Study of stacking faults in Co-alloy perpendicular media

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Stacking faults (SFs) and fcc-phased grains are studied by electron diffraction in perpendicular media. Co-alloy compositions, such as CoCrPt, CoCrPtB, are compared on different underlayers and deposition conditions. It is found that CoCrPtB alloys tend to have greater amount of SFs and fcc grains than the CoCrPt alloy. Underlayers as well as low deposition rate and base pressure help to reduce the amount of SFs and fcc phase.
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I. INTRODUCTION

High perpendicular anisotropy is critical for obtaining adequate thermal stability in future ultrahigh density magnetic recording media.[1] For Co-alloys, in order to achieve high K_u as well as an adequate ratio of anisotropy and demagnetization fields ($H_k/4\pi M_s \sim 2-3$), it is important to reduce the amount of fcc grains and stacking faults (SFs).[2] However, in pursuing the perfect preferred orientation, the control of hetero-epitaxy is different between longitudinal and perpendicular media. Figure 1 illustrates the difference in a schematic diagram. In the longitudinal case, there is a good match between Co hcp-(11.0) lattice plane and Cr (200) plane, while there is a poor lattice match between the corresponding Co fcc-(112) plane and Cr (200) plane. Therefore, it is much more favorable for hcp Co structure to grow at the interface.

On the other hand, in the perpendicular media case, the lattice match is always good between the underlayer [e.g., Ru (00.2)] and the magnetic layer, Co hcp-(00.2) or Co fcc-(111). Consequently, no constraint is available through the entire film to limit the fcc growth. Under these considerations, it can be predicted that there will be more fcc and SFs in the perpendicular media than in the longitudinal media. Moreover, it can also be expected that alloy compositions that work well for longitudinal media may not work for perpendicular media. For example, it has been found[3] that perpendicular media of CoCrPtB alloy have lower remanence and lower H_k compared to the respective longitudinal media[4] with same composition.

In addition, SF detection in longitudinal media is established based on x-ray diffraction,[5] transmission electron microscopy[6] and electron diffraction.[7] These techniques need to be re-visited for perpendicular media. In this work the amount of fcc grains and SF density in perpendicular media is studied by electron diffraction (ED). The purpose of this study is not only to demonstrate an ED method qualitatively studying the SFs and fcc grains in perpendicular media, but also to understand the role of alloy composition, deposition rate and underlayer on the SF density and number of fcc grains in the perpendicular media.

II. EXPERIMENT

CoCrPtB and CoCrPt thin films were dc-sputter deposited onto glass substrates (or Si wafers) with (or without) underlayers at elevated temperature. FeCoB is used as the soft magnetic underlayers (SUL).[8] The intermediate layer (IL) is similar to the one described in Ref. 9. The deposition was carried out by using an Intevac MDP sputter system at a deposition rate of 4 nm/s. One CoCrPtB sample was made in a K. J. Lesker UHV sputter system at lower base pressure (10^{-10} Torr) and much slower deposition rate (0.35 nm/s). A homemade PMOKE looper was utilized to obtain hysteresis loops. A Philips EM420 TEM was used for electron diffraction with a double tilt specimen holder.

III. RESULTS AND DISCUSSION

The geometric setting of the crystal structures in perpendicular media is different from longitudinal media. In the former, all the *c*-axes of Co-alloys are parallel to the film normal, while in the latter, the *c*-axes are randomly oriented in the film plane. Accordingly, the fcc grains can be randomly oriented in a longitudinal film, where the SF-caused

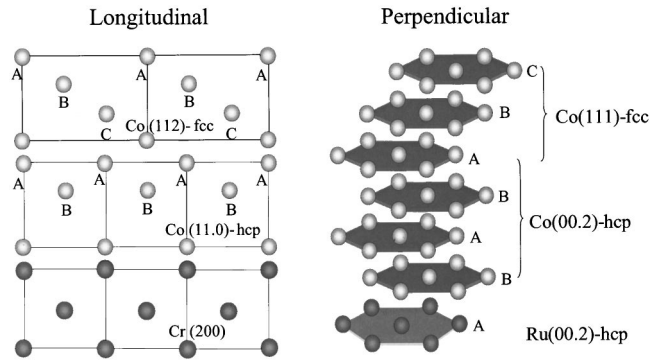

FIG. 1. Schematic diagram of the epitaxial relationships in longitudinal (left) and perpendicular media (right).

