Effects of substrate temperature and texturing on the magnetic properties and crystallographic structures of CoCrTa/Cr thin film

J. C. LIN, M. R. TSENG, J. J. CHU, C. M. WANG
Materials Research Laboratories, Industrial Technology Research Institute, 195-5 Chung Hsing Road, Section 4, Chutung, 31015, Hsinchu, Taiwan

Bi-layer CoCrTa/Cr films were deposited on textured aluminium or textured NiP-plated aluminium substrate by d.c. magnetron sputtering. The crystal anisotropy and thereby magnetic properties depending on substrate material, substrate temperature and texturing, were investigated. The magnetic crystal anisotropy induced by the mechanical texture on aluminium or NiP/Al substrates along the texture lines for the film deposited at high temperature, were clearly observed, while the film deposited at low temperature shows less prominent anisotropic behaviour. X-ray diffraction analysis indicates a change in the preferred orientation of the chromium and CoCrTa films sputtered on different substrates at different temperatures. It was found that a high substrate temperature was beneficial to the formation of Cr(0 0 2) and therefore epitaxial growth of Co(1 1 $\bar{2}$ 0) on Cr(0 0 2) for either aluminium or NiP/Al substrates.

1. Introduction

Thin films of CoCrTa sputtered on a chromium underlayer for longitudinal magnetic recording have been extensively investigated in recent years. They have been demonstrated to be the most promising media to meet the high-density recording requirement of high coercivity and low noise characteristics. It is generally recognized that a higher coercivity has a smaller transition width, and thereby a higher linear recording density. In order to increase the coercivity, a number of factors which influence the film structures and magnetic properties have been studied [1–5]. Generally, a chromium underlayer has been employed to enhance the coercivity by changing the crystal orientation of the magnetic film. The substrate was textured to improve the head–medium stiction performance in thin-film hard disc technology. The textured substrates also induce magnetic anisotropy of the cobalt alloy thin films and increase the coercivity [6, 7]. However, the origin of the magnetic anisotropy on a textured substrate has not been well clarified. The anisotropy also depends on substrate temperature which influences the mobility of sputtered atoms in the substrate to develop the preferred orientation. This work addressed the substrate texture and temperature effects on the crystallographic and magnetic anisotropic properties of the CoCrTa film deposited on aluminium and NiP/Al substrates.

2. Experimental procedure

Bi-layer thin films were sputtered by d.c. magnetron sequentially with a 4 in ($\sim$ 10 cm) diameter chromium target and a CoCrTa alloy target. The substrates for deposition were either 3.5 in ($\sim$ 8.9 cm) aluminium disc or 3.5 in ($\sim$ 8.9 cm) aluminium disc plated with a 12 μm NiP amorphous layer. The base pressure was kept at less than 3×10^{-6} torr (1 torr = 133.322 Pa) before sputtering. The argon pressure was 3 mtorr for chromium and 4 mtorr for CoCrTa sputtering. The electric power was a high-current and low-voltage system: the power density for chromium and CoCrTa targets were 12.3 and 8.3 W cm^{-2}, respectively. Substrates were heated in vacuum to elevated temperature prior to deposition of chromium. Typical thicknesses of chromium and CoCrTa were 200 and 50 nm, respectively. Magnetic measurements were performed using a vibrating sample magnetometer (VSM) with a maximum applied field of 12 kOe. Samples were measured circumferentially and radially in the film plane. Crystallographic structures of the films were investigated by using CuK_α X-ray diffraction (XRD). In the TEM work, both plane view and cross-sectional view specimens were prepared. For plane view sections, the samples were mechanically thinned to a thickness less than 10–25 μm. The thinned foil was subjected to argon-ion milling from the substrate side. When a perforation appeared in the sample, a brief clean using an argon-ion bombardment from the thin-film side was carried out to remove any possible unwanted deposit on the film surface left during the substrate thinning process. For the cross-sectional specimen preparation, the disc was cut using a diamond cutter into 3×10 mm^2 pieces. Then the film side of two such pieces were glued together with epoxy and baked to dry. The sandwich was mechanically ground on SiC

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paper to 10–25 μm, followed by argon-ion milling. The TEM work of the prepared specimens was performed with a Jeol-200CX or JEM-2000FX operated at 200 kV.

