Study of the growth characteristics of sputtered Cr thin films

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The crystallographic texture of Cr film deposited on glass substrates is found to depend on the film thickness d_{Cr} and the substrate temperature T_s. Without substrate preheating, only the Cr {110} peak was observed in the x-ray diffraction spectra for films between 60 and 400 nm in thickness. With increasing T_s (by substrate preheating), the Cr{200} peak became observable at progressively increasing intensity, whereas the intensity of the {110} peak decreased. Consequently the 170-nm-thick films deposited at $T_s \geqslant 200$ °C are predominantly {100} textured. However, even for these high T_s values ($\geqslant 200$ °C), the {110} peak intensity increases with increasing film thickness. Larger film thickness values are required at higher T_s for the {110} texture to overcome the {100} texture. The grain size of the Cr films deposited on glass increases with film thickness and with substrate temperature.

I. INTRODUCTION

In longitudinal magnetic recording media the magnetic films are often deposited on special underlayers in order to achieve the high coercivity H_c values and square hysteresis loops necessary for high-density magnetic recording.[1] Sputtered Cr thin films have been regarded as promising underlayer materials for recording media such a sputtered CoNi (Refs. 2 and 3) and CoNiCr (Refs. 4 and 5). It has been shown that the magnetic properties of the media were greatly improved by the presence of the Cr underlayer.[2,4]

Because of the nature of the bcc Cr structure, it is commonly believed that Cr film develops a {110} texture when deposited onto unheated substrates.[6] It has been reported that an epitaxial relationship exists for the Cr {110} planes and the Co-alloy $\{10\bar{1}1\}$ planes.[3,7] The $\{10\bar{1}1\}$ texture has been associated with the increase of H_c found when Co-alloy films were deposited on Cr underlayers.[3,5] However, in a previous paper[8] we have reported that when CoNiCr/Cr films were deposited onto a *preheated* substrate, higher H_c values ($\geqslant 1047$ Oe) were obtained than when the substrate was not preheated. It was also found that the {100} texture increased in the Cr underlayer when the substrate was preheated and that an epitaxial relation exists for the CoNiCr $\{2\bar{1}\bar{1}0\}$ planes and the Cr {100} planes.[8] Thus {100} texture in the Cr underlayer may induce higher H_c values in the CoNiCr layer than {110} texture. However, there have been few reports of {100} texture in the Cr underlayer. In this paper we present our data on the growth characteristics of Cr films deposited on substrates under different conditions. The circumstances under which {100} and/or {110} texture appear are discussed.

II. EXPERIMENTAL METHODS

Cr thin films were deposited on 7059 Corning glass substrates, NaCl crystal substrates, and NiP-coated Al substrates by rf diode sputtering in a LH Z400 system. After evacuation to 5×10^{-7} Torr, the Ar pressure was set at 10 mTorr during sputtering. The deposition rate was 10 nm/min and the Cr film thickness d_{Cr} ranged between 10 and 400 nm. Before deposition the substrates were preheated by a substrate heater to different temperatures. Because of the poor heat conductance between the substrate holder and the substrate in the vacuum, the substrate holder temperature measured by a thermocouple does not represent the substrate temperature accurately. Consequently, T_S, the substrate temperature before sputtering, was measured directly by placing Tempilable temperature monitors on the surface of the substrate. The film thickness d_{Cr} was measured by an Alpha-step profilometer. We found that the film thickness did not change with substrate temperature and did not depend on the substrate material. The crystal texture was monitored by x-ray diffraction using Cu radiation. The grain size was measured by transmission electron microscopy (TEM).

III. RESULTS AND DISCUSSION

For Cr deposited on glass substrates, the Cr {110} and {200} are the only two peaks observed in the x-ray diffrac tion spectrum. Their relative intensities depend on the preheating conditions of the substrates. We will focus our attention on the relative intensities of these two peaks.

