June 2004

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(Presented on 8 January 2004)

We have studied the effect of Au on the ordering temperature of CoPt films. The coercivity of the CoPt multilayer with 2 nm Au inserted is around 5 kOe after annealing at 400 °C. This ordering temperature is about 200 °C lower than that of a pure CoPt film. Crystallographical analysis using x-ray diffraction has also revealed that the lattice constant is drastically changed around the same temperature, which is related to the formation of the $L1_0$-ordered structure. Thus, the Au plays an important role in reducing the ordering temperature. © *2004 American Institute of Physics.*
[DOI: 10.1063/1.1667831]

I. INTRODUCTION

Binary alloys such as CoPt and FePt with an $L1_0$-ordered structure have been attractive as ultrahigh-density magnetic recording media, permanent magnets, and for other applications[1–10] because of their magnetocrystalline anisotropy in the order of 10^7 ergs/cm^3, and a relatively high saturation magnetization $M_s = 800$ emu/cm^3.[5,6] In general, an annealing process above 600 °C is necessary to obtain the $L1_0$-ordered structure.[7–10] Such high-temperature treatments are undesirable for the manufacturing process. Hence, there have been many attempts to reduce the ordering temperature. The addition of 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.[11–15] By using Ag as an under or a top layer, the reduction of the ordering temperature due to the change in the lattice parameter was also observed.[16,17] It was reported that in multilayered structures, such as Co/Pt, Fe/Pt, etc., their activation energy for ordering can be decreased.[18,19] The addition of Au is also expected to reduce the ordering temperature of CoPt, because it is in the same group as Ag and Cu on the periodic table and is expected to fill the same role as these atoms.[20] It is also expected that Au will not have much influence on the magnetic property of CoPt.

In this article, ultrathin CoPt films with Au layer inserted were prepared and the effect of Au for the reduction of the ordering temperature was investigated.

II. EXPERIMENT

Ultrathin CoPt (3 nm)/Au (x nm) multilayer films ($x = 1-2$, number of layers is 7 and total thickness of CoPt is 21 nm) were prepared on an Al_2O_3/Si substrate using a conventional direct current 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. 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. Growth temperature was fixed at room temperature. As-deposited films were annealed at 300–550 °C for 5–20 h under an Ar/H_2 atmosphere (Ar:H_2 = 3:1). The magnetic properties of the sample were measured at room temperature 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 $K\alpha$ radiation.

III. RESULTS AND DISCUSSION

Figure 1 shows typical magnetization versus applied magnetic field (M-H) curves, in-plane and out-of-plane, of a CoPt (3 nm)/Au (2 nm) multilayer film annealed at 550 °C. The saturation magnetization of this CoPt film is about 600 emu/cm^3 and the coercive field (H_c) is about 9 kOe. There are no significant differences in in-plane and out-of-plane H_c. This indicates that the magnetic easy axis of the crystallites in this film is randomly distributed. Therefore, we discuss only the in-plane H_c for CoPt films in this article. Figure 2 shows H_c at 300 K versus the annealing temperature (T_a) for the CoPt film with or without an Au layer inserted. The annealing time for the samples shown in Fig. 2 is 5 h. For as-deposited CoPt films, both with and without Au layers, the H_c at 300 K is about 30 Oe and the M-H curves exhibit soft magnetic properties. After annealing, the H_c of

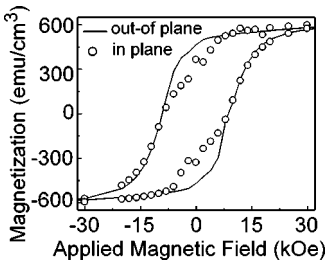

FIG. 1. Typical magnetization curves at in-plane (open circle) and out-of-plane (solid line) of a CoPt (3 nm)/Au (2 nm) multilayer film annealed at 550 °C for 5 h.

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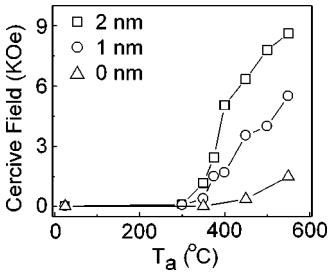

FIG. 2. Annealing temperature (T_a) dependence of the in-plane coercive force (H_c) for the different Au-layer thickness. (The square is 2, the open circle is 1, and the triangle is 0 nm, respectively.) The annealing time is 5 h.

