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The perpendicular magnetic anisotropy of CoPt/Au multilayer films

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Abstract

We have studied the magnetic properties of Au (2 nm)/Co₅₀Pt₅₀ (3 nm)/Au (2 nm) multilayer films prepared on amorphous Al₂O₃/Si and (0 0 1) MgO substrates. The as-deposited films on both substrates are magnetically soft with an FCC structure and exhibit a perpendicular anisotropy. After annealing at 500 °C, the sample on the Al₂O₃/Si substrate has become magnetically isotropic but the sample on the MgO substrate still has perpendicular anisotropy with FCT structure. This film deposited on the MgO substrate did not show a strong perpendicular anisotropy due to the diffusion of the Au and the (1 1 1) nucleation of initial Au layer. We can obtain a perpendicular anisotropy in the multilayer films without an initial Au layer on a (0 0 1) MgO substrate. After annealing at 400 °C, these films have L1₀ phase with (0 0 1) texture and strong perpendicular anisotropy.

Keywords: CoPt, L1₀ phase, Ordering temperature, Perpendicular anisotropy

1. Introduction

Binary alloys such as CoPt and FePt with an L1₀-ordered structure have been attractive as ultrahigh-density magnetic recording media, permanent magnets and other applications [1–10] because of their magnetocrystalline anisotropy (on the order of 10⁷ ergs/cm³), and a relatively high saturation magnetization ($M_s = 800$ emu/

cm³) [5, 6]. In general, an annealing process above 600 °C is necessary to obtain the L1₀-ordered structure [7–10]. This temperature is undesirable for the manufacturing process. Hence, there have been many attempts to reduce the ordering temperature. Adding a third element such as Sn, Pb, Sb, Bi, Ag, B, Cu, or Zr into these alloys was reported to be effective for reducing the ordering temperature [11–16]. We also re-

ported the effect of a Au spacer layer for the transition to the $L1_0$ phase. The $L1_0$ phase in the system of [CoPt/Au] films was observed at 400 °C. This ordered structure easily became the (1 1 1) texture, which has a random *c*-axis orientation. For perpendicular magnetic recording applications, it is also desirable for the easy axis of magnetization in the films to orient perpendicular to the plane. For example, CoPt film should have a (0 0 1) texture. In general, different kinds of seed layers such as MgO, Ag, and Mo are effective in controlling the crystal orientation [17–20]. Furthermore, a multilayered structure also produced perpendicular anisotropy [21–23].

In this article, we investigate the influence of crystal orientation and $L1_0$ phase formation on the perpendicular anisotropy of [Au (2 nm)/Co₅₀Pt₅₀ (3 nm)/Au (2 nm)]₇ multilayer structured films by preparing two sets of samples. The first set used two different substrates, amorphous Al₂O₃/Si and (0 0 1) MgO, to show their influence on crystal growth. The second set was prepared on MgO to investigate the influence of the Au initial layer on the crystal orientation of these films.

2. Experiment

Au (2 nm)/CoPt (3 nm)/Au (2 nm) multilayer films (number of CoPt layers is 7 and total thickness of CoPt is 21 nm) were prepared on an Al₂O₃/Si substrate and a (0 0 1) MgO substrate using a conventional direct current magnetron sputtering system. A CoPt alloy with 50:50 atomic ratios was used as a target. The base pressure before introducing the Ar gas was 1.0×10^{-7} Torr and the gas pressure during the deposition was 5–10 mTorr. The deposition rate was 0.5 Å/s for CoPt and 0.8 Å/s for Au, respectively. The growth temperature was changed from room temperature (RT) to 350 °C. We annealed the samples at 350–500 °C for 10 h in a 3:1 Ar:H₂ atmosphere. The magnetic properties of the sample were measured at RT using an Alternating Gradient Force Magnetometer and Superconducting Quantum Interference Device Magnetometer. The structural analysis of the films was performed with an X-ray diffractometer (XRD) using Cu K_α radiation.

