Highly oriented perpendicular Co-alloy media on Si(111) substrates

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CoCrPt/Ti/Ag films with the easy axes of the hexagonal-closed-pack Co grains perpendicular to the film plane were epitaxially grown on HF-etched Si(111) single crystal substrates by rf sputter deposition. The orientation relationship was determined by x-ray pole figure measurements and transmission electron microscopy to be CoCrPt(0001)$[10\bar{1}0]\|$Ti(0001)$[10\bar{1}0]\|$Ag(111)$[11\bar{2}]\times\|$Si(111)$[11\bar{2}]$. The magnetic properties of the CoCrPt films were greatly improved by introducing these single crystal templates. Rocking curve measurement showed a greatly improved *c*-axis orientation of the cobalt alloy. Highly oriented, high coercivity properties for perpendicular recording have been obtained. © *1999 American Institute of Physics.* [S0021-8979(99)51608-3]

I. INTRODUCTION

The looming thermal stability limits that have been espoused[1] for longitudinal media implies that a thicker perpendicular media will have larger grains and, hence, better stability. However, the additional complexity of the perpendicular head and the poor head field gradient associated with the orientation requires that either the orientation dispersion of the media be extremely small or that a thick magnetic head imaging soft magnetic underlayer be used. A potentially superior engineering compromise would be to use a conventional thin film ring head with a media of superior perpendicular orientation.[2] Also it has been advocated[3] that a singly oriented media will better utilize all of the magnetic grains in a bit cell and so should require fewer grains to achieve an acceptable signal-to-noise ratio. Here, we discuss new preparation methods for achieving highly oriented perpendicular Co-alloy films via the employment of epitaxial growth upon ⟨111⟩ oriented single crystal Si substrates. Si wafers are potentially suitable as small magnetic disk substrates as they are readily available, reasonably inexpensive, and can be polished quite smooth.

Ti has historically been used as the underlayer of Co alloy perpendicular media since Co alloys naturally evolve a hexagonal-closed-pack (hcp) (0001) texture on Ti underlayers. Although the texture of Ti underlayer is not essential for inducing the (0001) texture of Co, our work shows that highly (0001) oriented Ti underlayer can greatly improve the magnetic properties and reduce *c*-axis dispersion of the Co alloy media for perpendicular recording.

In this work, just as in the case of Ag(100) on Si(100),[4] it was observed that when sputter deposited upon hydrofluoric etched Si(111) single crystal substrates, Ag(111) grows epitaxially. Due to the close lattice match between Ag(111) and Ti(0001), Ti(0001) can epitaxially grow on the Ag(111) film. Even though the lattice mismatch between Ti and Co is somewhat large (~14.9%), Our results show that (0001) oriented Co alloys can still epitaxially grow on these Ti/Ag/Si(111) templates. Figure 1 schematically shows the lattice planes of Ag(111), Ti(0001), and Co(0001) and their lattice parameters, as well as the designed structure of the media.

II. EXPERIMENT

Si(111) wafers were first ultrasonically cleaned in organic solvents and rinsed in deionized water. Clean wafers were then immersed in HF to remove the native SiO_2 and obtain a hydrogen-terminated surface. The etched wafers were blown dry using N_2 gas, then placed into the sputtering system, and heated to about 250 °C in vacuum before deposition. Ag, Ti, and CoCrPt thin films were then deposited by rf diode sputtering in a Leybold–Heraeus Z-400 sputtering system. The base pressure was below 5×10^{-7} Torr. The Ar sputtering gas pressure was fixed at 10 mTorr and the sputtering power density was about 2.3 W/cm^2. The composition of the cobalt alloy is $Co_{68}Cr_{20}Pt_{12}$ which has lattice parameters slightly larger than that of pure Co. The Cr and Pt composition in the alloy effectively decreases the saturation magnetization so that it is appropriate for perpendicular recording.

III. RESULTS AND DISCUSSION

The epitaxial orientation relationships were studied with both θ/θ method and ϕ scan on a Rigaku x-ray diffractometer using a Cu $K\alpha$ radiation, as well as transmission electron microscopy (TEM). Rocking curves for CoCoPt/Ti/Ag/Si(111) samples have also been measured to investigate the dispersion of the textures.

