tab.1 Interface anisotropy K_s and volume anisotropy K_v at substrate temperature T_s .

T_s ($^{\circ}\text{C}$)	K_s (erg/cm ²)	K_v (erg/cm ³)
30	0.15	-7.1×10^6
80	0.18	-6.5×10^6
130	0.30	-8.0×10^6
300	0.01	$+6.1 \times 10^6$

Fig.2 Bilayer period λ times anisotropy $K_{\perp}$ vs Co layer thickness t_{Co} .

and sharper with elevating T_s . On the other hand, K_v hardly depends on T_s , which suggests that interdiffusion between Co and Pt layers remains insignificant in this temperature range. The similar increase in K_s with elevating T_s has been reported for Co/Pd multilayered films[4]. Though there seems no linear relation between $\lambda K_{\perp}$ and t_{Co} at $T_s=190$ and 260°C , $\lambda K_{\perp}$ increases almost linearly with increasing t_{Co} at $T_s=300^{\circ}\text{C}$. As shown in Tab.1, K_s is nearly zero, which suggests that CoPt alloy layers are formed at interfaces by interdiffusion. On the other hand, K_v is positive and as large as 6.1×10^6 erg/cm³. This volume anisotropy might be related to the perpendicular anisotropy observed in sputtered CoPt alloy films[5,6].

Figure 3 shows coercive force H_{c1} as a function of bilayer period λ and substrate temperature T_s , where H_{c1} was determined from the magnetization curve with applied field normal to the film plane.

Fig.3 Coercive force H_{c1} as a function of bilayer period λ and substrate temperature T_s .

Fig.4 Perpendicular(—) and in-plane(--) magnetization curves in films prepared at different substrate temperatures. Bilayer period is 2.0 nm.

In films prepared at $T_s \leq 190^\circ\text{C}$ H_{c1} is small, never exceeding 1 kOe. By elevating T_s to 260°C and higher, however, very high coercive force can be obtained. The highest one was 3.3 kOe in the film with $\lambda = 2.6$ nm prepared at $T_s = 300^\circ\text{C}$.

The magnetization curves of films prepared at different substrate temperatures are shown in Fig.4, where the bilayer period is constant at 2.0 nm. The solid and dashed curves are the magnetization curves with applied field normal and parallel to the film plane, respectively. The squareness S_1 , which is defined by the ratio of residual to saturation magnetization or $S_1 = M_{r1}/M_s$, increases with elevating T_s , reaching unity at $T_s = 130^\circ\text{C}$. Coercive force H_{c1} also increases with elevating T_s , reaching the maximum of 2.5 kOe at $T_s = 260^\circ\text{C}$. However, at $T_s = 300^\circ\text{C}$, both S_1 and H_{c1} decrease to values somewhat smaller than those at $T_s = 260^\circ\text{C}$.

Low angle X-ray diffraction peaks were observed in any film prepared at T_s up to 190°C . However, at $T_s = 260^\circ\text{C}$, clear diffraction peaks were observed only in films with $\lambda \geq 2.0$ nm. At $T_s = 300^\circ\text{C}$, clear diffraction peaks were not observed until λ was increased to 6.5 nm. This result suggests that layered structure becomes less sharp due to interdiffusion with elevating T_s . There was no correlation between low angle XRD intensity I_1 and K_1 or between I_1 and K_s .

It has been pointed out that films with higher (111) orientation have larger perpendicular anisotropy [7]. We also estimated the degree of (111) orientation by

Fig.5 Anisotropy K_1 vs dispersion of (111) orientation, $\Delta\theta_{50}$. T_s is shown in parentheses.

measuring rocking curves. Figure 5 shows the relation between K_1 and $\Delta\theta_{50}$, the FWHM of a rocking curve (Cu-K α radiation). Films with different bilayer periods are shown by different symbols with substrate temperatures in parentheses. It is seen that $\Delta\theta_{50}$ tends to decrease with elevating T_s . However, there is no clear correlation between K_1 and $\Delta\theta_{50}$. No correlation was found between H_{c1} and $\Delta\theta_{50}$ either. The increase in H_{c1} with elevating T_s might be caused by the growth of crystallites.