3. Results and discussion

The CoCrTa/Cr film deposited on a textured aluminium substrate with a temperature of 260 °C were measured in circumferential and radial directions in the film plane, respectively. The two magnetic hysteresis loops were compared, as shown in Fig. 1. The circumferential magnetic properties have $H_c = 1500$ Oe, $S = 0.78$, $S^* = 0.90$ and the radial magnetic properties have $H_c = 1220$ Oe, $S = 0.59$, $S^* = 0.52$. The results reveal that magnetic anisotropy in the film plane is very significant. It indicates that a large magnetic crystal anisotropy is induced by the texture of the substrate at high temperature, and that the anisotropy is parallel to the texture direction. However, the film deposited at room temperature exhibited the reverse results. Comparison of the two hysteresis loops shown in Fig. 2 shows that the radial magnetic properties have $H_c = 755$ Oe, $S = 0.71$, $S^* = 0.89$ and the circumferential magnetic properties have $H_c = 620$ Oe, $S = 0.71$, $S^* = 0.69$. The coercivity, H_c, squareness, S, and coercive squareness, S^*, are very well known terminologies in magnetic recording media. They are defined in the hysteresis loop as follows: H_c is the applied reverse field to diminish the remanent magnetization to zero, $S = M_r/M_s$ and $S^* = \Delta H/H_c$. It should be noted that the circumferential coercivity was less than the radial coercivity while the squareness was equal. This result implies that the magnetic anisotropic behaviour is less prominent for the low-temperature deposition. From the above results, it is believed that a high substrate temperature is necessary for high coercivity and the sputtered atoms obtain enough energy from the heating substrate to migrate to favourable low-energy sites which helps to form the preferred CoCrTa grain structure with its c-axis parallel to the texture line.

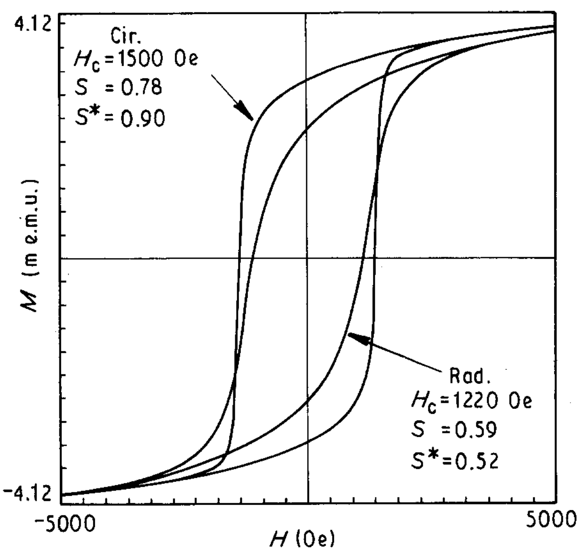

Figure 1 Comparison of hysteresis loops measured in the circumferential and radial directions on samples of CoCrTa/Cr sputtered on textured aluminium substrates at 260 °C.

