Annealing effects on magneto-optical Kerr effect and magnetic anisotropy in ultrathin Co films on Pt(1 1 1)

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Abstract

Large change in magneto-optical Kerr response and increase in perpendicular anisotropy were observed in ultrathin Co films on Pt(1 1 1) upon thermal annealing at elevated temperatures. Monitoring the film structure by using low-energy electron diffraction and Auger electron spectroscopy, these findings were found to be correlated to the Co–Pt alloy formation at interface. © 2000 Elsevier Science B.V. All rights reserved.

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Co–Pt-based alloy thin films and multilayers have attracted considerable interest due to their promising application in technology of magneto-optical recording media [1,2]. As compared to Co–Pt multilayer and alloy systems, there are, up to now, only few studies of Co/Pt films in ultrathin scale probably because of their limitation of a direct application. Nevertheless, studying the ultrathin film system could provide the basic and detailed information on the epitaxial process, growth modes, and interface or surface diffusion. In particular, the behavior of the surface or interface alloying may be completely different from those in the bulk. The information obtained in the ultrathin limit study may thus be of much use for further fabricating the Co–Pt multilayer and alloy thin film systems. In this contribution, we report the alloy formation at interface upon thermal annealing for Co/Pt(1 1 1) ultrathin films, and focus on their enormous influence on the perpendicular magnetic anisotropy and magneto-optical Kerr effect.

The experiments were carried out in an UHV-chamber with base pressure in the range 5×10^{-10} mbar. The pressure during Co deposition was kept at about 1×10^{-9} mbar at an evaporation rate of about 0.1 ML/min. All

Co films investigated were grown at 325 K and then annealed at different temperatures up to 850 K. The crystalline structure and composition of the film surface were checked by low-energy electron diffraction (LEED) and Auger electron spectroscopy (AES), respectively. Magnetic properties were monitored by magneto-optical Kerr effect (MOKE) using a p-polarized He–Ne laser (632.8 nm) as the light source.

Fig. 1 shows the results of measurements of both polar Kerr signal and $\text{Co}_{775 \text{ eV}}/\text{Pt}_{237 \text{ eV}}$ Auger signal ratio taken at 325 K of the 1.0 ML film annealed at 600 K for different annealing times. AES is used here to monitor the depth of diffusion of adsorbate as well as the surface composition during thermal annealing. The $\text{Co}_{775 \text{ eV}}/\text{Pt}_{237 \text{ eV}}$ Auger signal ratio shown in Fig. 1 drops drastically at the beginning and reaches a minimal value (not zero) after an annealing time above 15 min. As the Auger signal ratio decreases rapidly with increasing time, the polar Kerr remanence signal increases drastically. Corresponding to the stabilization of Auger signal ratio, the polar Kerr remanence signal also reaches a saturated value about 260% of that before annealing. The stabilized Auger signal ratio indicates a constant chemical composition and the formation of a metastable phase at interface, as identified more clearly as interface Co–Pt alloy later.

Not only the magneto-optical Kerr response but also the perpendicular magnetic anisotropy is enhanced after

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Fig. 1. The polar Kerr remanence signal (square) and the $\text{Co}_{775\text{ eV}}/\text{Pt}_{237\text{ eV}}$ Auger signal ratio (triangles) of the 1.0 ML Co/Pt(1 1 1) film annealed at 600 K for different times. Both MOKE and AES data were taken at 325 K.

Fig. 2. Compilation of both polar and longitudinal Kerr hysteresis loops for the 6.6 ML Co/Pt(1 1 1) annealed at 850 K for different times. The measurement temperature is 325 K.

thermal annealing. Fig. 2 shows the Kerr hysteresis loops for the 6.6 ML annealed at 850 K for different times. The 6.6 ML as-grown film has an in-plane magnetization with only tiny perpendicular Kerr signal. After 3 min of annealing at 850 K of the film, the perpendicular Kerr signal increases drastically, while the in-plane hysteresis loop becomes more round as compared to that before annealing, indicating clearly an increase in magnetic perpendicular anisotropy. After 6 min of annealing, both the perpendicular and in-plane Kerr signals become smaller. Since the diffusion mobility at this elevated temperature seems already too high to stabilize a Co–Pt alloy state at the interface, the Co atoms diffuse deeply into the substrate further. This indicates that the annealing temperature is a sensitive parameter for the interdiffusion process for forming interface alloy.

