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Perpendicular magnetic anisotropy of CoPt–AlN composite film with nano-fiber structure

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ABSTRACT Co–Pt–AlN films were prepared by sputtering a Co–Pt–Al composite target in Ar + N_2 atmosphere. Upon thermal annealing at elevated temperatures, fcc CoPt and a-AlN are formed in the films as phases separated from one other. Both phases develop as fiber-like columnar grains vertical to the substrate and with their lateral size less than 10 nm. Because of the shape anisotropy of the magnetic fiber grains the CoPt–AlN film shows a perpendicular magnetic anisotropy at a thickness equal to or larger than about 25 nm while the Co–TiN [6] and CoPt–TiO_2 [11] films do not unless their thicknesses reach 50 and 100 nm, respectively. This suggests that both the shape anisotropy of the CoPt magnetic fiber grains and their mutual separation in an a-AlN medium work more effectively in the formation with the perpendicular magnetic anisotropy. Such a perpendicular magnetic anisotropy of the CoPt–AlN film associated with the nano-scale feature makes it a very promising candidate for future recording media with ultra-high area density.

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1 Introduction

Magnetic nano-composite films have been investigated to realize high-density magnetic recording devices with high thermal stability [1–3]. A nano-composite film is commonly composed of a magnetic phase such as Co or its alloy and a nonmagnetic phase such as SiO_2 and Al_2O_3, and both phases are to be distributed with nano-scale sizes leading to the high-area magnetic density. In addition, it is very promising for ultra-high-area recording to develop a nano-composite film with perpendicular magnetic anisotropy [4–6]. On the other hand, to increase the high thermal stability, CoPt and FePt alloys have a great advantage because of their high crystalline magnetic anisotropy constants in their ordered fct (or L1o) structure, i.e. 5×10^7 erg/cm^3 for CoPt and 7×10^7 erg/cm^3 for FePt, respectively [7–10]. According to our previous works, the Co–TiN film thicker than 50 nm [6] and the CoPt–TiO_2 film thicker than 100 nm [11] show the perpendicular magnetic anisotropy due to the shape anisotropy for fcc Co (or fcc CoPt) fiber grains but not due to the high crystalline magnetic anisotropy for hcp Co (or fct CoPt), while the FePt–TiN film [12] was confirmed to show the in-plane magnetic anisotropy with an extremely high coercivity, i.e. about 4000 Oe, originated from a fct FePt phase with high crystalline magnetic anisotropy.

In the present work, subsequently to those previous works, the system Co–Pt–AlN is employed to form a CoPt-based nano-composite. The Al and N_2 are designated to form AlN as the nonmagnetic phase in the nano-composite, analogously to TiN in the Co–TiN system or TiO_2 in the Co–Pt–TiO_2 system. TiO_2, TiN and AlN are known as materials with high hardness and thermal and chemical stability. In this article we report the perpendicular anisotropy of the CoPt–AlN nano-composite films.

2 Experimental procedure

Co–Pt–AlN films were deposited onto SiO_2 glass substrates at room temperature by reactive sputtering in a mixed gas of Ar and N_2. A complex target set was used which includes a Pt plate at the back, a Co plate with a concentric hole 33 mm in diameter in the medium and a Al plate with a concentric hole 60 mm in diameter at the front with 81 mm as a common diameter, which means that the ratio between surface areas of Co, Pt and Al targets is 2.2/1.0/2.7.

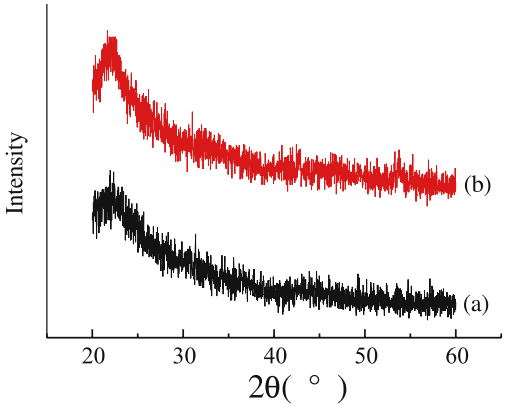

FIGURE 1 XRD profiles of the Co–Pt–AlN films with the thickness of 182 nm. The films are as-deposited (a) and annealed (b)