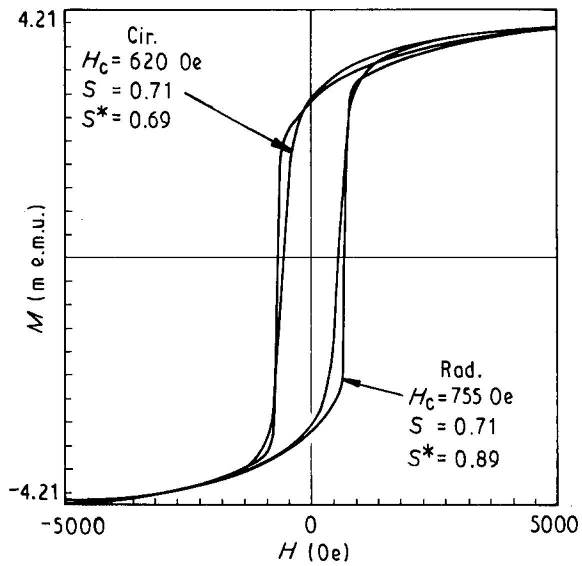

Figure 2 Comparison of hysteresis loops measured in the circumferential and radial direction on samples of CoCrTa/Cr sputtered on textured aluminium substrates at 25 °C.

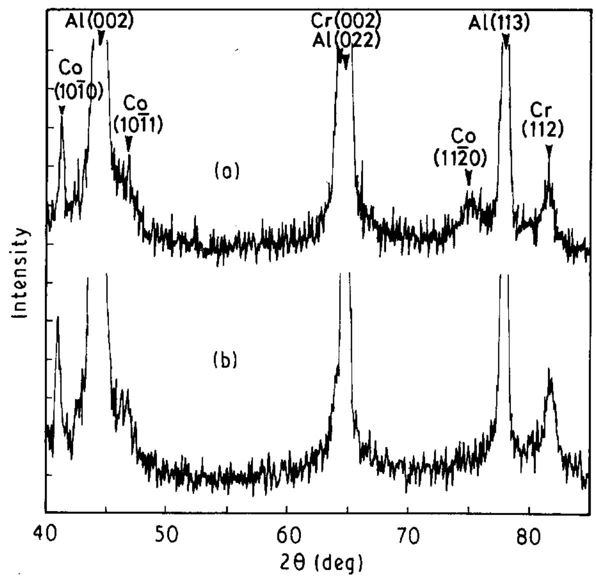

Figure 3 X-ray diffraction patterns of samples sputtered on textured aluminium substrates at (a) 260 °C and (b) 25 °C.

X-ray diffraction spectra as shown in Fig. 3 were obtained for discs sputtered at temperatures of 25 and 260 °C, respectively. For the film deposited at room temperature, the h c p cobalt phase has two peaks identified as $(1\,0\,\bar{1}\,0)$ and $(1\,0\,\bar{1}\,1)$, while the film sputtered at 260 °C, shows a peak at $(1\,1\,\bar{2}\,0)$ accompanied by peaks at $(1\,0\,\bar{1}\,0)$ and $(1\,0\,\bar{1}\,1)$. It reveals that a high substrate temperature is beneficial to the formation of $Co(1\,1\,\bar{2}\,0)$ lines on the substrate surface. This makes the easy magnetization (c-axis) lie in the film plane. Combined with the microstructure studies as described below, we propose that the c-axis is parallel to the texture direction and that the main contribution of the coercivity in the circumferential direction increases from 620 Oe to 1500 Oe.