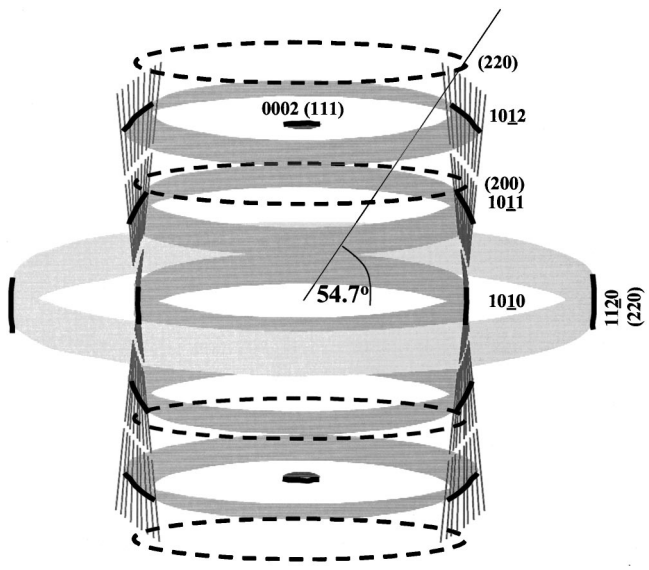

FIG. 2. Schematic diagram of the reciprocal structure of a perpendicular media with stacking faults and fcc grains.

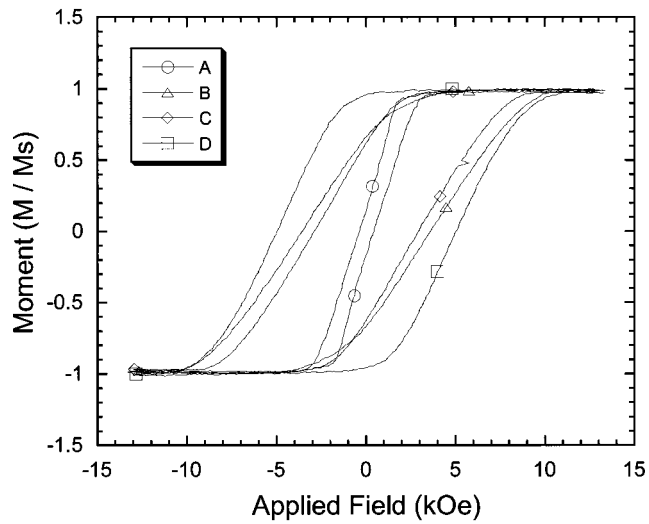

FIG. 3. Normalized hysterisis loops of samples A, B, C, and D.

ED streaks, which should always be parallel to the *c*-axis, lie randomly in the film plane.[7] In contrast, in the perpendicular media, the fcc grains are most likely (111) textured[10] and the SF streaks are parallel to the film normal. This difference in crystallographic configuration requires a different procedure to detect fcc grains and SFs in perpendicular media. Figure 2 shows a schematic diagram of the reciprocal structure of the Co-alloy film in a side-view. The hcp phases are plotted in dark bands, while the position of fcc reciprocal rings are marked by broken lines and indexed within the parentheses. The SF streaks and diffraction arcs of the hcp phase are plotted only at the cross-section plane, which contributes to a cross-sectional ED pattern. However, the major difficulty of the cross-sectional ED is the small amount of material participating in the ED and difficulty in preparing the specimen. Plan-view ED can overcome these two drawbacks by tiling the specimen to a high angle (e.g., 54.7° as marked in the Fig. 2). Under these tilted conditions one can see the SF-streak intersections with Ewald sphere as well as fcc (220) diffraction arcs (if present).

Five perpendicular media samples of different layer structures as described in Table I are investigated. The normalized MOKE hysteresis loops of samples A–D are plotted in Fig. 3. It can be seen that without any underlayers the Co-alloy film (sample A) has extremely low remanence and coercivity (H_c). The CoCrPtB films of samples B, C and E have low remanence and moderate coercivities, compared with their longitudinal-media equivalents.[4] On the other hand the CoCrPt media have the highest H_c and almost full remanence.

50°-tilt ED patterns of the samples A–E are shown in Figs. 4(a)–4(e), respectively. Figure 4(f) is the schematic diagram of the diffraction rings that may possibly be present in a perpendicular Co-alloy thin film. The dotted rings belong to the fcc phase and are indexed within parentheses. In Fig. 4(a) the presence of the 11.0 arc along the tilt axis indicates a (00.2) crystallographic texture of the Co-alloy film. In addition, there are two arcs at the same radial position as the 11.0 arc but perpendicular to the tilt axis. These cannot belong to the hcp phase, which has a uni-axial crystal structure. They originate from fcc 220 reflections in a (111) texture. Moreover, the arcs in the ED pattern are almost continuous, forming a whole ring, which indicates a weak hcp-(00.2)/fcc-(111) texture. There are many cloudy dots (pointed to by the arrow) between the first wide ring and the second ring. These dots are due to the SF streaks from 10.2 and 10.3 arcs intersecting with the Ewald sphere. Therefore, it can be concluded that the Co-alloy film that is directly deposited onto a glass substrate has poor crystallographic texture, and large amount of fcc grains and SFs.

