Crystallographic orientation of Cr in longitudinal recording media and its relation to magnetic anisotropy

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A specific growth of Cr layer grains is found to exist when grown on the mechanically textured NiP–Al substrates used for longitudinal recording. High resolution transmission electron microscopy analysis of a large number of individual Cr grains indicate a Cr[110] preferential growth along the textured direction (groove or circumferential direction). This particular orientation of the Cr underlayer is found to be the cause of an in-plane magnetic anisotropy of the Co based magnetic layer. The temperature dependence of this in-plane magnetic anisotropy study indicated the importance of the specific crystallographic orientations of both the underlayer and the magnetic layer. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1500433]

Longitudinal magnetic recording media made on circumferential mechanical textured (scratch) NiP/substrate, are known to show superior high density recording performance. When deposited at higher substrate temperatures (~200 °C), an epitaxial orientation relationship of Co(11**2**0)[00**0**2]‖Cr(002)[110]/NiP/Al is easily obtained. Samples made on a mechanically textured NiP layer, in addition, show an in-plane magnetic anisotropy of the Co(11**2**0) layer. This anisotropy is quantified as the orientation ratio (OR), a dimensionless quantity, calculated by the ratio of the coercivities (or remanent magnetization) when the applied magnetic field is along circumferential (easy axis) and radial directions, respectively. Although the origin of OR is so far not clearly understood, interesting studies have been reported which are beneficial for the future development of magnetic recording.[1–4] The two possible main mechanisms, suggested for this in-plane magnetic anisotropy, are stress on the magnetic layer,[1] and the *c*-axis (Co[0002] direction) preference of orientation along the groove direction.[2,3] However, there are no explanations for this particular predominant *c*-axis orientation of the Co grains in the magnetic layer along the mechanical groove direction. It was pointed out that this predominant orientation of the *c*-axis may be due to a particular nucleation of Cr.[3] In this letter, we explain in detail how this particular growth of Cr was observed, which in turn helps the orientation of Co[0002] along the circumferential direction and gives rise to an OR. We have also studied the OR with respect to temperature to understand the mechanism of in-plane magnetic anisotropy.

The above-mentioned epitaxial relationship of the Cr underlayer and Co magnetic layer is shown in Fig. 1, which explains the good lattice matching for Co *c*-axis (Co[0002]) along the Cr[110] direction. For the observed *c*-axis growth along the circumferential direction to occur, Cr lattice orientation has to be anisotropic in the plane; more precisely, Cr[110] has to be along the scratch direction (circumferential). This is because of the epitaxial growth of Cr and Co layers as mentioned above. The main difficulty in establishing the in-plane anisotropy of Cr is due to its high crystallographic symmetry. Also, mechanical scratches create surface topography with two-fold in-plane degeneracy, making it difficult to get the lattice orientation effects from grazing incidence x-ray diffraction or selected area diffraction. To avoid the above-mentioned modulation effects, instead of looking at a collective ensemble of Cr grains, we looked at individual grains and examined the [110] direction in relation to the groove direction using high resolution transmission electron microscopy (HRTEM). The method of observing a Cr grain's crystallographic orientation is schematically represented in Fig. 2. For this study, a layer of 5-nm-thick Cr was deposited on the mechanically textured NiP layer. The TEM sample was mounted on the platform and the electron beam was moved across the groove directions at an angle of 30° to scan six to eight grains, taking diffraction patterns of each of them. In order to observe the single grain diffraction images, an e-beam of diameter <3–4 nm was used, which is less than the average grain diameter of Cr grains (5~6 nm). The photograph is taken in such a way that the circumferential direction is parallel to one side of the photograph. This helps us to obtain the crystallographic orientation of Cr with respect to the circumferential direction. The diffraction pattern thus obtained is shown in Fig. 2(b). It is easy to identify the Cr[110] zone axis direction as shown in Fig. 2(b).