3. Results and discussion

Figure 1 shows magnetization curves (*M*–*H*) for Au/CoPt/Au layer films deposited at RT on (a) amorphous Al₂O₃/Si and (b) (0 0 1) MgO substrates. Both films show a perpendicular magnetic anisotropy. The magnetic anisotropy constants (K_u), evaluated using the magnetization curve, are 2.5×10^5 and 4.0×10^5 erg/cm³, respectively. Since both films show almost the same magnetic anisotropy, this magnetic anisotropy is suggested to be caused by the multi-layered structure [21]. In order to get an $L1_0$ phase formation, these samples were annealed at 500 °C. Figure 2 shows the *M*–*H* curves of these films. After annealing these samples, the coercive field became large (about 10 kOe) due to the $L1_0$ phase formation. All samples deposited on the amorphous Al₂O₃/Si substrate showed isotropic magnetic behavior. On the other hand, the films deposited on the MgO substrate still showed weak perpendicular anisotropy. Judging from these results, an orientation of the substrate seemed to affect the solid phase growth direction of the CoPt film [17]. Although Au is definitely

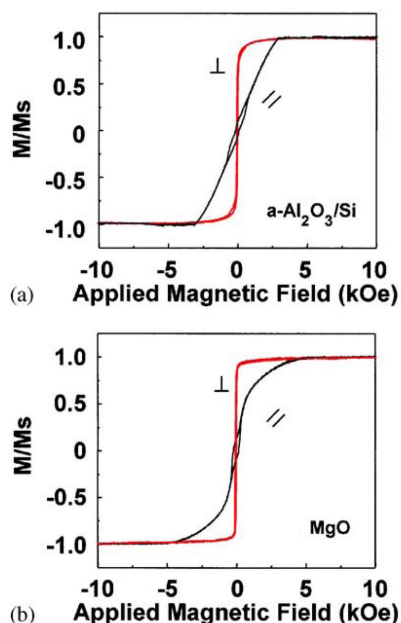


Figure 1. Magnetization curves of the [Au/CoPt/Au] film deposited at RT on (a) an amorphous Al₂O₃/Si substrate, and (b) a (0 0 1) MgO substrate.

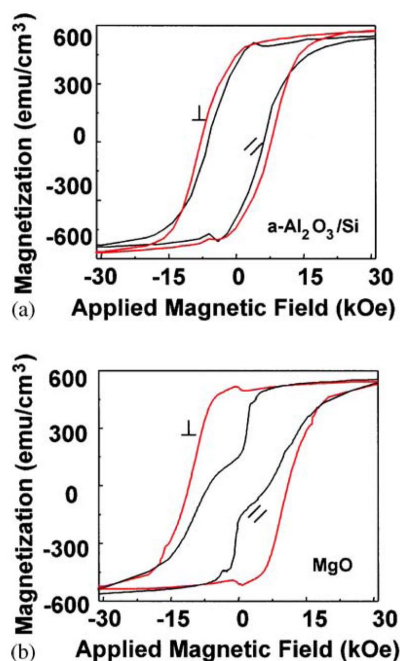


Figure 2. M - H curves of the [Au/CoPt/Au] film deposited on (a) an amorphous $\text{Al}_2\text{O}_3/\text{Si}$ substrate and annealed at 500°C (b) an MgO substrate and annealed at 500°C .

effective for the phase formation, a excess diffusion of Au seems to make the film magnetically isotropic. The high stability of the (1 1 1) surface of Au on the MgO substrate [24, 25] might also cause the reduction in the perpendicular anisotropy. During the solid phase growing process of the CoPt film, some Au with (1 1 1) texture might have also been grown on the MgO substrate. The Au (1 1 1) plane lattice is close to the CoPt (1 1 1) plane lattice. Although the (1 1 1) plane of FCC structure is the most stable plane, this might cause some CoPt to become a base for more (1 1 1) nucleation.

Because the crystal orientation of the initial layer is important for the growth direction of the film at a relatively high substrate temperature, we also investigated a growth behavior of the Au initial layer. The sample was prepared on an MgO substrate at 350°C , which is a starting temperature of L1_0 phase formation in this system. We expected that a film with L1_0 phase, in which the growth direction was assisted by the orientation of an MgO substrate, was produced

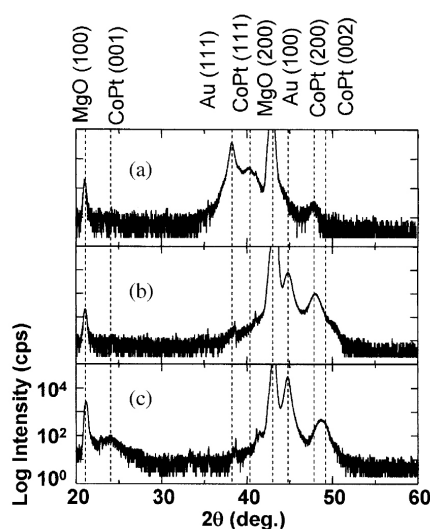


Figure 3. The X-ray diffraction patterns of (a) [Au/CoPt] film with Au initial layer deposited on MgO at 350°C (b) [Au/CoPt] film deposited on MgO at 350°C without the Au initial layer (c) [Au/CoPt] film without the Au initial layer deposited at 350°C and annealed at 400°C .