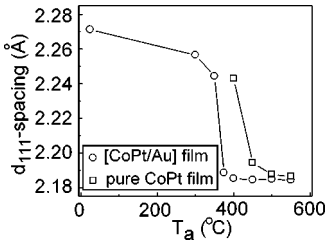

FIG. 4. Change in the d spacing (d_{111}) of both the CoPt multilayer with a 2 nm Au spacer layer (open circle) and pure CoPt film (open square) vs the annealing temperature (T_a).

pure CoPt film changed slowly. The H_c of pure CoPt film annealed at 550 °C is about 2 kOe. The H_c of CoPt (3 nm)/Au (2 nm) multilayer films began to change at 350 °C and drastically increased over 400 °C. The H_c of the CoPt (3 nm)/Au (2 nm) multilayer films annealed at 400 °C is already 5 kOe. The H_c of the CoPt (3 nm)/Au (2 nm) multilayer sample annealed at 350 °C is about the same as that of pure CoPt films annealed at 550 °C. A similar trend for the H_c of the CoPt (3 nm)/Au (1 nm) multilayer films was observed. These results clearly indicated the effect of adding Au for the reduction of the processing temperature. Such a remarkable improvement of processing temperature due to the addition of Au can be better understood by the temperature dependence of structure changes. Figure 3 shows the XRD patterns of CoPt (3 nm)/Au (2 nm) multilayer samples at various T_a. A very weak diffraction peak (002) from the ordered $L1_0$ CoPt phase appears separately from the fcc (200) diffraction peak for the CoPt (3 nm)/Au (2 nm) multilayer film annealed above 400 °C. This existence of a (002) diffraction peak might be enough evidence for a face-centered tetragonal (fct) phase. Since, on this temperature, the fct crystal does not have enough grain growth, the intensity is considered to be very small. All these samples show a relatively strong (111) diffraction peak that indicates the texture of the crystallites in these films. Since the magnetic easy axis of the ordered $L1_0$ CoPt phase is along the ⟨001⟩ direction, the (111) texture is consistent with a randomly distributed magnetocrystalline anisotropy in these films. Since the (111) diffraction peak was related to the *a* axis and the *c* axis, the peak shifts are related to the long-range chemically ordered fct structure.

Figure 4 shows the change in the d spacing (d_{111}) of the CoPt film both with and without an Au layer versus T_a. The d spacing of the pure CoPt film is rapidly decreased around 500 °C; it still is larger than that of [CoPt/Au] annealed at 400 °C. Then, with increasing annealing temperature, the d spacing is gradually decreased. On the other hand, the d spacing of the CoPt (3 nm)/Au (2 nm) multilayer samples is rapidly decreased around 400 °C. The change in the lattice parameter has the same tendency as that of the H_c. Judging from these results, the phase formation of the $L1_0$ structure of the CoPt inserted Au layer films starts around 350–400 °C. And, in the sample with a 2 nm Au layer, a temperature of 400 °C is enough for a high coercivity above 5 kOe. In order to further understand the ordering process, the annealing time dependence of H_c was investigated. Since the phase formation was started near 350 and 375 °C, we would expect large changes around these temperatures. The results of H_c versus annealing time for these two temperatures are shown in Fig. 5. The H_c gradually increases with increasing the annealing time in the sample annealed at 300 °C. In the sample annealed at 375 °C, however, the H_c was steeply changed over 10 h, and at over 15 h the H_c was almost saturated. These changes are likely related to the formation of the fct phase in the CoPt films. It indicates that the formation of the $L1_0$ CoPt phase is a very slow process.

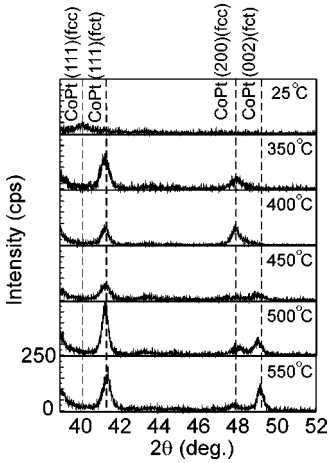

FIG. 3. XRD patterns of the CoPt multilayer with a 2 nm Au spacer layer with various annealing temperatures, T_a. The (002) diffraction from the ordered $L1_0$ CoPt begins to be observed at $T_a = 400$ °C.

