Magnetic and magneto-optical properties of Pd/Cr/Co multilayers

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Recent studies found that the (Pt/Co/Pt) trilayers can be used as a unit in combination with nonmagnetic or magnetic layer, X (X=Pd, Ag, Cu, and Ni), to enhance the perpendicular magnetic anisotropy of the films, reduce the Curie temperature, and alter the magneto-optical properties. The effects of intercalating Cr into Pd/Co multilayers on the magnetic and magneto-optical properties are studied in this article. The perpendicular magnetic anisotropy K_u and the coercivity H_c of the system decrease rapidly with increasing the Cr thickness (X_{Cr}) up to 0.4 nm, and change slightly when Cr thickness further increases. The dependence of the coercivity H_c on the Cr thickness, which obeys the law: $H_c\ (X_{Cr}) = X_{Cr}^{-2.66}$, indicates that the magnetization reversal is controlled by domain wall moving, mainly due to the interface roughness. Large decrease of the Kerr rotation θ_k of the Pd/Cr/Co multilayers compared with pure Pd/Co multilayers is also found in the wavelength ranging from 200 to 800 nm. As it is well known, the large anisotropy and Kerr rotation in Pd/Co system are mainly caused by the polarization of Pd atoms due to nearby Co atoms. As the intercalating of Cr layer between Pd and Co layer, the average polarization of Pd atoms will be reduced largely. As a matter of fact, the Cr atoms can also be polarized by nearby Co atoms, which, however, seems to take a minor effect on the anisotropy and Kerr rotation of the system. [DOI: 10.1063/1.1357149]

I. INTRODUCTION

Co/Pt and Co/Pd multilayers (MLs) have attracted much attention for their potential application as high-density reversible magneto-optical (MO) recording media due to their perpendicular magnetic anisotropy (PMA), high coercivity, square hysteresis loops, and large Kerr rotations.[1–8]

G. A. Bertero[9] has suggested recently that the (Pt/Co/Pt) trilayers can be used as a unit in combination with nonmagnetic layer, X (X=Pd, Ag, Cu, and Ni), to enhance the perpendicular magnetic anisotropy of the films. Furthermore, it is also found that the Curie temperature of (Pt/Co/Pt)Ni film was largely reduced, and the Kerr rotation was enhanced at lower wavelengths, compared with pure Pt/Co film.[10]

On the other hand, it was also found[11] in Co_xCr_{1-x}/Pt films that the non- or weak-ferromagnetic Cr-rich phases formed at the grain boundaries may reduce the exchange coupling between the grains, which leads to the reducing of the noise when used as perpendicular magnetic recording media.

In this article, we have investigated the effects of intercalating Cr into the Co/Pd multilayers on the magnetic and magneto-optical properties. We found that the perpendicular magnetic anisotropy K_u, the coercivity H_c, and the Kerr rotation θ_k of the system decrease rapidly with increasing the Cr thickness (X_{Cr}) up to 0.4 nm.

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II. EXPERIMENT

Glass/Pd (40 nm)/(Co/Cr)(X_{Cr})/(Pd) modulated multilayers were deposited on water-cooled glass substrates by magnetron sputtering. The background vacuum was better than 5×10^{-5} Pa and the Ar gas pressure was 0.5 Pa. All samples were grown on a 40 nm thick Pd buffer layer, with the thickness of Co and Pt layers fixed at 0.33 and 0.8 nm, respectively. The Cr layer thickness X_{Cr} was varied from 0 to 0.66 nm. The number of the modulation period of all samples is 20. The modulation character and interface structures of the samples were analyzed by small- and large-angle x-ray diffraction (XRD) method. The magnetic properties were characterized using an alternating gradient force magnetometer with the applied magnetic field perpendicular to the film plane. The perpendicular anisotropy constant K_u was determined from torque curves measured at an applied field of 10 kOe at room temperature. MO characterization was carried out using a variable wavelength Kerr rotation system with the wavelength ranging from 200 to 800 nm.

III. RESULTS AND DISCUSSION

Small- and large-angle XRD measurements were performed for samples with the structure Glass/Pd (40 nm)/(Co/Cr(X_{Cr})/Pd) (X_{Cr}=0–0.66 nm), which were presented in Fig. 1. From the small-angle XRD spectra, one can clearly see a strong first-order ($n=1$) peak for almost all the samples, confirming the layered structure in the film. With the increasing of the Cr layer thickness, the first-order peak shifts gradually to low angle, attributed to the increasing of the modulation period length.

