Curie temperature dependence of magnetic properties of CoNi/Pt multilayer films

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Abstract

The Curie temperature of $\text{Co}_{1-x}\text{Ni}_x/\text{Pt}$ multilayer films ($x = 0.5$ and 0.6) has been studied as a function of CoNi and Pt layer thicknesses. Magnetic properties at room temperature are dominated by the Curie temperature. Interlayer coupling and interdiffusion are discussed as possible contributions to the thickness dependence of the Curie temperature and magnetic properties.

In order to increase the data rate and the number of write/erase cycles in magneto-optical (MO) recording, the thermomagnetic switching temperature, which depends on the Curie temperature T_c of the recording media, should be as low as possible. T_c of Co/Pt multilayer films can be reduced by adding Ni to Co to form CoNi/Pt multilayer films which are suitable for lower power recording (high write sensitivity) and high write/erase cyclability [1]. Since the T_c of CoNi/Pt multilayers is closer to room temperature (RT), the magnetic quality at room temperature is influenced by T_c . Therefore, the effect of T_c on the magnetic properties of CoNi/Pt multilayers has been studied as a function of CoNi and Pt layer thicknesses.

$\text{Co}_{1-x}\text{Ni}_x/\text{Pt}$ multilayers ($x = 0.5$ and 0.6) were prepared on Si substrates by magnetron sputtering at an Ar pressure of 1.6×10^{-2} mbar. The base pressure was lower than 5×10^{-8} mbar. A multilayer composition was designed as [Si-substrate/Pt-seedlayer/($\text{Co}_{1-x}\text{Ni}_x/\text{Pt}$) $\times n$]. The individual layer thicknesses t_{CoNi} and t_{Pt} were estimated from the product of the deposition time and deposition rate and confirmed by low and high angle XRD measurements. Saturation magnetisation and perpendicular coercivity H_c were obtained from perpendicular VSM loops. Two parameters of the saturation magnetisation, M_s (per unit CoNi volume) and m_s (per unit CoNi/Pt volume), are used in this discussion. Saturation polar Kerr rotation angles $\theta_{K,310}$ and $\theta_{K,630}$ (i.e. $\lambda = 310$ nm and 630 nm) were obtained from measured Kerr spectra. Most of the measured Kerr spectra from the CoNi/Pt multilayers

showed the maximum Kerr rotation angle to be around $\lambda = 310$ nm [2]. Effective magnetic anisotropy energy K_{eff} (per unit CoNi volume) was measured by a torque magnetometer and T_c was measured with a temperature scan of the saturation Kerr rotation at a certain light wavelength.

Low and high angle XRD measurements demonstrated a well defined periodic compositional modulation with an fcc $\langle 111 \rangle$ texture along the growth direction. Cross-sectional TEM images have revealed a pronounced columnar growth mechanism as well as the multilayered structure.

Fig. 1 shows t_{CoNi} dependence of T_c , M_s , m_s , $\theta_{K,310}$ and $\theta_{K,630}$ for a series of $\text{Co}_{0.5}\text{Ni}_{0.5}/\text{Pt}$ multilayers with composition of $[23 \text{ nm Pt}/(t_{\text{CoNi}}/14.7 \text{ \AA Pt}) \times 17]$. T_c (indicated by dots), m_s and $\theta_{K,630}$ increase with increasing t_{CoNi} . M_s and $\theta_{K,310}$ increase rapidly with increasing t_{CoNi} from 3.3 Å to 6.3 Å and then become saturated when $t_{\text{CoNi}} \geq 6.3$ Å. Fig. 2 shows the t_{CoNi} dependence of K_{eff} and H_c . H_c follows the same trend as K_{eff} . K_{eff} increases

Fig. 1. CoNi layer thickness dependence of T_c , M_s , m_s and θ_K for $\text{Co}_{0.5}\text{Ni}_{0.5}/\text{Pt}$ multilayers of 23 nm Pt/($t_{\text{CoNi}}/14.7 \text{ \AA Pt}$) $\times 17$.

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Fig. 2. CoNi layer thickness dependence of K_{eff} and H_c for $\text{Co}_{0.5}\text{Ni}_{0.5}/\text{Pt}$ multilayers as indicated in Fig. 1.

with decreasing t_{CoNi} from 37.5 Å to 6.3 Å and then rapidly decreases with decreasing t_{CoNi} from 6.3 Å to 3.3 Å. The increase would be expected as a result of the interface magnetic anisotropy [3] and the decrease can be explained with respect to the misfit interface strain anisotropy as proposed by Bloemen et al. [4]. However, the decrease in T_c may also result in the decrease of M_s , θ_K and K_{eff} when $t_{\text{CoNi}} < 6.3$ Å. Because T_c is closer to RT, the magnitude of the magnetic properties will be lower at RT. When T_c is lower than RT, the magnitude of properties will be zero at RT although the CoNi layer has not been zero. This can be revealed by extrapolating the curves in Figs. 1 and 2 to cross the X-axis. However, when the samples with lower T_c are measured at low temperature, their magnetic properties will be enlarged. For instance, CoNi/Pt multilayer with the thinnest CoNi layers (3.3 Å) demonstrated enhanced perpendicular anisotropy and enlarged H_c and M_s when it was measured at low temperature by a VSM [2]. Those enhancements at low temperature have also been observed in Ni/Pt multilayers when their T_c are lower than RT [2]. In this case almost no magnetic properties can be measured at RT.