Diffraction patterns of more than 100 grains were taken and the [110] orientation with respect to circumferential direction was estimated. The statistics thus obtained is illustrated in Fig. 3. Figure 3 clearly shows that number of Cr

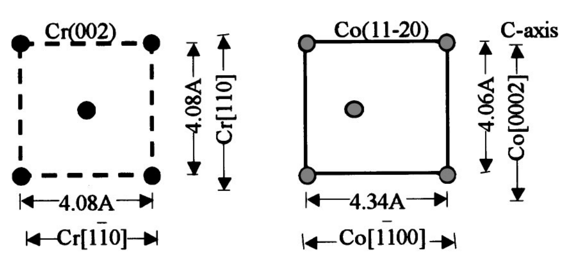

FIG. 1. Epitaxial and interatomic spacing relationship for Cr(002) and Co(11$\bar{2}$0). Note that lattice mismatch between Cr and Co lattice along the *c*-axis (Co[0002]) direction is 0.5% and that perpendicular to it is 5.4%.

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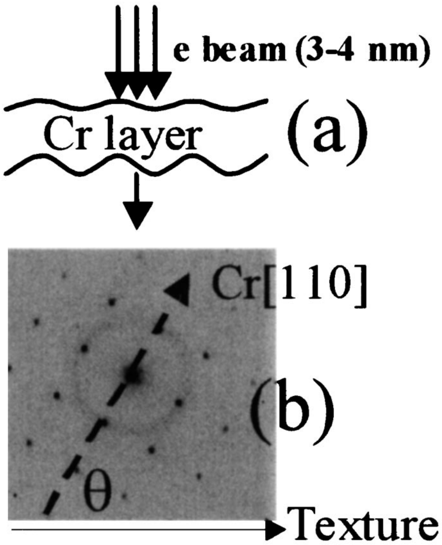

FIG. 2. (a) Schematic representation of TEM observation of Cr grains on mechanically textured NiP–Al substrates and (b) diffraction pattern from a single grain with arrows indicating Cr[110] direction.

grains with the [110] direction along 0° (circumferential direction) and 90° (radial direction) are prominent over any other direction, within the plane of the film. Since Cr (002) has a square lattice structure (as shown in Fig. 1), circumferential and radial directions are equivalent and hence indistinguishable. This preference of the Cr lattice is an important result, believed to be random within the plane. Although the reason for the Cr [110] towards the texture lines is not clear, we believe it may be either to reduce the surface energy or to grow less stressed lattice structure. It is interesting to note that specific crystal orientation induced by scratches are also found for the thin film transistor systems.[5] Recent observation of OR on samples made using the skewed angle deposition of Cr layer[6] (with no scratches) also shows the importance of specific orientation requirements of Cr grains.

The Co grains formed on this particular Cr [110] orientation are expected to have the four-fold periodicity (equal preference along circumferential and radial directions) of its c-axis (circles in Fig. 4) due to the epitaxial growth. Figure 4 shows the schematic representation of the expected and the experimentally observed Co c-axis orientation on top of the above-mentioned Cr[110](002) anisotropic orientation. However, experimentally we only see a preference of c-axis orientation along circumferential direction and not along the radial direction (two-fold) (solid lines in Fig. 4).[2,3] If there were any other angle of preference in the plane, then the distributions shown in Figs. 3 and 4 of Cr[110] and Co[0002] would show a maximum at that corresponding angle.

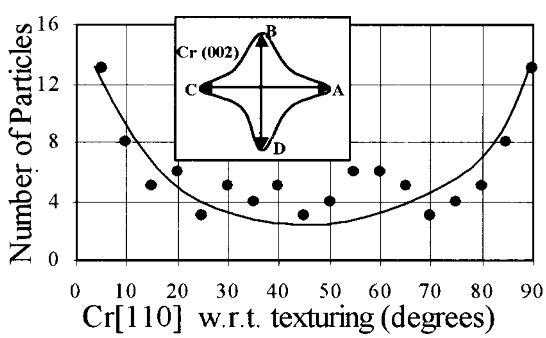

FIG. 3. Cr [110] orientation on the textured substrate. Note that [110] direction is likely to lie along circumferential (0°) or radial direction (90°) than any other angle. Inset shows the schematic of the same population of [110] of Cr(002). AC indicate the circumferential and BD indicate the radial directions.