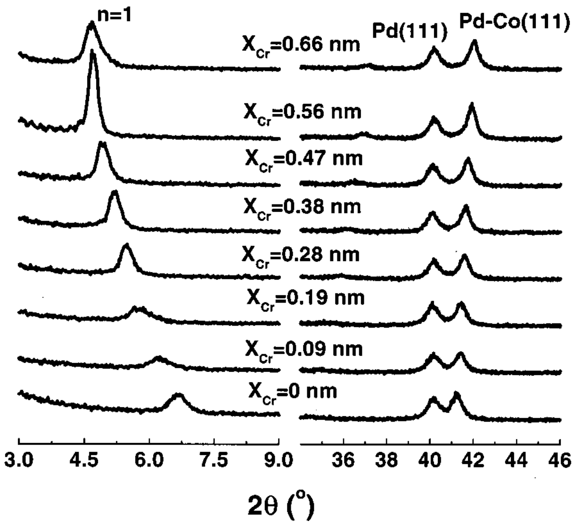

FIG. 1. Small- and large-angle XRD pattern of Glass/Pd(40 nm)/(Co/Cr(X_{Cr})/Pd) multilayers with the Cr layer thickness X_{Cr} varying from 0 to 0.66 nm.

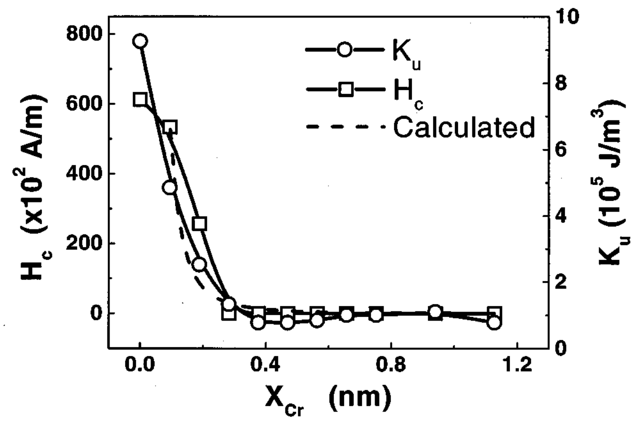

FIG. 2. Cr layer thickness X_{Cr} dependence of the PMA constant K_u *and* the coercivity H_c of Glass/Pd(40 nm)/(Co/Cr(X_{Cr})/Pd) multilayers. The calculated results with the equation: $H_c = X_{Cr}^{-2.66}$ is also presented in Fig. 2 as dashed line.

All the samples exhibit a Pd(111) peak due to Pd buffer layer. In previous studies, the face-centered-cubic (fcc) (111) texture structure is generally found in CoPt alloy films and Co/Pt MLs, which is necessary for PMA. The Pd–Co (111) peak in Pd/Co MLs could mainly come from the Pd/Co superlattice character if one supposes a sharp interface between the well-matched Pd and Co lattice. The position of the Pd–Co (111) peak is between fcc Pd (111) and fcc/Co (111) reflections. One can also find two high-angle satellite peaks with the increasing of Cr thickness, which is also a clear evidence for a modulated periodic structure.

The PMA constant K_u can be obtained by torque measurement. According to Torque measurement, if the applied field is large enough, one obtains

$$T = VK_{u\mathrm{eff}} \sin 2\phi, \tag{1}$$

where T is the torque experienced by the sample under the applied field, V is the volume of the magnetic layer, and ϕ is the angle between the magnetization and the normal direction of the film; $K_{u\mathrm{eff}}$ is the effective PMA constant, and

$$K_{u\mathrm{eff}} = K_\nu - 2\pi M_s^2, \tag{2}$$

where K_u is the PMA constant and M_s is the saturation magnetization. $K_{u\mathrm{eff}}$ value can be obtained through the torque curve by: $K_{u\mathrm{eff}} = T_{\mathrm{peak}}/V$, where T_{peak} is the peak value of T on the torque curve.

In Fig. 2, the PMA constants K_u are plotted against the Cr layer thickness for all samples. For pure Pd/Co multilayers, K_u is about 9.25×10^5 J/m^3. K_u drops quickly with increasing Cr thickness. When the Cr thickness is larger than 0.4 nm, K_u changes slightly.

