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Study of in-plane magnetic anisotropy in Co-based thin-film media

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Abstract

The relationship among macroscopic in-plane magnetic anisotropy, the crystal structure of both the Co-based magnetic layer and the Cr under-layer, and the surface morphology of the textured substrate was studied. In the highly oriented media, the preferred orientation of the *c*-axis of Co to the circumferential direction and the distortion of the Cr crystal lattice were observed. In-plane magnetic anisotropy is induced when the grain of the under-layer is smaller than the texture grooves.

Keywords: Magnetic recording media; Crystal structure; Anisotropy induced; X-ray diffraction

1. Introduction

Generally, in Co-based thin-film media on textured NiP coated substrates, macroscopic in-plane magnetic anisotropy is induced. In this case, H_C is higher in the circumferential direction than in the radial direction. Several models for the origin of this in-plane magnetic anisotropy had been reported, such as the effect of inverse magnetostriction induced in Co crystal grain due to anisotropic stress [1] and the crystal orientation of Co-alloy [2,3]. However, there is no common understanding of the mechanism that causes this phenomenon. To clarify the origin of the magnetic anisotropy, we studied the relationship between the in-plane magnetic anisotropy and the crystal structure of both the magnetic layer and under-layer.

2. Experimental method

On mechanically textured NiP/Al substrates with Ra 1.7 nm, a Cr under-layer, a Co-based magnetic layer and protective layer were formed sequentially using the DC magnetron sputtering method. The substrate temperature just before sputtering was 180°C. The under-layer thickness was varied within the range of 20–200 nm; the thickness of the Co-based magnetic layer was 26 nm (M_s: 0.48 T).

The magnetic properties were measured both in the circumferential and in the radial directions with a vibrating sample magnetometer. The crystal structure of the Co-alloy and the Cr layer was analyzed with an X-ray diffractometer (Cu-Kα line), using the $\theta-2\theta$ scanning method and the glazing angle incidence X-ray diffraction method (GIXD; glazing angle: 0.3°). Using the GIXD method, we were able to analyze the crystallographic data of planes perpendicular to the substrate surface. The GIXD measurements were done from the circumferential and the radial direction to analyze the planes perpendicular to each direction. For the GIXD measurements of the Cr layer, samples without a magnetic layer were used. The microstructure of the film was observed from both the in-plane and cross-sectional direction with a transmission electron microscope (TEM). The surface morphology of the textured substrate was observed with an atomic force microscope (AFM).

3. Results and discussion

Fig. 1 shows the dependence of the thickness of the Cr layer on H_C and the orientation ratio. In this study, the

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orientation ratio refers to the ratio of H_C in the circumferential direction to H_C in the radial direction (H_C^{cir}/H_C^{rad}). H_C in both directions increases as the Cr thickness increases, however, H_C^{cir}/H_C^{rad} decreases.

From the GIXD analysis of the Co-alloy layer of high H_C^{cir}/H_C^{rad} media, it was found that the diffraction intensity of the Co(0 0 2) perpendicular to the circumferential direction ($I_{Co(0\,0\,2)}^{cir}$) is stronger than that to the radial direction ($I_{Co(0\,0\,2)}^{rad}$). This means the number of Co-alloy grains in which the *c*-axis is oriented to the circumferential direction is larger than that to the radial direction. Fig. 2 shows the relationship between H_C^{cir}/H_C^{rad} and the Co(0 0 2) intensity ratio ($I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$). They show a good correlation, and H_C^{cir}/H_C^{rad} increases monotonously with $I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$. This result suggests that the preferred orientation of the easy magnetization axis of the Co-alloy to the circumferential direction induces macroscopic in-plane magnetic anisotropy. We have found that the Co(0 0 2) interplanar spacing is almost constant as the Cr thickness changes. In contrast, for the Cr layer, the Cr(1 1 0) interplanar spacing in the circumferential direction ($d_{Cr(1\,1\,0)}^{cir}$) becomes shorter than that in the radial direction ($d_{Cr(1\,1\,0)}^{rad}$) as the Cr thickness decreases, and the Cr crystal lattice becomes slightly distorted from the BCC structure.