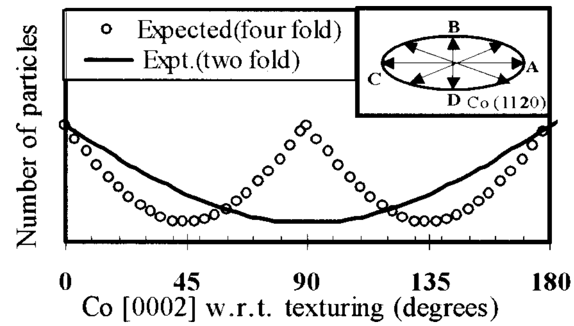

FIG. 4. Expected (4 fold) and experimentally observed (two fold) Co c-axis in plane orientation on the anisotropic Cr [110]. Inset shows the experimental c-axis population of Co(1120) texture, highest along the circumferential (AC) and lowest along the radial directions (BD).

Figure 5 shows the typical in-plane bright field TEM image of magnetic grains of Co alloy (CoCrPtB) layer whose c-axis distribution is shown in Fig. 4. From the large number of grains we have studied, it is clear that the c-axis of the grains (shown as white arrows) near the mechanical texture line (shown as black arrows) is mostly in the same direction. Also along the scratch lines grain boundaries are formed. It is evident from different c-axis orientation of neighboring grains on either side of texture line, that they are not originating from a single grain with the texture line acting as a stacking fault direction.

It is a known fact that magnetostriction parallel to the Co c-axis direction is zero and is relatively higher in the perpendicular direction and highest at 60° to c-axis.[7,8] However, CoPt systems show an increase in magnetostriction,[9] although for the c-axis direction it is still the lowest. Ross *et al.*[10] have reported that along the groove direction, magnetic grains undergo higher compressive stress than that of the radial direction for a thick layer of CoCrTa alloy system, although the stress induced magnetic anisotropy is much lower than the crystalline magnetic anisotropy. The above factors indicate that Co nucleation on [110] oriented Cr grains will happen when the c-axis is along the groove direction. Thus the grains may form by minimizing the lattice distortion by aligning the c-axis along the texture direction. If it were the other way, with the c-axis along the radial

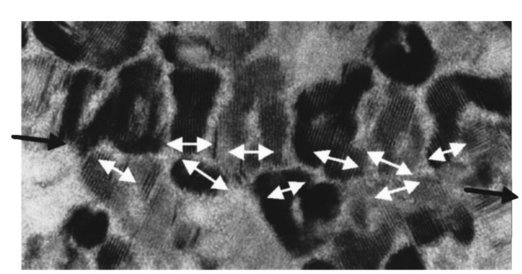

FIG. 5. HRTEM image of Co grains of CoCrPtB(20 nm)/Cr(5 nm)/NiP–Al. White arrows are indications of each grain's c-axis orientation, near to the mechanical texture lines (shown as black arrow). Note the Cr rich grain boundary formation along the texture lines.