[19]. Figure 3 shows XRD patterns of the [Au/CoPt] films deposited at 350°C (a) with and (b) without the initial Au layer. From the $\sim 3.5\%$ lattice mismatch between Au (4.06 \AA) and MgO (4.21 \AA), we initially expected a (1 0 0) Au texture, but the sample with the Au initial layer shows a strong (1 1 1) Au ($2\theta = 28.18^\circ$) orientation due to the high stability of the (1 1 1) Au surface energy (Figure 3(a)). This can cause the [Au/CoPt] film also to have a (1 1 1) orientation. We have prepared a sample without the Au initial layer to investigate the effect of this layer. The sample without the Au initial layer (Figure 3(b)) has a (0 0 2) orientation. Especially in the [Au/CoPt] film the (0 0 2) diffraction, which is related to the FCT phase, is observed. This FCT phase is assumed to be constituted by both inter-diffusion of the Au during the deposition and assistance from the orientation of the MgO substrate. Furthermore, it is suggested that the initial CoPt layer behaves as a seed layer and the [Au/CoPt] film with FCT phase is grown by nucleation using this seed layer. The sample was annealed at 400°C to produce a well-ordered crystal structure. This XRD pattern is shown in Figure 3(c). After annealing the sample, the intensity of the

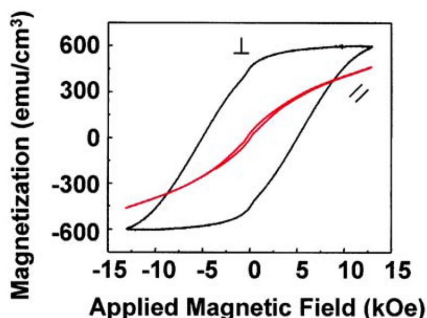


Figure 4. In-plane and out-of-plane M - H curves of the [Au/CoPt] sample grown on the MgO substrate without the Au initial layer and annealed at 400 °C.

(0 0 2) diffraction peak became large and a (0 0 1) diffraction peak ($2\theta = 24.02^\circ$) was observed. From the XRD patterns, we deduced the integrated intensity ratios $I_{(0\ 0\ 1)}/I_{(0\ 0\ 2)}$ and extracted the degree of long-range chemical ordering, S . S is defined as the probability of correct site occupation in the $L1_0$ lattice, and is given by

$$S^2 = [I_{(0\ 0\ 1)}/I_{(0\ 0\ 2)}]/[I_{(0\ 0\ 1)}/I_{(0\ 0\ 2)}]_{\text{calc}} \quad (1)$$

By taking the X-ray penetration depth [26] and Debye-Waller factor [27] into account, $[I_{(0\ 0\ 1)}/I_{(0\ 0\ 2)}]_{\text{calc}}$ is calculated to be around 1.87 and S is estimated to be about 0.71 [28], [29] and [30].

Figure 4 shows in-plane and out-of-plane M - H curves for the [Au/CoPt] sample grown on the MgO substrate without the Au initial layer. Strong perpendicular anisotropy was obtained in this film.

4. Summary

We investigated the magnetic anisotropy of a CoPt/Au film with a low $L1_0$ phase formation temperature. Below the $L1_0$ phase formation temperature, all the films have a perpendicular anisotropy irrespective of the kind of substrate. This behavior is due to the multi-layered structure. In order to get an $L1_0$ phase, samples were annealed at over 350 °C. After annealing the samples, the magnetic anisotropy behavior was different for different substrates. The sample de-

posited on the amorphous $\text{Al}_2\text{O}_3/\text{Si}$ substrate shows isotropic magnetic behavior. On the other hand, although the perpendicular anisotropy behavior of the sample deposited on the MgO substrate became lessened, it still showed perpendicular anisotropy. The film without a Au initial layer deposited at 350 °C has a (0 0 1) orientation. After annealing the sample at 400 °C, it showed strong perpendicular anisotropy and an $L1_0$ phase with a coercivity of 6 kOe.

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