Fig. 3 shows the t_{Pt} dependence of T_c , M_s , m_s , $\theta_{K,310}$ and $\theta_{K,630}$ for a series of $\text{Co}_{0.4}\text{Ni}_{0.6}/\text{Pt}$ multilayers with

Fig. 3. Pt layer thickness dependence of T_c , M_s , m_s and θ_K for $\text{Co}_{0.4}\text{Ni}_{0.6}/\text{Pt}$ multilayers of $23 \text{ nm Pt}/(5.5 \text{ Å Co}_{0.4}\text{Ni}_{0.6}/t_{\text{Pt}}) \times 20$.

Fig. 4. Pt layer thickness dependence of K_{eff} and H_c for $\text{Co}_{0.4}\text{Ni}_{0.6}/\text{Pt}$ multilayers as indicated in Fig. 3.

composition of $[23 \text{ nm Pt}/(5.5 \text{ Å Co}_{0.4}\text{Ni}_{0.6}/t_{\text{Pt}}) \times 20]$. T_c (indicated by dots), M_s , m_s , $\theta_{K,310}$ and $\theta_{K,630}$ increase with decreasing t_{Pt} from 29 Å to 2.9 Å. Fig. 4 shows the t_{Pt} dependence of K_{eff} and H_c . H_c follows the trend of K_{eff} as in the case of t_{CoNi} dependence. K_{eff} increases with decreasing t_{Pt} from 29 Å to 8.7 Å. It seems to be attributed to the increase in T_c similar to the effects as discussed in the case of t_{CoNi} dependence. This implies that an effective perpendicular anisotropy can be obtained at RT in ultrathin CoNi/Pt and Ni/Pt multilayers by reducing the Pt layer thickness. For instance, a CoNi/Pt multilayer with a composition of $[10 \text{ nm Pt}/(2.5 \text{ Å CoNi}/2.5 \text{ Å Pt}) \times 20]$ and a Ni/Pt multilayer with $[45 \text{ nm Pt}/(5 \text{ Å Ni}/5 \text{ Å Pt}) \times 60]$ exhibited $K_{\text{eff}} > 0$ at RT [2]. However, K_{eff} decreases with decreasing t_{Pt} from 8.7 Å to 2.9 Å although T_c increases. This can be explained by taking into account interdiffusion at interfaces [3]. Interdiffusion may cause a solid solution of CoNi and Pt and degrade the interface. This effect might contribute to the reduction of K_{eff} in Figs. 2 and 4 as well as reduction of M_s in Fig. 1. Interdiffusion effects have been proposed as a main contribution to the thickness dependence of T_c in Co/Pt multilayers [5–7]. To explain the increases of T_c and M_s in Fig. 3, it must be assumed that less Pt is present in the solution of Co–Ni–Pt at the interfaces [5]. On the contrary, less Co–Ni must be present to explain the decreases in T_c and M_s in Fig. 1 [6]. This implies that the solution or interdiffusion occurs at interfaces within a thick regime, e.g. four monolayers [5] and hence depends on the individual layer thickness when it is thinner than four monolayers. On the other hand, to explain the thickness dependence of T_c and M_s in the present CoNi/Pt system, the effect of interlayer coupling between CoNi layers seems to be more reasonable. In principle, when the t_{CoNi} thickness decreases, coupling between CoNi layers will be reduced, which causes the decrease in T_c and M_s as shown in Fig. 1. When the Pt layer thickness decreases, interlayer coupling between CoNi layers across Pt layers will be enhanced, which causes the increases in T_c and M_s as shown in Fig. 3. However, in Fig. 1 the M_s does change

slightly when $t_{\text{CoNi}} > 6.3 \text{ \AA}$. This reflects that the interlayer coupling effects on T_c and M_s are different. In Fig. 4, the decrease in K_{eff} when $t_{\text{Pt}} < 7.8 \text{ \AA}$ seems not to relate with the enhanced interlayer coupling. Nevertheless, there is some kind of relation between interdiffusion and interlayer coupling. Further studies on those effects are required.

In addition, the diffusion occurring at interfaces and column boundaries strongly contributes to the mechanism of H_c as has been observed in annealed CoNi/Pt multilayers [2]. It could be the reason why the maximum of H_c in Fig. 4 is larger than that in Fig. 2 although the correlated K_{eff} in Fig. 4 is smaller than that in Fig. 2 and their T_c and m_s are almost same. It implies that H_c has its own mechanism with respect to the microstructure besides the dependence on the magnetic anisotropy. Moreover, it is worth noting that the larger $\theta_{K,310}$ compared with $\theta_{K,630}$ (Figs. 1 and 3) reveals existence of the spin polarised Pt in CoNi/Pt multilayers as has been observed in CoPt and CoPd alloys [8]. The difference between $\theta_{K,310}$ and $\theta_{K,630}$ demonstrates some kind of relation with the origin of the perpendicular magnetic anisotropy as proposed by Weller et al. in CoPt and CoPd alloys [8].

In conclusion, T_c of CoNi/Pt multilayers decreases with decreasing t_{CoNi} but increases with decreasing t_{Pt} . Magnetic properties at room temperature are dominated by T_c as a function of CoNi and Pt layer thicknesses. This

effect of T_c is evidenced by the low temperature measurements. Interlayer coupling contributes to the dependence of T_c on CoNi and Pt layer thicknesses. The reduction of M_s and K_{eff} when $t_{\text{CoNi}} < 6.3 \text{ \AA}$ is attributed to the lower T_c . However, this lower T_c could be caused by the interdiffusion besides the reduced interlayer coupling and the interdiffusion could also cause the reduction of M_s and K_{eff} besides the lower T_c . The reduction of K_{eff} when $t_{\text{Pt}} < 8.7 \text{ \AA}$ is mainly because of the interdiffusion.

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