Fig. 3 shows the $d_{Cr(1\,1\,0)}^{cir}/d_{Cr(1\,1\,0)}^{rad}$ dependence of $I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$. In this study, the Cr(1 1 0) interplanar spacing ratio ($d_{Cr(1\,1\,0)}^{cir}/d_{Cr(1\,1\,0)}^{rad}$) was used to express the degree of lattice distortion. $I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$ increases monotonously as $d_{Cr(1\,1\,0)}^{cir}/d_{Cr(1\,1\,0)}^{rad}$ decreases, and the Cr lattice distortion becomes larger. Considering the crystal growth of the HCP Co-alloy with the Co(1 1 0) plane grown on the Cr(2 0 0) plane [4], it is consistent that the

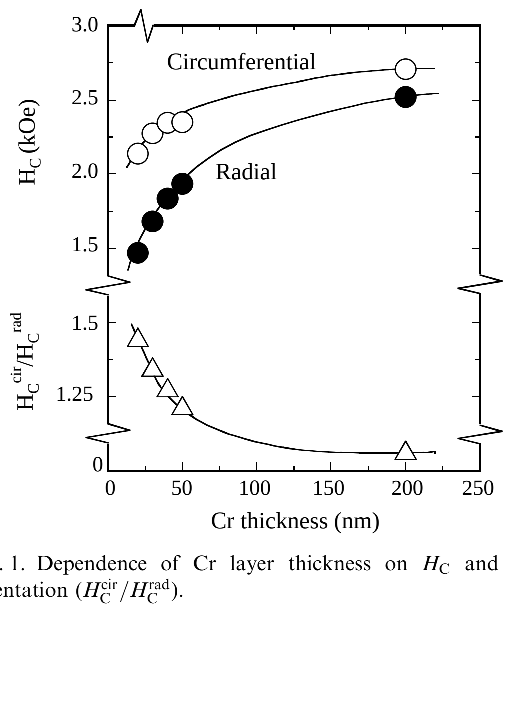

Fig. 1. Dependence of Cr layer thickness on H_C and H_C orientation (H_C^{cir}/H_C^{rad}).

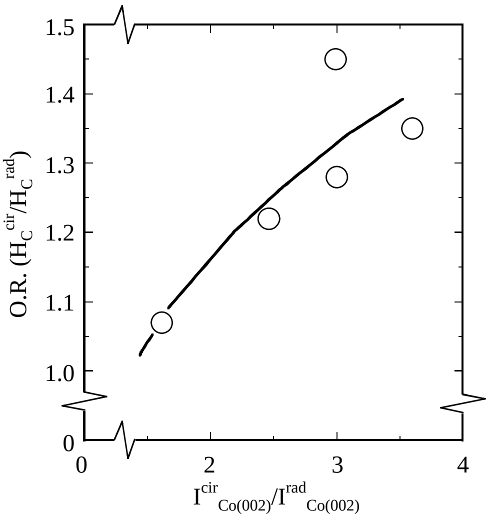

Fig. 2. Co(0 0 2) intensity ratio ($I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$) dependence on H_C orientation ratio (H_C^{cir}/H_C^{rad}).

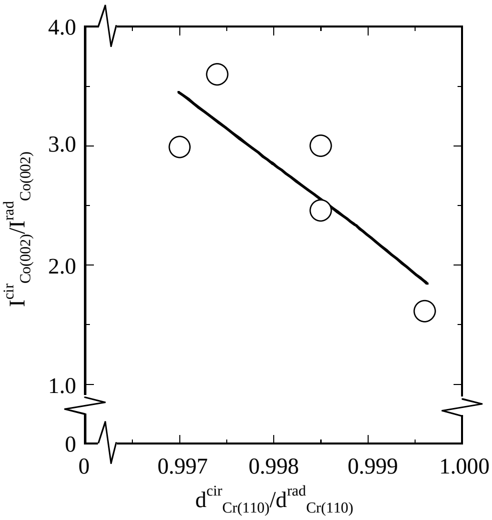

Fig. 3. Cr(1 1 0) interplanar spacing ratio dependence on $I_{Co(0\,0\,2)}^{cir}/I_{Co(0\,0\,2)}^{rad}$.

