Microstructure and magnetic properties of CoCrPt/Cr films on ultrasmooth NiP/AlMg substrates

Li Tang, David E. Laughlin, and David N. Lambeth
Data Storage Systems Center, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213

Mary F. Doerner
IBM Storage Systems Division, 5600 Cottle Road, San Jose, California 95193

Investigation of the correlation between the microstructure and magnetic properties of $Co_{68}Cr_{20}Pt_{12}$/Cr thin films which were sputter deposited under different conditions onto 95 mm ultrasmooth NiP/AlMg disk substrates ($R_a \sim 2$ Å) has been carried out. Grain morphology characteristics of the films and disk surface roughness were studied by transmission electron microscopy (TEM) and by atomic force microscopy. Tilted-specimen electron diffraction patterns were used to determine the crystallographic texture of the films. The low coercivity of the disks deposited at 100 °C preheated substrates is attributed to the randomly oriented grains of the CoCrPt/Cr layers. Enhancement of the coercivity of the disks deposited on 220 °C preheated substrates is thought to be mainly due to the $(11\bar{2}0)$CoCrPt/(002)Cr crystallographic texture and uniformly distributed grains which are equiaxed in shape. The strength of the $(11\bar{2}0)$CoCrPt/(002)Cr texture can be modified by the Ar gas pressure during the deposition of the Cr underlayer. © *1996 American Institute of Physics.* [S0021-8979(96)09808-1]

For magnetic recording thin film media, structural characteristics such as grain size, shape, and separation, as well as composition inhomogeneity are believed to be closely related to the media magnetic and recording properties.[1,2] Another important feature is the crystallographic texture of the films. This is difficult to measure by x-ray diffraction techniques for Co–alloy/Cr thin films deposited on NiP/AlMg substrates since the substrates are much thicker than the Co–alloy/Cr layers and usually contribute a strong background signal to the x-ray diffraction spectra of Co–alloy/Cr/NiP/AlMg disks.[3,4] On the other hand, tilted electron diffraction patterns of both the Cr underlayer and Co–alloy film can be obtained separately from the same transmission electron microscopy (TEM) specimen in which thin areas of both the layers exist and the NiP/A1Mg substrates are removed.[5] From these diffraction patterns the texture axis and the distribution angle about the axis of the layers can be determined. Furthermore, information of grain morphology of the films including grain size, shape, and separation can also be obtained from TEM images. In this article, we present results of TEM and atomic force microscopy (AFM) studies of the microstructures of $Co_{68}Cr_{20}Pt_{12}$/Cr films sputter deposited under different conditions onto ultrasmooth NiP/AlMg substrates. Correlation between the microstructure and magnetic properties of the films is also discussed.

$Co_{68}Cr_{20}Pt_{12}$ (220 Å)/Cr (750 Å) films were dc-magnetron sputter deposited onto 95 mm ultrasmooth NiP/AlMg disk substrates ($R_a \sim 2$ Å) at varying substrate temperatures and Ar gas pressures (Table I). In-plane magnetic properties of the disks were measured using a vibrating sample magnetometer (VSM). Microstructural studies of the CoCrPt/Cr films were carried out using a Philips 420T transmission electron microscope. Specimen-tilted electron diffraction patterns were used to determine the crystallographic texture of the magnetic and underlayer films. This method has been described in detail elsewhere.[5,6] Surface roughness of the disks was measured using an atomic force microscope.

In-plane magnetic properties of the CoCrPt/Cr/NiP/AlMg disks prepared under different conditions are listed in Table I. It can be noted that when the Ar gas pressure during the sputtering of Cr (15 mTorr) and of CoCrPt (5 mTorr) films is kept the same, raising the substrate temperature from 100 °C (sample no. 1) to 220 °C (sample no. 2) increases the coercivity of the CoCrPt film significantly. Reducing the Ar gas pressure from 15 to 5 mTorr during the deposition of the Cr underlayer on 220 °C heated substrates, however, reduces the coercivity (sample no. 3) of the magnetic layer.

The bright field TEM images of the Cr underlayer and CoCrPt film at 0° tilt for sample no. 1 are shown in Figs. 1(a) and 2(a), respectively. The Cr grains in Fig. 1(a) (grains in dark contrast in this figure are residual CoCrPt grains which have not been totally removed) are well separated and elongated with a length to width (~100 Å) ratio of 4:1. The CoCrPt grains in Fig. 2(a) are not obviously elongated in shape as are the grains of its Cr underlayer, and furthermore the grain size seems to have a wide distribution. Grain sepa-

TABLE I. Processing parameters and magnetic properties of CoCrPt/Cr thin films.

