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Temperature-dependent interface magnetism and magnetization reversal in Co/Pt multilayers

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We report on the temperature dependence of the magnetic properties and interface magnetism of Co/Pt multilayers. The magnetic properties including magnetization and anisotropy change substantially as the temperature varies from 300 to 10 K for samples with Co layer thickness in the range from 3 to 7 Å. The interface anisotropy of about 0.38 erg/cm^2 is nearly independent of temperature. The magnetization reversal is dominated by domain wall motion for the thinner Co layers and dominated by nucleation for the thicker Co layers.

INTRODUCTION

Co/Pt multilayers have attracted much attention as possible magneto-optical recording media because of their large perpendicular anisotropy, large Kerr rotation at short wavelength, and high corrosion resistance.[1–5] However, aside from the study of magnetization by Bloemen *et al.*,[6] very little work on the temperature dependence of the magnetic properties of this system has been presented. Recently, we have studied these properties and the magnetization reversal of Co/Pt, Co/Au, and Co/Pd multilayers. In this paper we report our studies on Co/Pt, and the results for Co/Au and Co/Pd will be published elsewhere.

EXPERIMENT

Co/Pt multilayers of the form X ÅCo/15 ÅPt (X=3, 4, 5, 7, 9, 12, 15, and 20) were fabricated by sputtering on Si(111) substrates with a 200 ÅPt buffer layer. The sputtering rate and power for Co (DC gun) were ~0.6 Å/s and 20 W and for Pt (RF gun) were 1.1 Å/s and 40 W, respectively. The vacuum prior to sputtering was 1×10^{-7} Torr and the Ar pressure during sputtering was 5×10^{-3} Torr. All eight samples were prepared in one vacuum run to ensure the same preparation conditions.

Measurements of the hysteresis loops were carried out using an alternating gradient magnetometer (AGM) and SQUID from 300 to 10 K. The measured magnetic anisotropy was determined from the area between the perpendicular and parallel (in-plane) magnetization curves. The time decay of Kerr rotation was measured on the apparatus described in Ref. 7. Structural properties were analyzed with both small and large angle x-ray diffraction.

STRUCTURE

A small angle x-ray diffraction scan [see Fig. 1(a)] showed that the peaks corresponding to the multilayer structure appeared at the right positions and up to the fourth superlattice peak was observed for the thinnest Co layer sample (X=3 Å). Therefore all samples have distinct interfaces. Large angle x-ray diffraction [see Fig. 1(b)] showed a pronounced FCC (111) texture, with the main peak falling between the pure FCC Co(111) and Pt(111).

MAGNETIC PROPERTIES

Both perpendicular ($\mathbf{H}_\perp$ film plane) and parallel ($\mathbf{H}_\parallel$ film plane) hysteresis loops were measured from 300 to 10 K for all samples. The temperature dependences of magnetization, anisotropy, and polarization of Pt atoms are summarized as follows.

A. Temperature dependences of magnetizations

The temperature (or Co layer-thickness) dependences of saturation magnetization for X=3, 4, 5, 7, 12, and 20 Å (or T=10, 100, 200, and 300 K) are illustrated in Fig. 2(a) [or Fig. 2(b)]. The magnetization here is defined as the ratio of the measured moment to the Co mass, assuming that all the moment is from Co atoms. It is seen that (1) The samples with thinner Co layers show the stronger temperature dependence. As the temperature varies from 300 to 10 K, the saturation magnetization increases by 30, 20, 13, 6.7, and ~2.4% for X=2, 4, 5, 7, and 12 Å, respectively. We notice that the X=12 and 20 Å samples have essentially the same magneti-

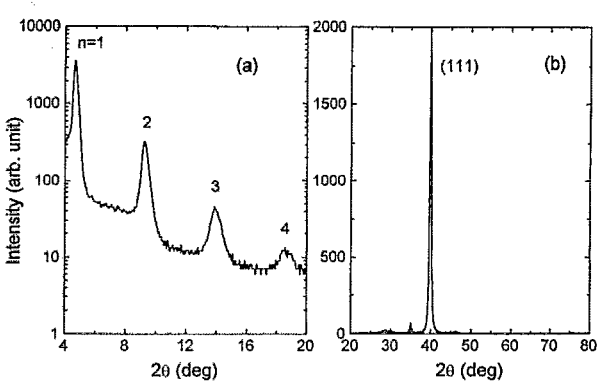

FIG. 1. CoK_α (a) small-angle and (b) large-angle diffraction intensity for 3 ÅCo/15 ÅPt as a function of 2θ.