Figure 6 shows the effect of buffer layer thickness on perpendicular anisotropy K_1 and coercive force H_{c1} . The films shown by open circles have 15 nm thick buffer layers while those shown by closed circles have 1 to 2 nm thick buffer layers depending on bilayer period. It is seen that K_1 hardly depends on the thickness of a Pt buffer layer except in a few films. On the other hand, H_{c1} increases with thickening a Pt buffer layer in any film. The most remarkable increase in H_{c1} as well as in K_1 is obtained in the film with $\lambda = 1.3$ nm prepared at $T_s = 260^\circ\text{C}$. The similar effect of Pt buffer layer on K_1 and H_{c1} has been reported for sputtered Co/Pt multilayered films [8].

Low angle X-ray diffraction intensities hardly depended on buffer layer thickness. However, $\Delta\theta_{50}$ in films prepared at $T_s = 260^\circ\text{C}$ is much smaller than those at $T_s = 30$ and 130°C , as shown in Fig.5. This is due to the fact that the (111) orientation of 15 nm thick Pt layer deposited at $T_s = 260^\circ\text{C}$ is much higher than those at $T_s = 30$ and 130°C .

Fig.6 $K_{\perp}$ and H_{c1} in films with (○) and without (●) 15 nm thick Pt buffer layer as a function of λ and T_a .

We also investigated the effect of annealing on magnetic properties. Films with different bilayer periods prepared on room temperature substrates were annealed in vacuum at the pressure of 3×10^{-7} Torr. They were kept at annealing temperature T_a for two hours. Though $K_{\perp}$ decreased with elevating T_a in films with smaller bilayer periods, it hardly depended on T_a or slightly increased with elevating T_a in films with larger bilayer periods. The interface anisotropy K_s and volume anisotropy K_v were evaluated at each annealing temperature T_a and shown in Tab.2. With elevating T_a , K_s decreases while K_v slightly increases. It was found that low angle XRD diffraction became less intensive as T_a became higher. However, $\Delta\theta_{50}$ was hardly affected by annealing. We also found that H_{c1} decreased with elevating T_a in films with $\lambda=1.3$ nm. This might result from the decrease in $K_{\perp}$ with elevating T_a .

CONCLUSIONS

We prepared Co/Pt multilayered films on heated glass slides by electron beam evaporation. Perpendicular anisotropy $K_{\perp}$ increased with elevating substrate temperature T_s . In the range of T_s from 30 to 130°C, interface anisotropy K_s increased with elevating T_s while volume anisotropy K_v hardly depended on T_s . On the other hand, at $T_s=300^\circ\text{C}$, K_s was almost zero but K_v was positive and large.

We found that substrate heating was quite effective to enhance coercive force H_{c1} . Further increase in H_{c1} was obtained by thickening Pt buffer layer.

The low angle XRD intensity I_1 and dispersion of (111) orientation, $\Delta\theta_{50}$, also

Tab.2 Interface anisotropy K_s and volume anisotropy K_v in films annealed at T_a .

T_a ($^\circ\text{C}$)	K_s (erg/cm 2)	K_v (erg/cm 3)
30*	0.15*	-7.1×10^6 *
80	0.12	-6.1×10^6
130	0.12	-6.0×10^6
190	0.10	-5.4×10^6
260	0.08	-5.4×10^6
300	0.08	-5.3×10^6

* As deposited.

depended on T_s . However, there was no clear correlation between I_1 and $K_{\perp}$ or between $\Delta\theta_{50}$ and $K_{\perp}$. No correlation was found between $\Delta\theta_{50}$ and H_{c1} either.

Annealing the films prepared on room temperature substrates in vacuum, we found that K_s decreased while K_v slightly increased with elevating annealing temperature T_a . Though $\Delta\theta_{50}$ was hardly affected by annealing, I_1 decreased with elevating T_a .

Further investigations, especially those on microstructures of films, are required to elucidate why $K_{\perp}$ and H_{c1} are enhanced by substrate heating.

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