Sample no.	Substrate temperature (°C)	Ar pressure CoCrPt/Cr (mTorr)	H_c (Oe)	M_rT (memu/cm^2)	S^*
1	100	5/15	1360	0.68	0.91
2	220	5/15	2400	0.75	0.84
3	220	5/5	2000	0.75	0.91

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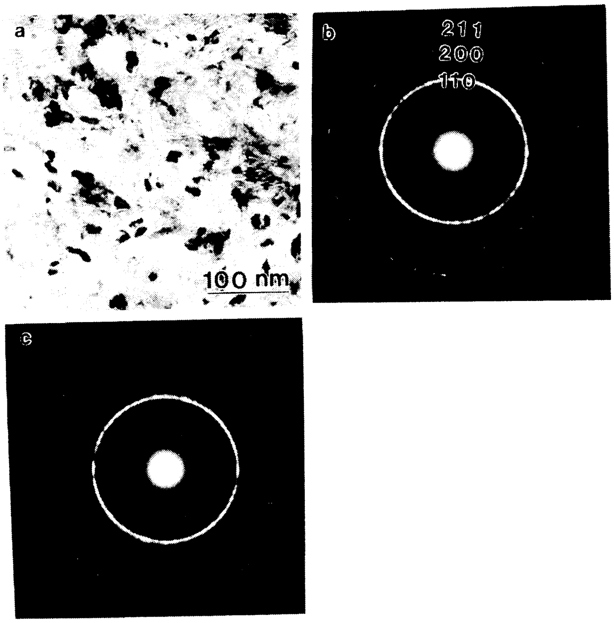

FIG. 1. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt and (c) 40° tilt of the Cr underlayer of sample no. 1.

ration is also noted between some of the grains. AFM measurement indicates that the surface of the disk after the media is deposited is much rougher ($R_a \sim 13$ Å) than the NiP/AlMg substrate. Electron diffraction patterns at 0° tilt and 40° tilt from the bcc Cr underlayer and from the hcp CoCrPt film of sample no. 1 are shown in Figs. 1(b) and 1(c) Figs. 2(b) and 2(c), respectively. No distinction can be made between the diffraction patterns at 0° and 40° tilt of the layers, indicating that grains in the Cr underlayer and CoCrPt film are randomly oriented three dimensionally. This may contribute to the low coercivity of this disk.

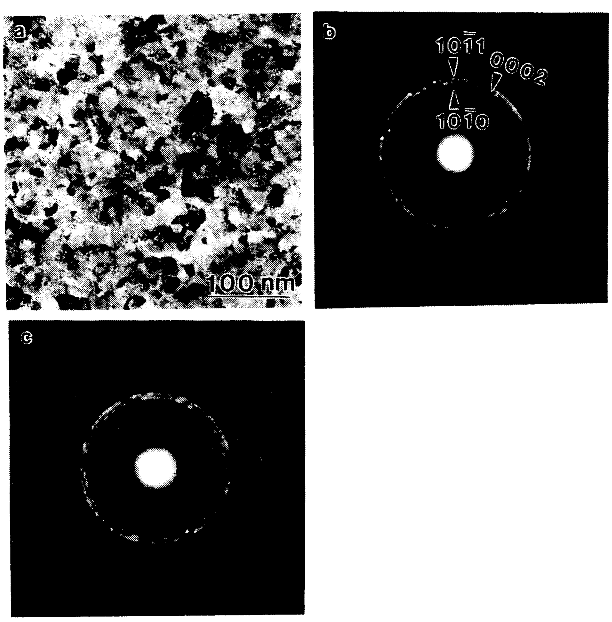

FIG. 2. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt and (c) 40° tilt of the CoCrPt film of sample no. 1.

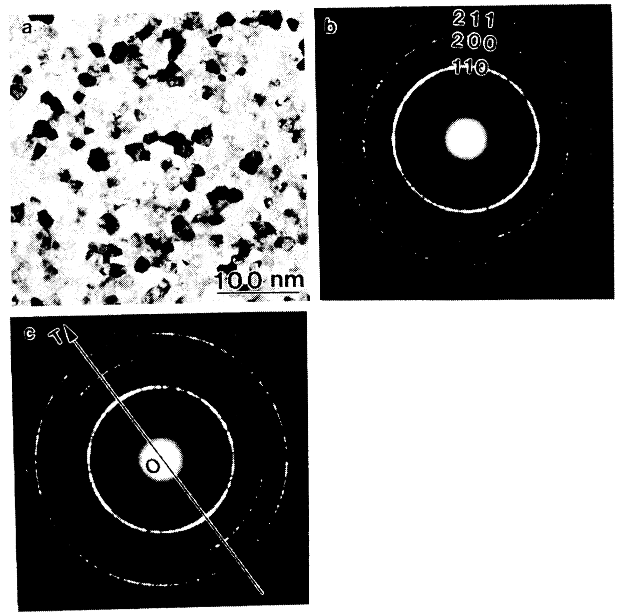

FIG. 3. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt and (c) 50° tilt of the Cr underlayer of sample no. 2.