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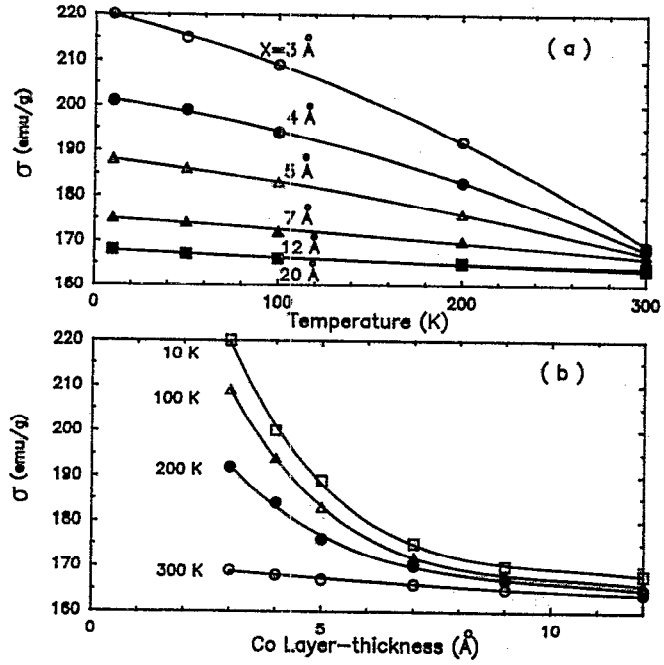

FIG. 2. Temperature dependence of Co saturation magnetization for (a) different Co layer-thickness and (b) layer-thickness dependence of Co saturation magnetization at different temperatures.

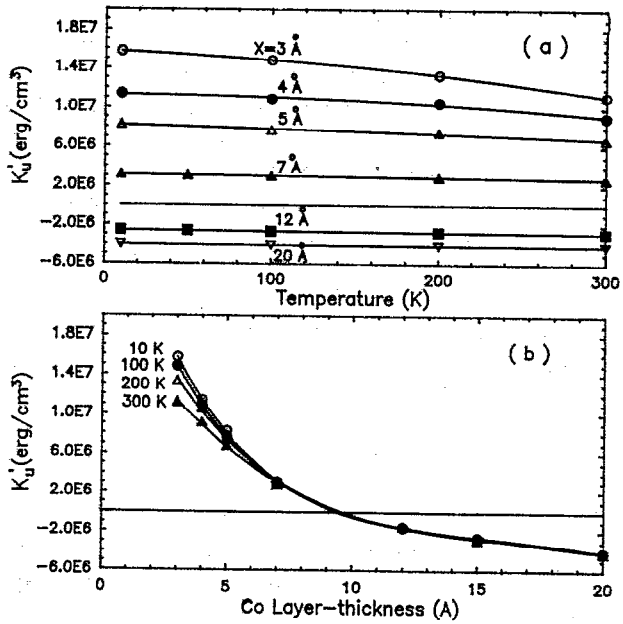

FIG. 3. Temperature dependence of measured anisotropy for (a) different Co layer thickness and (b) layer-thickness dependence of measured anisotropy at different temperatures.

zations. (2) The Co layer-thickness dependence of magnetization becomes much stronger at the lower temperature [see Fig. 2(b)].

It is well known that the magnetization of pure Co is only weakly temperature dependent (σ_{Co} only increases ~1% as the temperature decreases from 300 to 4.2 K). The enhancement of magnetization in Figs. 2(a) and 2(b) thus originates from the multilayer structure and interface magnetism. Because of the interdiffusion or mixing between Co and Pt atoms at the interface region, as the Co layer becomes very thin, e.g., one to three atomic layers, the interfaces may approximately be regarded as a disordered Co–Pt alloy. Then the polarization of Pt atoms and the temperature dependence of magnetization of the interfaces can be calculated in terms of the mean-field theory, as has been done for Co–Pd and Co–Cu alloys in Refs. 8 and 9. We will not give a detailed discussion of the mean-field calculation to save space, and only point out the main result here: Co–Pt alloys with smaller Co concentration have a lower ordering temperature and show a stronger temperature dependence of magnetization. Thus one might expect that thinner Co-layer samples, whose interfaces correspond to Co–Pt alloys with smaller Co concentration, manifest the stronger temperature dependence of magnetization.

B. Temperature dependences of anisotropy

A summary of the temperature (or Co layer-thickness) dependencies of measured anisotropy for $X=3$, 4, 5, 7, 12, and 20 Å (or $T=10$, 100, 200, and 300 K) are shown in Fig. 4(a) [or 4(b)]. It is worthwhile to mention the following: (1) The measured anisotropy K_u is positive for $X\leqslant 9$ Å and negative for $X\geqslant 10$ Å over the whole temperature range [see Fig. 4(b)]. (2) Samples with thinner Co layers show a stronger temperature dependence of K_u [see Fig. 4(a) and 4(b)]. K_u values increase by 40%, 24%, and 22% for $X=3$, 4, and 5 Å as temperature decreases from 300 to 10 K. (3) We have determined the interface anisotropy K_i for these samples using the standard method of plotting "λK_u vs d_{Co}," as described in Refs. 9 and 10. We found K_i to be ~0.38 (erg/cm^2). K_i is also nearly independent of temperature. The fact that the samples with thinner Co layers ($X=3$, 4, and 5 Å) show stronger temperature dependences of the anisotropy, while, for samples with $X\geqslant 7$ Å the anisotropy is nearly independent of temperature, implies that the interfaces give the major contribution to the temperature dependence the of anisotropy.