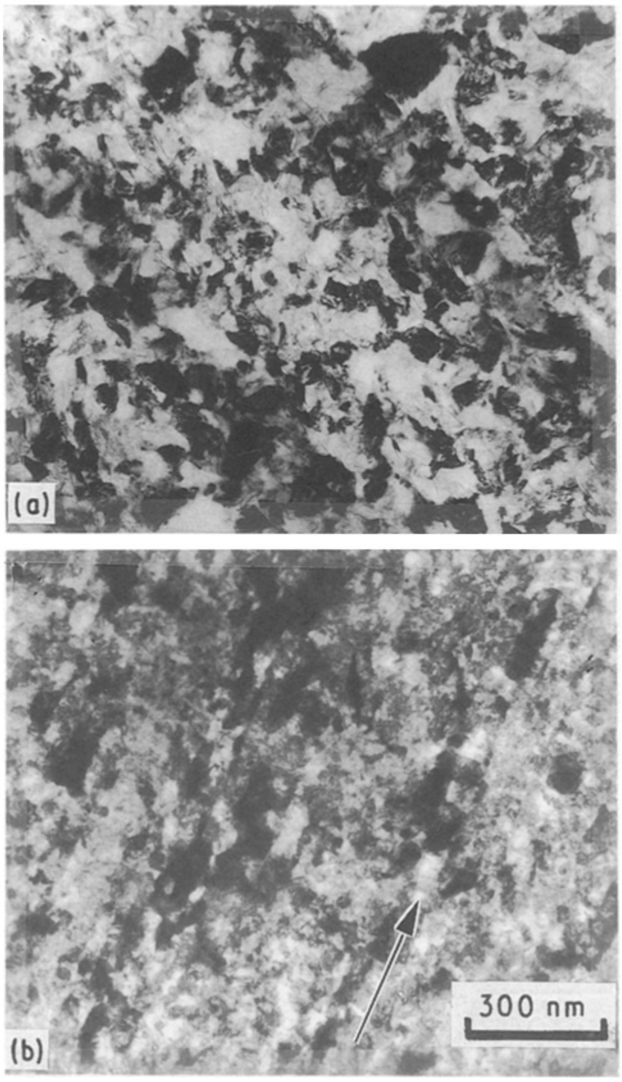

Figure 4 Transmission electron micrographs of samples sputtered on textured aluminium substrates at (a) 25 °C and (b) 260 °C.

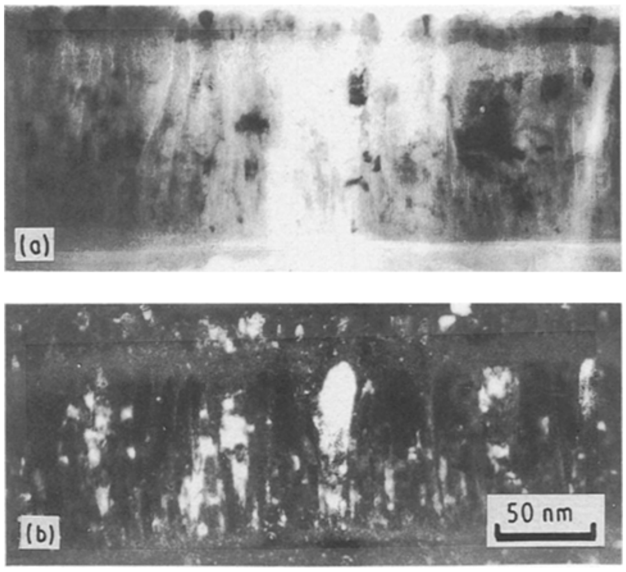

Figure 5 (a) Bright-field and (b) dark-field images of cross-sectional micrographs of samples deposited on textured aluminium substrates at 260 °C.

Plane view microstructures of the two samples examined by transmission electron microscopy are illustrated in Fig. 4. The film deposited at room temperature (Fig. 4a) shows the grain boundary ambiguously. The grain size estimated by dark-field image is about 40 nm. From the image contrast observation, the micrograph indicates that grain orientation is randomly distributed. On the other hand, Fig. 4b shows the microstructure of the high-temperature deposition of CoCrTa/Cr on an aluminium substrate. The grain boundaries are again not easy to distinguish; however, the grain growth along the texture lines can be clearly observed. The image contrast reveals more or less preferred orientation. Fig. 5 shows the bright- and dark-field images of the cross-sectional view of the CoCrTa/Cr structure on an aluminium substrate. The bright-field image (Fig. 5a) shows the isolated columnar structure of the chromium underlayers. The CoCrTa grains replicate the chromium surface morphology. The dark-field image gives detail information about growth. In the initial stage of chromium growth, the grains are small and numerous. As the film becomes thicker, the small columnar grains merge and coarsen. This phenomenon explains how grain size increases with chromium thickness, as shown by the plain micrograph. Finally, the CoCrTa grains grow on the well-textured chromium surface to replicate its preferred orientation.