Fig. 3 combines the results of the Kerr remanence signal measured at 325 K for the 1.0 ML films annealed

Fig. 3. Combination of magneto-optical Kerr remanence signal (squares and circles for the polar and longitudinal geometry, respectively), the $\text{Co}_{775\text{ eV}}/\text{Pt}_{237\text{ eV}}$ Auger signal ratio (triangles), and the schematic LEED patterns for the 1.0 ML Co/Pt(1 1 1) annealed at different temperatures for 5 min. The measurement temperature is 325 K.

at different temperatures for 5 min, the $\text{Co}_{775\text{ eV}}/\text{Pt}_{237\text{ eV}}$ Auger signal ratio, and the schematic LEED pattern. An onset of enhancement of the polar Kerr signal is observed at about the annealing temperature of 475 K. The polar Kerr signal is enhanced drastically when the film is annealed above 500 K, and at about 700 K annealing temperature it reaches a maximal value about 300% of that before annealing. Accompanying the large enhancement of Kerr signal, a rapid drop of the Co/Pt Auger signal ratio is observed, indicating a strong Co–Pt interdiffusion at the interface. The LEED patterns in the upper-panel of Fig. 3 reveal two different characteristic structures. The first one for the films with the annealing temperature range up to about 550 K reveals an incommensurate mode, including a p(1x1) structure based on symmetry fitted to the Pt(1 1 1) substrate and a six-fold superstructure around each integer spot. This is attributed to an incoherent epitaxy of the Co film on the Pt(1 1 1) surface [3]. For annealing temperatures above 550 K, the LEED patterns become fuzzy and have a p(1x1) structure with similar value of the lattice constant as the Pt(1 1 1) substrate. Together with the finding of the rapid drops of the Co/Pt Auger signal ratio, this structural evolution observed in LEED patterns provides the strong evidence of the Co–Pt alloy formation, which can be stabilized even for a long annealing time below a certain annealing temperature, as mentioned above.

On increasing the annealing temperature further up to 850 K, both the polar and longitudinal Kerr remanence signals vanish completely, indicating disappearance of the ferromagnetic ordering or magnetization. (Note that the longitudinal Kerr remanence signal is zero for all

annealing temperatures for the 1.0 ML film.) The annealing temperature 850 K is obviously too high for forming a metastable alloy phase, and the Co atoms diffuse deeply and completely into the Pt(1 1 1) substrate, losing the ferromagnetic ordering.

The correlation of the alloy formation at the interface and the enhancement of the magneto-optical Kerr effect and increase in magnetic perpendicular anisotropy may be mainly traced back to the transfer of the strong spin-orbit coupling of the Pt into the magnetic Co orbital due to the hybridized electronic structure, as suggested in the theoretical study for the Co–Pt ultrathin multilayer system [4]. The contribution of the enhanced Co magnetic moment is, however, only of minor importance. The 300% maximal value of the enhanced magneto-optical Kerr signal after thermal annealing is an amazing factor as compared to the previous study for the Co/Pt multilayer and Co–Pt alloy systems [5], in which an overall 50% enhancement of magneto-optical response is found. The significant enhancement of the magneto-optical Kerr signal in our case may be due to a special hybridization state between the Co and Pt through the thermal annealing, which is different from the expected structure in the Co–Pt alloy and multilayer systems as usual. This suggests that thermal annealing could be an effective postdeposition processing to optimize the magneto-optical properties and magnetic anisotropy, and may become technologically relevant.

In conclusion, thermal annealing of Co/Pt(1 1 1) ultrathin films at appropriate temperatures results in a kind of Co–Pt alloy formation at the interface, which in turn, gives rise to a large enhancement of magneto-optical Kerr response up to about 300% and increase in perpendicular magnetic anisotropy. The highly enhanced magneto-optical response is believed to be mainly attributed to the transfer of the strong spin-orbit coupling of the Pt into the Co caused by the hybridized electronic state at the alloying interface.

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