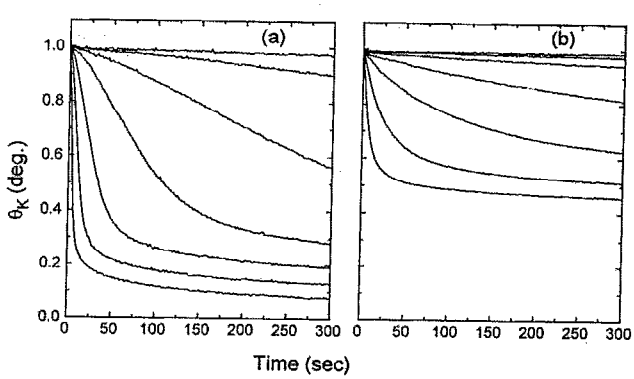

FIG. 4. Kerr rotation as a function of time after magnetization reversal for (a) 3 ÅCo/15 ÅPt and (b) 5 ÅCo/15 ÅPt. Different curves correspond to the different reversing fields ($\leqslant H_c$), with the uppermost curve corresponding to the smallest field.

To study the origins of anisotropy, Co/Pt, and Co/Au multilayers were prepared, and their temperature dependencies of the anisotropy K_u have been measured. We note that the thermal expansion coefficients of Au, Co, and Pt are 14.2×10^{-6}, 12×10^{-6}, and 9×10^{-6} ($°C^{-1}$), respectively.[11] Also, the expansion coefficient of Au is greater than that of Co, while the expansion coefficient of Pt is less than that of Co. Therefore, if stress anisotropy were the major source of K_u, one would expect that the anisotropy of Co/Pt and Co/Au would show opposite temperature dependences: one increasing with decreasing temperature while the other decreasing with decreasing temperature. However, our experiment shows that both for Co/Pt and Co/Au multilayers, the K_u values increase with decreasing temperature for samples with thin Co layers. This may be regarded as evidence that stress plus inverse magnetostriction is a minor contribution to the anisotropy in our (111) textured samples, in comparison with magnetocrystalline anisotropy generated by spin–orbit interaction in the highly anisotropic multilayers structure.[12,13]

C. Magnetization reversal

Magnetization reversal can be studied by the time decay of Kerr rotation. The measurement procedure was described in Ref. 7, and results are given in Figs. 5(a) and 5(b) for $X=3$ and 5 Å, respectively.

Several authors[14,15] have pointed out that if the nucleation rate is small and the domain wall motion velocity is large, the decay curve will first decrease slowly by nucleation at a few isolated sites and then fall quickly through the rapid expansion of the domain walls. The decay curves in Fig. 5(a) are consistent with this behavior. On the other hand, if the nucleation rate is large and the domain wall velocity is very small, the decay curve first decreases exponentially and then decreases approximately as $\ln(t)$ (t is the time) at long times. The decay curves in Fig. 5(b) show such behavior. The $\ln(t)$ behavior can arise either as a consequence of a distribution of thermal activation energies or because part of the driving force (the demagnetizing field) for reversal is decreasing with time as the sample reverses.[16] Therefore the reversal is dominated by domain wall motion for samples with thinner Co layers, while it is dominated by nucleation for thicker Co layer samples. Presumably this difference in behavior results from details of the nanostructures (defects, interface mixing, etc.), as well as differences in demagnetizing fields, both of which must be further investigated to obtain a clear understanding of the reversal behavior.

CONCLUSIONS

It is concluded that the substantial temperature dependence of the magnetic properties of the thin Co layer multilayers originates from the alloying effect at the interfaces. As the temperature decreases, the enhancement of magnetization can be understood in terms of mean-field theory and the enhancement of anisotropy results from the interfacial magnetism, however, the detailed mechanism still remains to be solved. This is a challenging problem when interfacial mixing is present, because up to the present time the theoretical calculations of magnetic anisotropy in multilayers have assumed perfect boundaries with no atomic disorder. Some experiments were performed to probe the origin of the anisotropy. It was found that stress plus magnetostriction does not appear to play a dominant role. Magnetization reversal is dominated by wall motion and nucleation for thinner and thicker Co layers, respectively.

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