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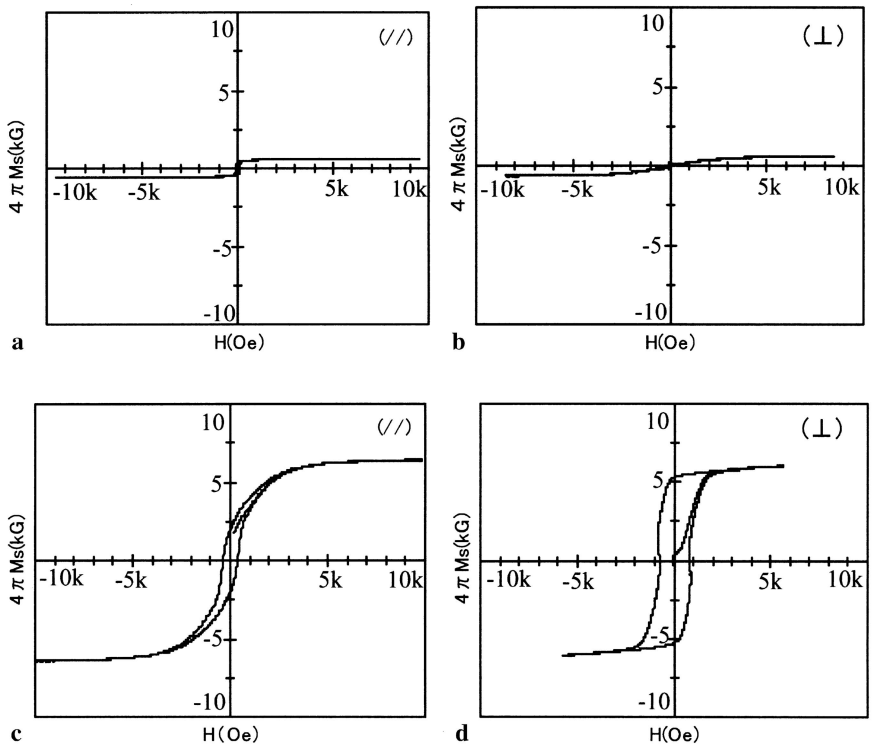

FIGURE 2 Magnetization curves of the Co–Pt–AlN films. The films are as-deposited (**a**, **b**) and annealed (**c**, **d**). The in-plane magnetization curves (**a**, **c**) are denoted by // and the perpendicular magnetization curves (**b**, **d**) are denoted by ⊥

The vacuum chamber was evacuated to 1.3×10^{-4} Pa before sputtering, and then the mixed gas of Ar and N_2 was introduced up to 4 Pa with 1/200 as the pressure ratio of N_2 to Ar during the sputter deposition. After the sputter deposition the films were in situ annealed in a vacuum of 1.3×10^{-4} Pa at a temperature of 700 °C for 2 h. Such a preparation condition was determined to be the best process to prepare the nano-fiber film with a perpendicular magnetic anisotropy on the basis of preparation conditions for the Co–TiN film [6], the CoPt–TiO_2 film [11] and the FePt–TiN film [12] in the previous experiments. The atomic composition of the film was analyzed by X-ray photoelectron spectroscopy (XPS). The structural aspects of the film were investigated by X-ray reflection diffraction (XRD) and by transmission electron microscopy (TEM). The magnetic properties of the film were characterized by measuring its magnetization curve at room temperature with the use of a vibrating sample magnetometer (VSM).

3 Results and discussion

The average atomic composition ratio in the as-deposited films investigated is estimated to be Co/Pt/Al/N = 25/25/30/20. The as-deposited film retains an amorphous-like structure as shown in the XRD profile (Fig. 1a), showing only a small ferromagnetism as shown in Fig. 2a and b. Upon the thermal annealing, although it seems to be still amorphous as shown by XRD (Fig. 1b), the film becomes obviously ferromagnetic with hysteresis curves in both the in-plane and the perpendicular magnetization curves and, in addition, the film shows a perpendicular magnetic anisotropy, as shown in Fig. 2c and d where the saturation magnetization $4\pi M_s$ and the coercivity H_c are estimated to be 6 or 7 kG and 500 or 800 Oe for the in-plane and the perpendicular magnetization

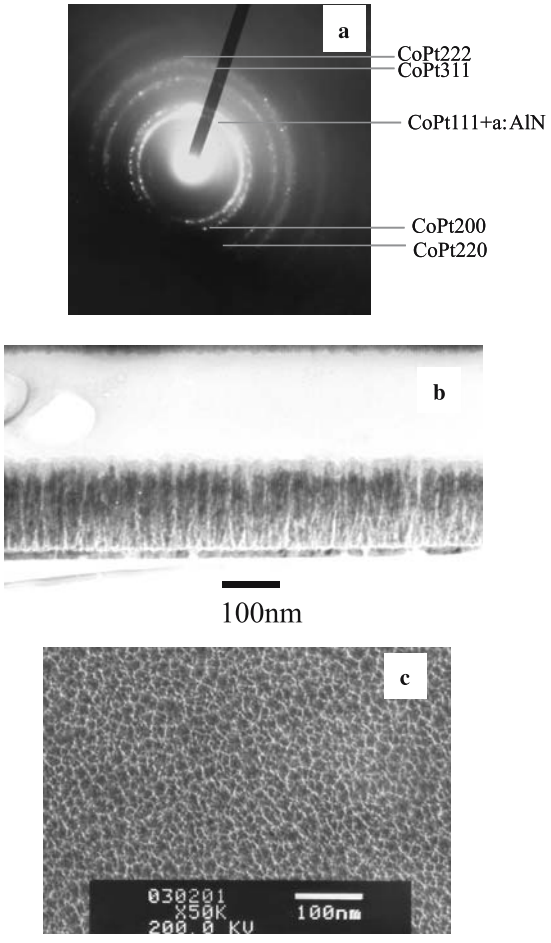

FIGURE 3 The cross-sectional transmission electron diffraction pattern (**a**), the cross-sectional TEM image (**b**) and the plane-view TEM image (**c**) of the CoPt–AlN film