For films of CoCrTa/Cr sputtered on circumferential textured NiP/Al substrate, the magnetic behaviour is similar to that of deposition on an aluminium substrate. The circumferential coercivity and squareness are larger than the radial properties for the high-temperature sputtered film, as shown in Fig. 6. However, the crystallographic orientation exhibited a very different pattern. Fig. 7a shows the X-ray diffraction patterns of the Cr(0 0 2), Co$(1\,1\,\bar{2}\,0)$ and Co$(1\,1\,\bar{2}\,1)$ reflections of CoCrTa/Cr films deposited on NiP/Al substrates at 260 °C. The results indicate that the CoCrTa polycrystal film with $(1\,1\,\bar{2}\,0)$ and weak $(1\,1\,\bar{2}\,1)$ preferred orientation, occurs when the deposition temperature is high enough to develop the Cr(0 0 2) texture. The dominant anisotropy of the magnetic film is $(1\,1\,\bar{2}\,0)$ rather than $(1\,0\,\bar{1}\,0)$ or $(1\,0\,\bar{1}\,1)$ as the film deposited on an aluminium substrate without an NiP layer or deposited on glass, as is usually reported [2, 8]. Fig. 7b shows a very weak Cr(0 0 2) but without Co$(1\,1\,\bar{2}\,0)$ diffraction for the film sputtered at 100 °C. This different crystal structure from the high-temperature deposition film is very significant.

The corresponding microstructures of the films deposited on textured NiP/Al substrates at temperature of 260 and 100 °C are shown in Fig. 8. Fig. 8a shows the well-developed grains aligned periodically along the texture direction for the high-temperature growth film. The low-temperature film has a smaller grain size and well-distinguished grain boundaries. However, the grain orientation is more or less randomly distributed, as shown in Fig. 8b. The results of crystal growth along the texture lines as revealed in the micrographs are in agreement with the results of magnetic anisotropy measurement.

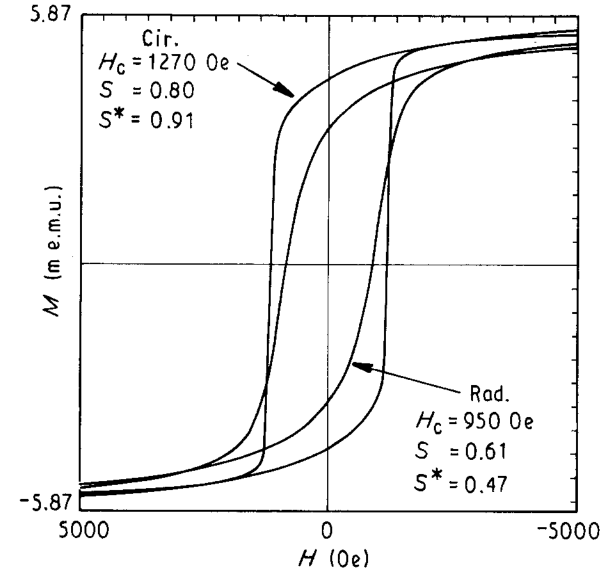

Figure 6 Comparison of hysteresis loops measured in the circumferential and radial directions on samples of CoCrTa/Cr sputtered on textured NiP/Al substrates at 260 °C.