Figure 2(a) shows the x-ray diffraction (XRD) pattern of a $Co_{68}Cr_{20}Pt_{12}$(50 nm)/Ti(50 nm) film deposited on a Si(111)

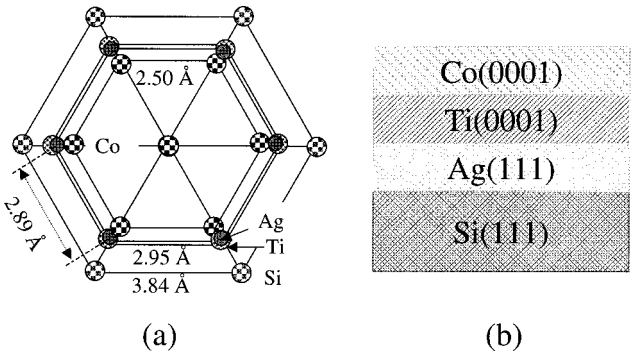

FIG. 1. (a) Schematic draw of the lattice planes of Ag(111), Ti(0001), and Co(0001). (b) The designed structure of the highly oriented thin film media.

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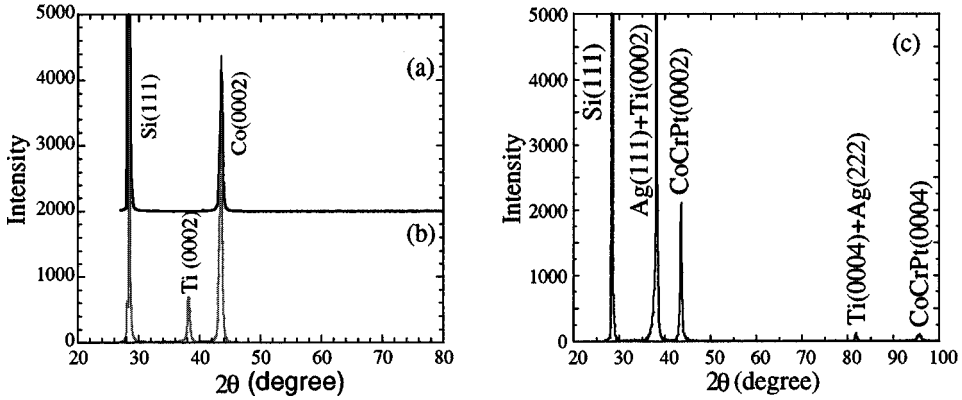

FIG. 2. X-ray diffraction patterns of (a) $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm/Si(111) without HF etching; (b) $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm/HF–Si(111); (c) $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm/Ag 12 nm/HF–Si(111).

substrate without HF etching. The Ti film does not show any texture in this case and the $Co_{68}Cr_{20}Pt_{12}$ shows only (0002) texture. Figure 2(b) is the XRD spectra of $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm deposited on a HF etched Si(111) substrate. A Ti(0002) peak shows up in this case along with the (0002) CoCrPt peak. However, the Ti(0002) peak is not particularly strong. The x-ray diffraction spectra for a representative $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm/Ag 12 nm film grown on HF–Si(111) is shown in Fig. 2(c). Only those peaks corresponding to $Co_{68}Cr_{20}Pt_{12}$(0001), Ti(0001), and Ag(111) planes can be observed. It is seen that in the presence of a thin Ag intermediate layer, the intensity of Ti(0002) peak increased significantly. It was also observed that epitaxial Ti was obtained for various Ag layer thickness, even as thin as 10 nm.

The ϕ scan spectra of a $Co_{68}Cr_{20}Pt_{12}$ 50 nm/Ti 50 nm/Ag 50 nm/HF–Si(111) film are shown in Fig. 3. As expected from the cubic crystal (111) stereographic projection, three diffraction peaks that are 120° apart were found in the Si{220} pole ϕ scan spectrum [Fig. 3(a)] for the single crystal Si(111) substrate. However, for the (111) textured Ag layer, six evenly spaced diffraction peaks were observed from the {220} pole figure scan spectrum [Fig. 3(b)]. The second, fourth, and sixth Ag{220} pole scan spectrum peaks appear at the same locations as the three peaks in Si{220} scan, confirming the epitaxial relationship between the Si$[11\bar{2}]$ and Ag$[11\bar{2}]$ directions. For a perfect cubic single crystal, the (111) stereographic projection should only show three {110} poles. However, the six peaks observed for the Ag film suggests that twinning has occurred during film growth. This was confirmed by TEM.