For sample no. 2, which was deposited at higher substrate temperature, the surface roughness (6 Å) is much smaller than that of sample no. 1. The grains of the Cr underlayer [Fig. 3(a)] are no longer elongated but are equiaxed in shape and uniformly distributed with a grain size of about 230 Å. This change of grain shape is believed to be due to the higher adatom mobility on the higher temperature substrate. Also, separation between some of the grains can be observed from Fig. 3(a). The Cr underlayer has a small amount of (002) texture, as can be seen from the change of the diffraction patterns when the specimen is tilted from 0° position [Fig. 3(b)] to 50° [Fig. 3(c), **OT** is the tilt axis

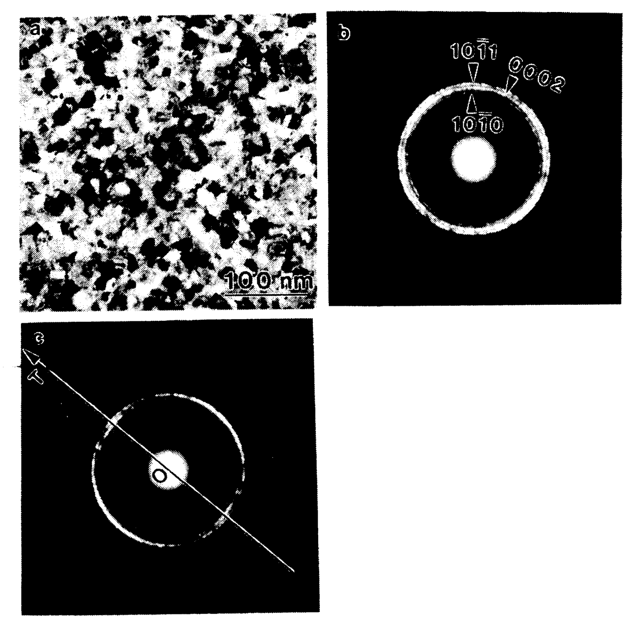

FIG. 4. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt and (c) 50° tilt of the CoCrPt film of sample no. 2.

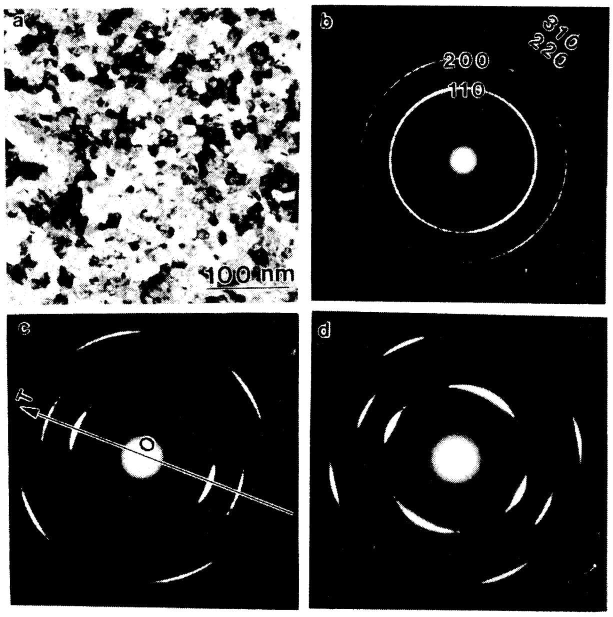

FIG. 5. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt, (c) 30° tilt, and (d) 42° tilt of the Cr underlayer of sample no. 3.