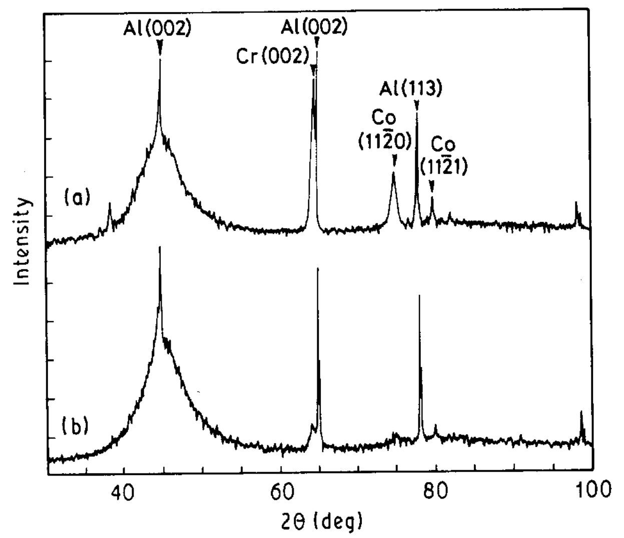

Figure 7 X-ray diffraction patterns of samples sputtered on textured NiP/Al substrates at (a) 260 °C and (b) 100 °C.

4. Conclusion

The CoCrTa/Cr films deposited on textured substrates, either aluminium or NiP-plated aluminium, have the same magnetic anisotropy behaviour. However, the crystallographic orientation related to the anisotropy mechanism is different. For the film deposited on the NiP/Al substrate, the Co(1 1 $\bar{2}$ 0) growth on the Cr(2 0 0) surface is dominant, while for the film sputtered directly on the aluminium substrate, the contribution is from the Co(1 0 $\bar{1}$ 0) combined with Co(1 1 $\bar{2}$ 0), which is the origin of magnetic anisotropy. As the sputtered atoms gain energy from the substrate heating, the cobalt (1 1 $\bar{2}$ 0) preferred orientation makes the easy magnetization axis lie in the film plane and along the texture lines, which is the origin of magnetic anisotropy.

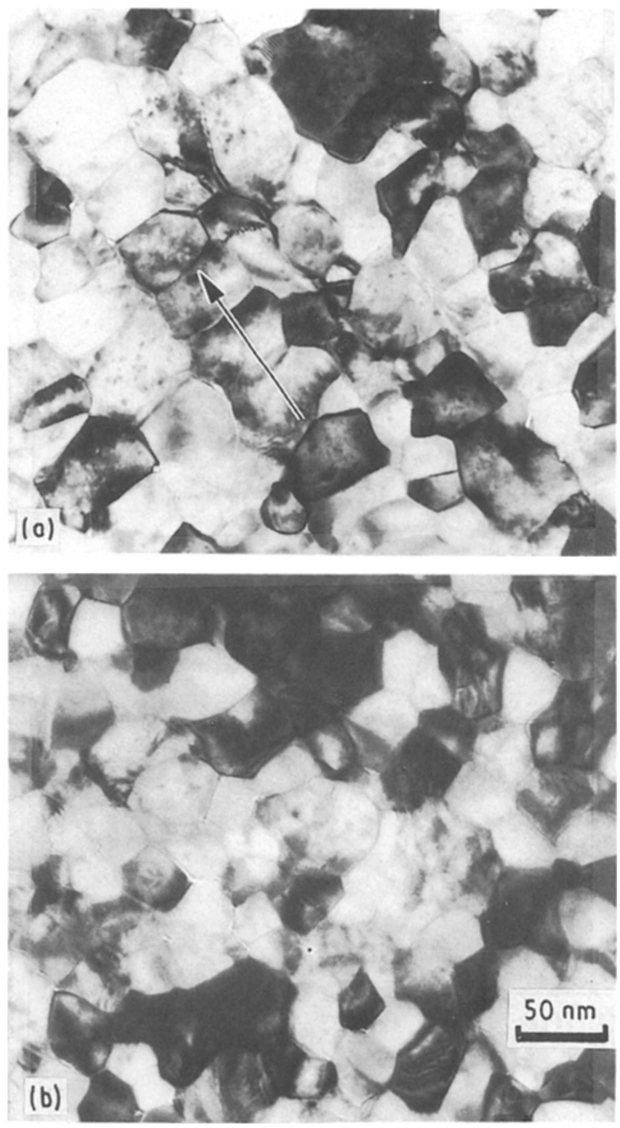

Figure 8 Plane-view micrographs of samples sputtered on textured NiP/Al substrates at (a) 260 °C and (b) 100 °C.

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