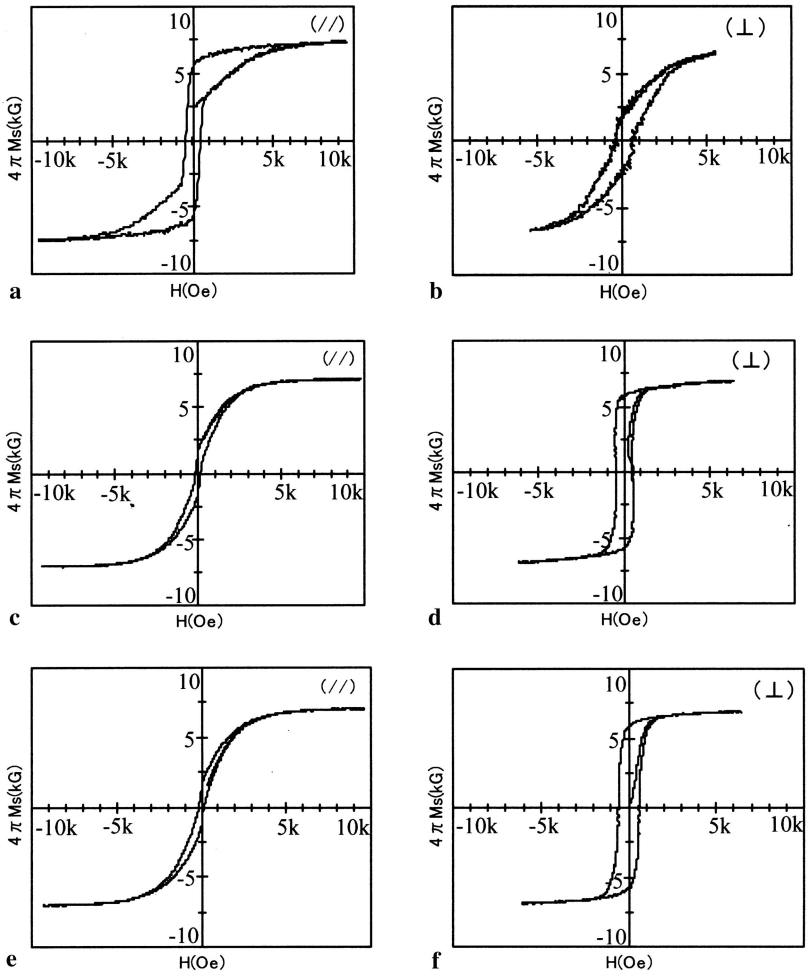

FIGURE 4 The in-plane (//) and the perpendicular (⊥) magnetization curves of CoPt–AlN films with different thicknesses: 10 nm (**a**, **b**); 25 nm (**c**, **d**); 50 nm (**e**, **f**)

curves, respectively. These results suggest that some structural change happens in the film during the thermal annealing. In fact, the TEM observation shows that the annealed film consists of the polycrystalline fcc CoPt phase and the amorphous AlN phase, as shown by the cross-sectional transmission electron diffraction (XTED) pattern in Fig. 3a. Both phases seem to grow in fiber-like columnar grains of 20–30 nm in the average lateral size as seen both in the cross-sectional image and in the plane-view image of TEM in Fig. 3b and c, respectively. The XTED signals from the AlN phase could not be detected, probably because it might be perfectly amorphous. Next, the magnetization curves of the annealed CoPt–AlN films are shown in Fig. 4 over the thickness range from 10 nm to 50 nm. As seen in Fig. 4, the macroscopic magnetization easy axis stands up from the in-plane direction in the direction perpendicular to the film surface as the film thickness increases from 10 nm to 25 nm. The reason why the perpendicular magnetic anisotropy is established for the thicker films may be due to the strong shape anisotropy of the magnetic fcc CoPt fiber grains separately embedded in amorphous nonmagnetic AlN phase. These features of structural and magnetic properties of CoPt–AlN films are quite similar to the cases of the previous works on Co–TiN [6] and CoPt–TiO_2 [11] films, except that the characteristic thickness d_p at which the perpendicular magnetic anisotropy is established is only 25 nm for the present case, which is very thin as compared with 50 nm for the Co–TiN film [6] and 100 nm for the CoPt–TiO_2 film [11]. The value of d_p may be smaller for the film system where the magnetic fiber grains are more effectively elongated and more effectively separated from one another in a nonmagnetic amorphous medium.

4 Summary

Co–Pt–AlN films prepared by sputtering a Co–Pt–Al composite target in $Ar + N_2$ atmosphere and then subjected to an in situ thermal annealing process show a perpendicular magnetic anisotropy as their thickness increases up to only 25 nm. This is believed to be the result of the shape magnetic anisotropy caused by the CoPt magnetic fiber grains in the alignment vertically to the substrate. The thickness of 25 nm makes a practical application to future recording media possible.

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