For the (0001) textured Ti film, six evenly spaced diffraction peaks were observed from the $\{10\bar{1}1\}$ pole figure scan [Fig. 3(c)]. This is in agreement with the stereographic projection of single crystal hcp (0001) lattice. The peaks also occurred at the same positions with Ag{220} pole figure scan peaks, indicating that the epitaxy relationship between

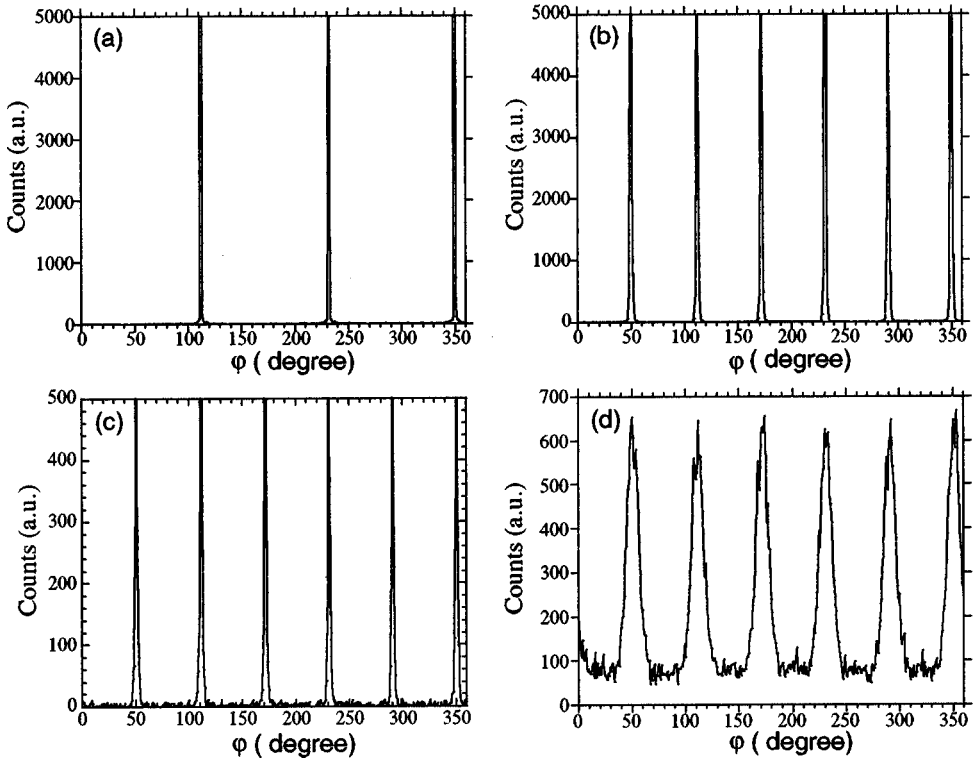

FIG. 3. X-ray pole figure scan spectra. (a) {110} poles for single crystal Si(111); (b) {110} poles for Ag(111); (c) {1011} poles for Ti(0002); (d) {1011} poles for CoCrPt (0002).

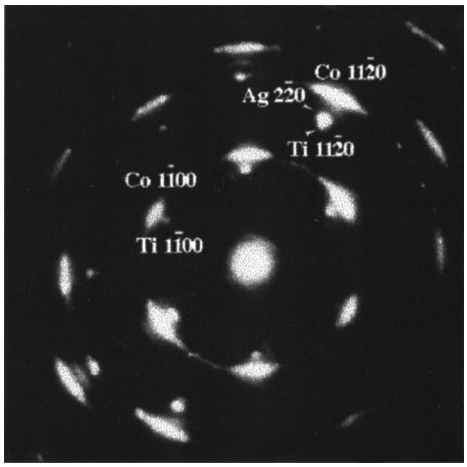

FIG. 4. TEM selected area diffraction patterns of CoCrPt 50 nm/Ti 50 nm/Ag 50 nm/HF–Si(111) film.

Ti(0001) and Ag(111) is Ti$[10\bar{1}0]\|$Ag$[11\bar{2}]$. Finally, the orientation relationship of CoCrPt$[10\bar{1}0]\|$Ti$[10\bar{1}0]$ is determined from the observation that the six peaks of CoCrPt spectrum [Fig. 3(d)] appear at the same ϕ positions as those in the Ti and Ag spectra. The diffraction peaks in Co$\{10\bar{1}1\}$ pole figure spectrum are wider than those of the Ag and Ti which is probably due to the relatively large lattice mismatch between Co(0001) and Ti(0001) degrading the epitaxy of CoCrPt film.