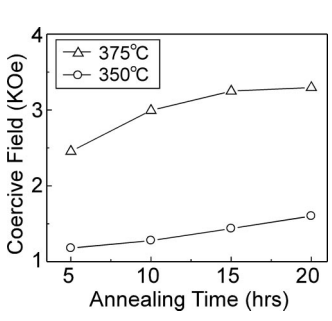

FIG. 5. Annealing time dependence of the coercivity of the CoPt multilayer with a 2 nm Au spacer layer annealed at 350 °C (open circle) and 375 °C (open triangle). The sample was annealed under an Ar/H_2 atmosphere ($Ar:H_2 = 3:1$).

IV. SUMMARY

We investigated the reduction in the ordering temperature using a CoPt multilayer with an Au layer inserted. It is revealed that the addition of Au is effective for reducing the ordering temperature. From the structural analysis, the phase formation of the $L1_0$ structure of the CoPt inserted Au layer films starts at around 350–400 °C. At the same temperature, the H_c of these films shows drastic changes. It shows clearly that the occurrence of a high H_c is related to the phase formation of the $L1_0$ structure of CoPt. From these XRD results, the lattice change and the coercivity change, we can conclude the achievement of reduction of the ordering temperature by about 200 °C. And the interdiffusion of Au seems to be assisting the CoPt phase formation. The study of the time dependence of H_c reveals that the phase formation of $L1_0$ structure of CoPt is a slow diffusion process.

ACKNOWLEDGMENTS

This research is supported by NSF MRSEC DMR-0213808, Army Research Office DAAD 19-03-1-0298 INSIC, NRI, and CMRA. T. Yokota is supported by a Grant-in-Aid for JSPS Fellows, No. 00000652.

[1] E. S. Murdock, IEEE Trans. Magn. **28**, 3078 (1992).
[2] K. R. Coffey, M. A. Parker, and J. K. Howard, IEEE Trans. Magn. **31**, 2737 (1995).
[3] S. Sun, C. B. Murray, D. Weller, L. Folks, and A. Moser, Science **287**, 1989 (2000).
[4] S. H. Liou and Y. D. Yao, J. Magn. Magn. Mater. **190**, 130 (1998).
[5] A. S. Darling, Platinum Met. Rev. **7**, 96 (1963).
[6] R. A. MacGuire and P. Gaunt, Philos. Mag. **13**, 567 (1966).
[7] M. R. Visokay and R. Sinclair, Appl. Phys. Lett. **66**, 1692 (1995).
[8] S. Stavroyianns, I. Panagiotopoulos, D. Niarchos, J. A. Chistodoulides, Y. Yang, and G. C. Hadijipanayis, Appl. Phys. Lett. **73**, 3453 (1999).
[9] V. Parasote, M. C. Cadeville, G. Garreau, and E. Beaurepaire, J. Magn. Magn. Mater. **198–199**, 375 (1999).
[10] R. F. C. Farrow, D. Weller, R. F. Marks, M. F. Toney, S. Hom, G. R. Harp, and A. Cebollada, Appl. Phys. Lett. **69**, 1166 (1996).
[11] C. Chen, O. Kitakami, S. Okamoto, and Y. Shimada, Appl. Phys. Lett. **76**, 3218 (2000).
[12] H. Yamaguchi, O. Kitakami, S. Okamoto, Y. Shimada, K. Oikawa, and K. Fukamichi, Appl. Phys. Lett. **79**, 2001 (2001).
[13] O. Kitakami, Y. Shimada, K. Oikawa, H. Daimon, and K. Fukamichi, Appl. Phys. Lett. **78**, 1104 (2001).
[14] T. Maeda, T. Kai, A. Kikitsu, T. Nagase, and J. Akiyama, Appl. Phys. Lett. **80**, 2147 (2002).
[15] S.-R. Lee, S. Yang, Y. K. Kim, and J. G. Na, Appl. Phys. Lett. **78**, 4001 (2001).
[16] Y. N. Hsu, S. Jeong, D. E. Langhlin, and D. N. Lambeth, J. Appl. Phys. **89**, 7068 (2001).
[17] Z. L. Zaho, J. Ding, K. Inaba, J. S. Chen, and J. P. Wang, Appl. Phys. Lett. **83**, 2196 (2003).
[18] C. P. Luo and D. J. Sellmyer, IEEE Trans. Magn. **31**, 2764 (1995).
[19] D. M. Artymowicz, B. M. Lairson, and B. M. Clemens, J. Cryst. Growth **169**, 83 (1996).
[20] T. B. Massalski, in *Binary Alloy Phase Diagrams*, 2nd ed., edited by H. Okamoto, P. R. Subramanian, and L. Kacprazak (ASM International, Cleveland, OH, 1996).