The origin of the perpendicular anisotropy in Co/Pt multilayers has been attributed to a lack of cancellation of orbital moment due to the symmetry breaking presence of interfaces.[12] Based on this idea, G. A. Bertero and coworkers suggested that additional magnetic anisotropy can be introduce in multilayers by introducing extra structure and/or chemical anisotropy at the interfaces.[9] Thus, extra X (X = Pd, Ag, Cu, and Ni layer) monolayers adjacent to the Co layers are introduced at the interfaces where the crystal symmetry is broken, resulting in extra spin–orbit coupling which leads to extra magnetic anisotropy. However, with increasing the spacer thickness, the population of the polarized Pd atoms adjacent to Co atoms will also decrease, which may result in the decrease of the spin–orbit coupling, leading to the drop of the perpendicular magnetic anisotropy. This could be clearly seen from Fig. 2. As the Cr thickness increases, the perpendicular magnetic anisotropy constant K_u drops quickly. As a matter of fact, Cr atoms can also be polarized by adjacent Co atoms. However, this polarization effect is much smaller than that of Pd atoms, which is evident from our study.

The coercivity H_c dependence on the Cr thickness of the samples is also presented in Fig. 2. The interface roughness takes an important role in determining the coercivity of multilayers. P. Bruno[13] found that $H_c \propto X^{-2.5}$, where X is the

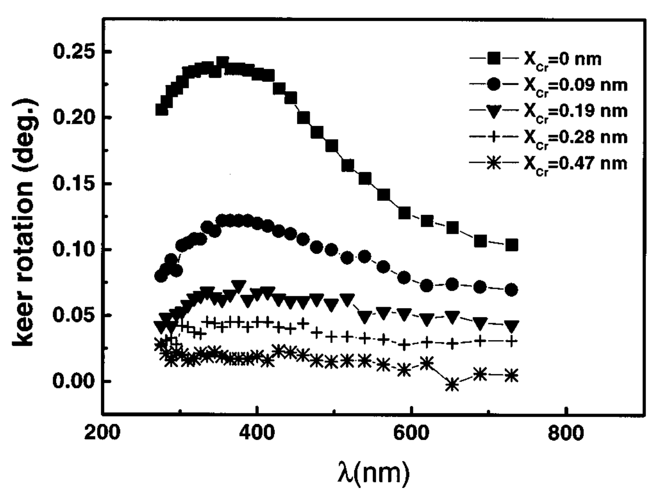

FIG. 3. Spectral dependence of the Kerr rotation θ_k of Glass/Pd(40 nm)/(Co/Cr(X_{Cr})/Pd) multilayers.

spacer thickness in Pd/Co/Pd trilayer. He suggested that the magnetization process is mainly controlled by the domain wall movement, where the main obstacle comes from the interface roughness. The relationship between coercivity and the spacer thickness was also found later by S. T. Purcell and co-workers in Pd/Co/Pd trilayer.[14] In our study, we found that $H_c \propto X_{\mathrm{Cr}}^{-2.66}$, which is almost the same as previous results. The simulated curve calculated with this equation is also presented in Fig. 2. As one can find through our XRD analysis, with increasing the Cr thickness, the intensity of the peaks at small-angle XRD patterns is getting larger and the satellite peaks at large-angle XRD patterns appear more clearly, indicating an increasing quality of the layered structure and the reducing of the interface roughness of the multilayers. Since the domain wall could move more easily when the interface is sharper, the coercivity will drop quickly, which could be seen in Fig. 2.

The MO properties are presented in Fig. 3. The enhancement of Kerr rotation θ_k at lower wavelengths was observed and similar to that of Pd/Co multilayers, which is due to the hybridization of strongly spin-polarized Co/d states with spin–orbit-splitted Pd d states.[15] It has also been pointed out[3] that the chemical and structural ordering, especially at the interfaces, accompanied by the substantial electronic structure changes can also modify the MO Kerr spectra drastically.

In (Pt/Co/Pt/Ni) multilayers,[16] an increase of the Kerr rotation with increasing Ni layer thickness was generally found. In our study, however, an overall decrease of the Kerr rotation θ_k with increasing Cr thickness in all the measured wavelength range was found. The common microscopic origin of both the Kerr rotation θ_k and PMA K_u is spin–orbit coupling. A functional relationship between K_u and Kerr rotation θ_k arising from the exchange polarized Pt and Pd was also established.[3] As discussed above, the intercalating of Cr layer in Co/Pd multilayers could reduce the average polarization of Pd atoms and spin–orbit coupling, leading to the decrease of Kerr rotation. Both Kerr rotation θ_k and PMA constant K_u drop more quickly with increasing Cr thickness in our samples as compared to those of (Pt/Co/Pt/Ni) multilayers, which might be due to the nonmagnetic character of Cr atom.

IV. CONCLUSIONS

We found that the PMA K_u, the coercivity H_c, and the Kerr rotation θ_k of the system decrease rapidly with increasing the intercalated Cr thickness (X_{Cr}) in Co/Cr(X_{Cr}) Pd multilayers. This is ascribed to the reducing of the the average polarization of Pd atoms with the intercalating of Cr between Pd and Co layer.

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