In the ED pattern of Fig. 4(b) the rings break into arcs indicating a stronger texture than found in sample A. However, the hcp-11.0 and fcc-220 arcs still stay at the same ring position perpendicular to each other, though the fcc-220 arcs bear lower intensity than the ones in Fig. 4(a). In the position where 10.2, 10.3 arcs are present [refer to the indexed arc

TABLE I. Samples of the perpendicular Co-alloy thin films for the electron diffraction study.

ID	Substrate	SUL thickness	IL thickness	Magnetic layer	H_C (Oe)	S
A	Glass	0	0	$CoCrPtB_{10}$ (20 nm)	349	0.13
B	Glass	200 nm	10 nm	$CoCrPtB_{10}$ (24 nm)	3575	0.67
C	Glass	200 nm	10 nm	$CoCrPtB_{12}$ (24 nm)	2914	0.62
D	Glass	200 nm	10 nm	CoCrPt (24 nm)	4985	0.96
E	Si-wafer	0	30 nm	$CoCrPtB_6$ (40 nm)	3000	0.57

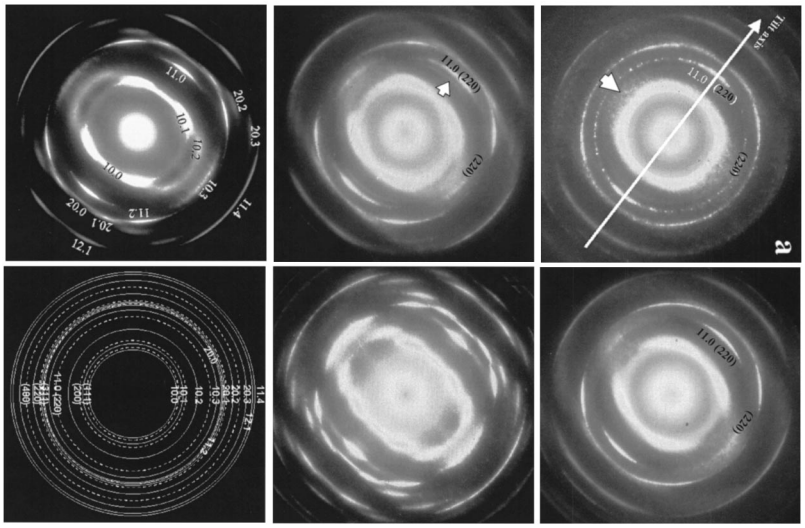

FIG. 4. Electron diffraction (ED) patterns of (a) sample A, (b) sample B, (c) sample C, (d) sample D (e) sample E, and (f) a schematic diagram of the possible ring positions in an ED pattern with both hcp and fcc Co-alloy existing.

positions in Fig. 4(e)] there are cloudy intensities. Again these intensities are caused by SFs. However, the intensities are not as strong as in Fig. 4(a). Figure 4(c) has an almost identical ED pattern to Fig. 4(b), except for the additional weak arc (pointed to by the arrow) identified as Ru 11.0. These findings indicate that the $CoCrPtB_{10}$ and $CoCrPtB_{12}$ films with soft-underlayer and interlayer still contain many fcc grains and SFs, though the number of fcc grains and SF density are reduced compared with the film without any underlayer. The high level of fcc grains and SFs explains the inferior magnetic properties of the perpendicular CoCrPtB media.

Figure 4(d) shows many short arcs indicating a much stronger (00.2) texture than the previous three films. Moreover, there are no fcc-220 arcs present in the pattern, which indicates that few fcc grains exist in the film. It can also be seen that the 10.2 and 10.3 arcs are of very strong intensity, around which there is weak cloudy contrast observed. This suggests a lower SF density in the present CoCrPt film. The ED pattern of sample E in Fig. 4(e) also shows hcp diffraction arcs only. The SF intensity is comparable with that in Fig. 4(d), though the lengths of the arcs are greater. This demonstrates that the CoCrPtB film deposited at low sputtering rate and low base pressure can have few fcc grains and SFs. This finding is consistent with the results of a previous sputtering rate study.[11]

It is worth mentioning that magnetic properties of sample E are inferior to sample B even though sample E contains less SFs. This is because SF density is not the only reason responsible for the magnetic properties of perpendicular media. The fact that the M_s value of sample E is much higher may be responsible for its poorer perpendicular magnetic properties.

IV. CONCLUSION

CoCrPtB alloy perpendicular media have been found containing high level of fcc grains and SFs. CoCrPt perpendicular media does not have ED-detectable fcc grains and it has lower SF density than the CoCrPtB media. The use of underlayers can decrease the number of fcc grains and SFs. Low deposition rate and low base pressure can significantly reduce the amount of fcc grains and SF density in CoCrPtB films.

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