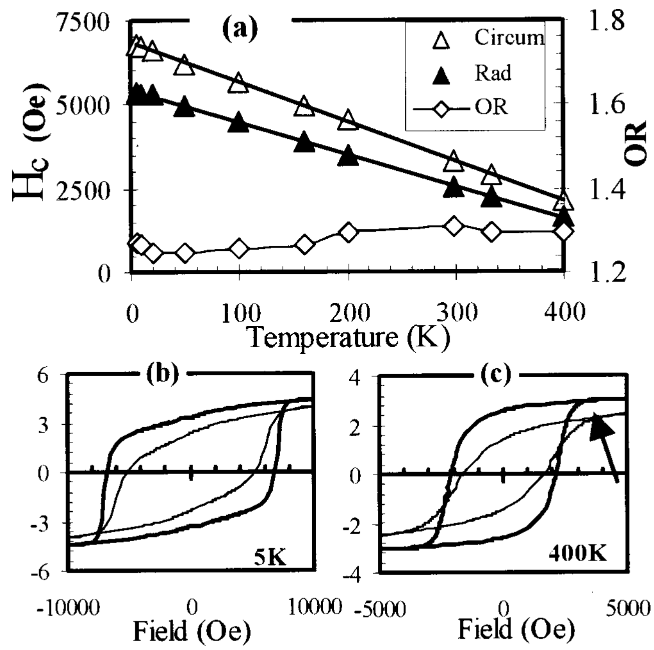

FIG. 6. (a) Temperature dependence of orientation ratio for 20 nm CoCrPtB on 5 nm layer, (b) and (c) show the $M-H$ loop shapes at 5 and 400 K, respectively (y-axis is M in 10^{-4} emu). Note radial loop closes outside circumferential loop (shown as arrows) at 400 K and inside at 5 K.

direction, lattice distortion along texture lines would have been increased due to the high stress along the groove direction. The above mentioned c-axis preference would happen mostly for grains near the texture lines. This tendency of Co grains to avoid lattice distortion along the circumferential direction is also evident from the Cr rich grain boundary formation along the groove direction (Fig. 5). It is important to point out that such grain boundary formations are not seen for the Cr underlayer, but are unique only to the magnetic layer. We have verified this c-axis orientation along the texturing direction for a large number of films studied, and the results were similar to those shown in Figs. 4 and 5. Away from the texture lines, c-axis orientation of Co grains is comparatively more random. This would also explain the increase in the OR values with an increase in density of mechanical texture lines.[1,4] For different Pt containing systems the stress or magnetostriction values are different, hence with different alloy compositions, the OR value could be slightly different.

Apart from the above-mentioned crystalline in-plane anisotropy, we have studied the temperature dependence of the OR. This was carried out to estimate the changes in OR possibly due to intergranular exchange (predicted in Ref. 4), stress or strain, and c-axis distribution. Since the intergranular exchange and magnetoelastic values are significantly higher for Co[8] and CoPt systems at lower temperatures, we expect large increase in OR at lower temperatures. On the other hand, if c-axis distribution is causing the anisotropy, OR values are expected to remain constant since c-axis distribution of grains, once formed, is independent of temperature. Figure 6(a) illustrates the circumferential and radial coercivity values and OR for 20 nm CoCrPtB layer on the 5 nm Cr layer, measured using a superconducting quantum interference device, from 5 to 400 K. From Fig. 6(a), it is clear that the OR is nearly constant from the 5 K value (1.27) to 400 K value ($\sim$1.31). In Figs. 6(b) and 6(c), $M-H$ loops measured at 5 and 400 K, respectively, are shown. It is interesting to note that the loop shapes are significantly different, and the radial loop closes predominantly outside the circumferential loop more so at 400 K than at 5 K. Although only 5 and 400 K data are shown, the changes in loop shape are gradual going from 5 K to 400 K. Khanna *et al.*[4] have pointed out that the radial loop closes outside the circumferential loop due to the incomplete magnetization along the texture lines. Since the grain boundaries are more magnetic at lower temperatures (larger exchange) and less magnetic at higher temperatures (weaker exchange), the radial loop would predominantly close outside the circumferential loop at higher temperatures, in agreement with Ref. 4. Similarly, the stress state at lower temperatures is higher, hence OR is expected to be larger. Even though the exchange and stress values are higher we do not find any increase in the OR at 5 K; instead a nearly constant OR value was observed. This near constant value indicates the c-axis distribution as the cause of OR, as mentioned previously. This result is thus consistent with the TEM observation[2–4] and also the specific Cr orientation mentioned previously. Since the OR is determined by measuring the coercivity, thermal effects sets in when the thickness or grain sizes are smaller. Hence we believe a slight increase in the OR value at high temperature is due to the thermal instability (detailed results will be discussed elsewhere).

In conclusion, we report evidence for strong lattice orientation anisotropy in the plane of the film for both underlayers and magnetic layers grown on the mechanically textured NiP–Al substrates. Complementary effects from specific Cr[110] orientation and stress anisotropy within the magnetic layer, induced by mechanical texturing, are believed to be helping the Co grains c-axis nucleation along the texturing direction. Results from temperature dependence of the OR are consistent with the observation of c-axis distribution as the cause of OR.

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