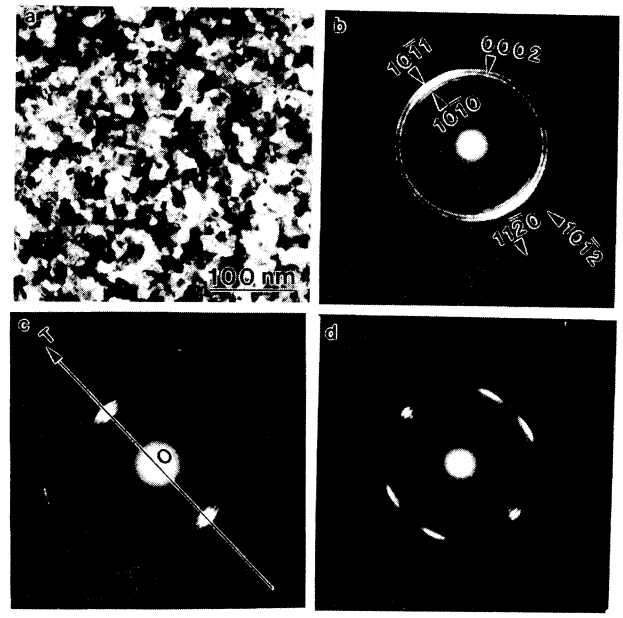

FIG. 6. (a) Bright field TEM image at 0° tilt. Electron diffraction patterns at (b) 0° tilt, (c) 36° tilt, and (d) 56° tilt of the CoCrPt film of sample no. 3.

direction]. Correspondingly, grains of the CoCrPt film are also equiaxed in shape but without separation [Fig. 4(a)] and there is a tendency for $(11\bar{2}0)$ texture, as can be seen from the diffraction patterns at 0° [Fig. 4(b)] and 50° tilt [Fig. 4(c)]. It is well known that $(11\bar{2}0)$ textured CoCrPt bicrystals with the c axis 90° relative to each other grow on (002) textured Cr grains.[7] Micromagnetic modeling studies show that exchange coupling between the bicrystals reduces the coercivity of the magnetic layer significantly.[8] Since the CoCrPt(1120)/Cr(002) texture is weak in this disk, the above mentioned effect is also weak which allows a high in-plane anisotropy and therefore high in-plane coercivity and small S^*. It seems that equiaxed grain shape is also important for the coercivity enhancement of this disk.

The grain shape of the Cr underlayer [Fig. 5(a)] and CoCrPt film [Fig. 6(a)] for sample no. 3 is similar to that of sample no. 2. But the grain size is a slightly smaller (~200 Å) and the disk surface roughness is further reduced to 3.5 Å as measured by AFM. No grain separation is observed in either of the layers. The (002) Cr and $(11\bar{2}0)$ CoCrPt textures of this disk are much stronger than that observed in sample no. 2. This can be seen from the diffraction patterns of the Cr underlayer at 0°, 30°, and 42° tilt [Figs. 5(b)–5(d)] and the CoCrPt film at 0°, 36°, and 56° tilt [Figs. 6(b)–6(d)]. The distribution angles of the Cr [002] and CoCrPt $[11\bar{2}0]$ texture axis are determined to be 10° and 6°, respectively.[5] The coercivity (2000 Oe) of this disk, however, is lower than that of sample no. 2. This is believed to be due to the lower effective anisotropy of the strongly exchange coupled CoCrPt bicrystals arising from the strong CoCrPt $(11\bar{2}0)$/Cr (002) texture.[8] The slightly smaller grain size may also play a role here.

In summary, the grains of both the Cr underlayer and CoCrPt films deposited at 100 °C preheated substrates are randomly oriented and result in the low in-plane coercivity. For films deposited on substrates which were preheated to 220 °C, the enhancement of in-plane coercivity is believed to be mainly due to the $(11\bar{2}0)$ CoCrPt/(002)Cr texture. In order to achieve the highest in-plane coercivity the strength of the $(11\bar{2}0)$CoCrPt/(002)Cr texture seems to be of critical importance. The surface roughness (3.5–6 Å) of the disks deposited on higher temperature substrates is much lower than that (13 Å) of the disks deposited on low temperature substrates. The correlation between the surface roughness and the magnetic properties, however, needs further study.

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[1] D. E. Laughlin, Y. C. Feng, L. L. Lee, D. N. Lambeth, and L. Tang, these proceedings.
[2] T. Lin, J. Magn. Magn. Mater. **86**, 159 (1990).
[3] M. F. Doerner, P.-W. Wang, S. M. Mirzamaani, and D. S. Parker, Mater. Sci. Symp. Proc. **232**, 27 (1991).
[4] H.-C. Tsai, B. B. Lal, and A. Eltoukhy, J. Appl. Phys. **71**, 3579 (1992).
[5] L. Tang, D. Lu, and G. Thomas, J. Appl. Phys. **77**, 47 (1995).
[6] L. Tang and D. E. Laughlin, J. Appl. Crystallogr. (to be published).
[7] B. Y. Wong, D. E. Laughlin, and D. N. Lambeth, IEEE Trans. Magn. **27**, 4733 (1991).
[8] Q. Peng, H. N. Bertram, N. Fussing, M. Doerner, M. Mirzamaani, D. Margulies, R. Sinclair, and S. Lambert, IEEE Trans. Magn. **31**, 2821 (1995).