Rocking curve measurements were employed to investigate the texture dispersion of the films. The dispersion of the Ti(0002)/Ag(111) peak was measured to be only $\Delta\theta_{50}=0.78°$. This implies very good epitaxial growth of the Ti(0001) film and the Ag(111) films. The dispersion of CoCrPt(0002) peak was measured to be $\Delta\theta_{50}=2.4°$ which is larger than that of Ti(0002)/Ag(111). This is consistent with the results from the pole figure scan measurements in which CoCrPt shows wider diffraction peaks.

TEM was also used to investigate the microstructure of the films. The TEM selected area diffraction patterns (SADP) for the $Co_{68}Cr_{20}Pt_{12}$50 nm/Ti 50 nm/Ag 50 nm/Si(111) film are shown in Fig. 4. It shows the (111) zone axis of Ag to be parallel to the (0002) zone axis of the hcp Ti and Co alloy with the (220) reflections from the face-centered-cubic (fcc) phase being parallel to the $(11\bar{2}0)$ reflections of the hcp phases. This result is in agreement with the pole figure measurements. The diffracted spots from the Ag and Ti are both sharp spots indicating very good epitaxial growth. However, the $Co_{68}Cr_{20}Pt_{12}$ film produced a dispersion of the diffracted spots into a weak ring pattern. The strong reflections in the sixfold pattern parallel to the Ti$(11\bar{2}0)$ spots also shows weak ring patterns between them. It can be concluded that while most Co grains grow epitaxially on Ti, a portion grows randomly. This result is consistent with the rocking curve measurements discussed above.

To study the effect of the oriented underlayers, samples with various underlayer structures have been compared. Table I shows the magnetic properties obtained for samples with various underlayer structures. In samples A and B the CoCrPt/Ti films were deposited on a glass substrate and a Si(111) wafer covered with native oxide, respectively. Sample C has the same structure as sample B except that the Si(111) wafer was etched by HF before sputtering. Sample D was also prepared on a HF-etched Si(111) wafer, prior to the deposition of the Ti film, a 12 nm Ag underlayer was deposited. The thicknesses of $Co_{68}Cr_{20}Pt_{12}$ were 50 nm for all samples. Both samples A and B show relatively low coercivity and the sides of their hysteresis loops have obvious curvature. The large *c*-axis dispersion of $Co_{68}Cr_{20}Pt_{12}$ film is believed to be the main reason for the curvature. Even though both substrates provide an amorphous surface, the difference in the perpendicular coercivity between samples A and B indicates different substrate effects. Much higher coercivities and nearly ideal shapes of the hysteresis loops were obtained from samples C and D where the films were grown on HF-etched Si(111). However, the coercivity of sample D, prepared with the thin 12 nm Ag layer prior to the Ti layer, is much higher than that of sample C. This is at least in part due to the better epitaxial growth and *c*-axis orientation. Similar results were obtained for samples with thicker Ag layers.

TABLE I. Magnetic properties of CoCrPt films grown on different templates.

Sample	Film structure	$H_{c\perp}$ (Oe)	S
A	CoCrPt 50 nm/Ti 50 nm/glass	1928	0.82
B	CoCrPt 50 nm/Ti 50 nm/Si(111)	2514	0.83
C	CoCrPt 50 nm/Ti 50 nm/HF–Si(111)	3550	0.96
D	CoCrPt 50 nm/Ti 50 nm/Ag 12 nm/HF–Si(111)	4580	0.85

IV. CONCLUSIONS

In this study, (0001) textured Ti films were epitaxially grown on HF etched Si substrates by introducing a Ag underlayer. Then, using this Ti/Ag template, (0001) textured $Co_{68}Cr_{20}Pt_{12}$ film was epitaxially grown. The epitaxial relationships have been determined by x-ray and TEM. Very small *c*-axis dispersion was observed for this highly oriented underlayer structure resulting in significantly improved magnetic properties.

ACKNOWLEDGMENTS

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[1] P. Lu and S. H. Charap, IEEE Trans. Magn. **30**, 4230 (1994).
[2] M. Futamoto, Y. Honda, Y. Hirayama, K. Itoh, H. Ide, and Y. Maruyama, IEEE Trans. Magn. **32**, 3789 (1996).
[3] D. N. Lambeth *et al.* Mater. Res. Soc. Symp. Proc. **517**, 181 (1998).
[4] W. Yang, D. E. Laughlin, and D. N. Lambeth, J. Appl. Phys. **81**, 4370 (1997).