Co(0 0 2) prefers to orient to the circumferential Cr(1 1 0) of the distorted Cr crystal, because the Co(0 0 2) interplanar spacing corresponds to the short side of the rectangular (1 1 0) plane of a Co unit cell. These results suggest that the distortion of the Cr crystal lattice influences the preferred orientation of the *c*-axis of the Co-alloy and the appearance of the macroscopic in-plane magnetic anisotropy.

The distortion of the Cr crystal lattice is considered to be caused by the stress of anisotropic compressive stress from the substrate surface, which is primarily induced by the cooling of the substrate surface after layer formation. Therefore, we analyzed the relationship between the substrate surface morphology and the grain growth of the Cr layer. In cross-sectional TEM images from the radial direction, fine grooves with a roughness smaller than Ra value were observed on the surface of the textured substrates. In the highly oriented media, the Cr grains are small and grow along these fine grooves. As for the low oriented media with 200-nm thick Cr, large Cr grains grow over several grooves. These results suggest that the compressive stress that the Cr grains receive from the substrate surface is anisotropic between the circumferential direction and the radial direction, if the Cr grains are smaller than the fine grooves. The relation between the distortion of Cr crystal and the anisotropic surface morphology was supposed to play an important role in the preferred orientation of *c*-axis. A detailed analysis of the relationship between grain size and groove width was necessary to better discuss the origin of the in-plane anisotropy. The morphology of the fine grooves was analyzed by the use of an AFM image of the substrate surface. In the AFM image of the substrate surface with Ra 1.7 nm, fine grooves observed in the TEM images are formed on the deep scratches. To analyze the morphology of these fine grooves, components of the wave with a wavelength of over 30 nm were removed from the image thorough a high-pass filter. The half-width of the fine groove (L_0) was taken from the filtered image; its measured L_0 value was 11.1 nm.

Fig. 4 shows the relationship between the ratio of the grain diameter to the half-width of the fine groove (GD/L_0), $d^{cir}_{Cr(1\,1\,0)}/d^{rad}_{Cr(1\,1\,0)}$ and H^{cir}_C/H^{rad}_C. Both $d^{cir}_{Cr(1\,1\,0)}/d^{rad}_{Cr(1\,1\,0)}$ and H^{cir}_C/H^{rad}_C exhibited drastic changes at $GD/L_0 = 1$. When $GD/L_0 < 1$, a large degree of Cr lattice distortion and a high H^{cir}_C/H^{rad}_C were observed. These results demonstrate that the anisotropic stress from the substrate surface induces the distortion of the Cr crystal lattice and the anisotropic crystallographic orientation of the Co-alloy when the Cr crystal grain is smaller than the half-width of the texture grooves. In contrast, when the Cr crystal grain is larger than the half-width of the grooves, the morphology of the grooves does not influence the Cr crystal lattice and the crystallographic orientation of the Co-alloy layer.

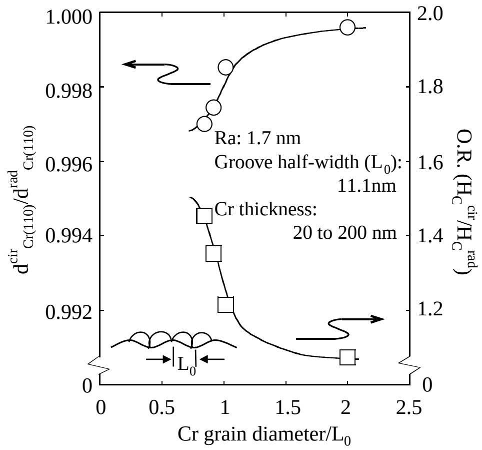

Fig. 4. Cr(1 1 0) interplanar spacing ratio and H^{cir}_C/H^{rad}_C as a function of the ratio of grain diameter and groove half-width L_0.

4. Summary

The origin of the macroscopic in-plane magnetic anisotropy that is induced on a mechanically textured substrate is the preferred orientation of the Co *c*-axis to the circumferential direction. This preferred orientation is strongly related to the distortion of the Cr crystal lattice. The lattice distortion is caused by the stress of anisotropic compression from the substrate surface, when the grain diameter is smaller than the half-width of the fine grooves on the substrate surface.

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