The x-ray diffraction spectra of Cr thin films with different film thicknesses, d_{Cr}, deposited on glass substrates without substrate preheating are shown in Fig. 1. Only the Cr {110} peak was observed at all thicknesses. The intensity ratio of the {110} peak to the {200} peak for a random polycrystalline (powder) sample,[9] $I\{110\}/I\{200\}$, is 6.25. Therefore for the 60-nm-thick film, in which the signal-to-noise ratio for the {110} peak is only about 5 and the {200} peak was not seen, we cannot conclude that {110} texture exists. However, for $d_{\mathrm{Cr}} \geqslant 100$ nm, only the Cr {110} peak was observed and the signal-to-noise ratio of the {110} peak was larger than 7. For film thicknesses $\geqslant 100$ nm, we infer

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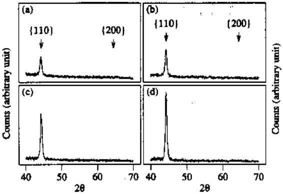

FIG. 1. X-ray diffraction spectra of (a) $d_{\rm Cr} = 60$ nm, (b) $d_{\rm Cr} = 170$ nm, (c) $d_{\rm Cr} = 250$ nm, and (d) $d_{\rm Cr} = 400$ nm samples deposited without substrate preheating.

from these x-ray diffraction spectra that the films deposited without substrate preheating have stronger {110} texture than films with randomly oriented grains would have.

The changes in Cr texture associated with changes in T_S were examined in a series of experiments. The x-ray diffraction spectra of 170-nm-thick films with various T_S values are shown in Fig. 2. At $T_S = 105$ °C, at which the {110} peak was strong, a weak {200} peak became observable. At $T_S = 200$ °C, the {200} peak became strong; the {110} peak was weak. At $T_S = 260$ °C, the {200} peak was very strong and the {110} peak was much weaker. Hence the 170-nm-thick films deposited at $T_S \geqslant 200$ °C have {100} instead of the $\{\bar{1}\bar{1}0\}$ texture. The {100} texture is favored at higher T_S values.

The sensitivity of Cr texture to film thickness was also examined. The x-ray diffraction spectra of Cr films, of various thicknesses, deposited at $T_S = 200$ and 260 °C, are shown in Fig. 3(A) and 3(B), respectively. At $T_S = 200$ °C, as film thickness increased from 170 to 400 nm, the {200} peak intensity did not change very much. However, the {110} peak intensity increased dramatically with increasing $d_{\rm Cr}$. At $T_S = 200$ °C the {110} peak of the 250-nm-thick film was already higher than the {200} peak. At $T_S = 260$ °C, as the film thickness increased from 170 to 400 nm, the {200} peak decreased slightly. However, as in the $T_S = 200$ °C case, the {110} peak also increased noticeably; however, here the {110} peak is still weaker than the {200} peak even when the film thickness had increased to 400 nm.

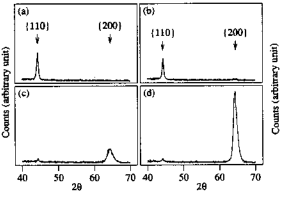

FIG. 2. X-ray spectra of $d_{\rm Cr} = 170$ nm samples deposited at (a) $T_S = 45$ °C, (b) $T_S = 105$ °C, (c) $T_S = 200$ °C, and (d) $T_S = 260$ °C.

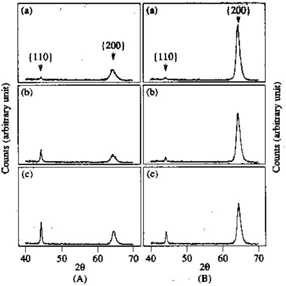

FIG. 3. X-ray spectra of (a) $d_{\rm Cr} = 170$ nm, (b) $d_{\rm Cr} = 250$ nm, and (c) $d_{\rm Cr} = 400$ nm samples deposited at (A) $T_S = 200$ °C and (B) $T_S = 260$ °C.

Summarizing, the crystal texture in these Cr films depends both on the thickness of the films, $d_{\rm Cr}$, and on the initial substrate temperature T_S. A higher T_S value promotes {100} texture whereas a larger thickness, $d_{\rm Cr}$, promotes the {110} texture.

Other substrates (NaCl and NiP-coated Al) were also used but here interpretation of the x-ray was made difficult by the overlapping of the Cr diffraction peaks with the substrate diffraction peaks. Also, when the NiP-coated Al substrates were heated many extra peaks were seen, possibly due to the crystallization of NiP which made comparison difficult.

The microstructure of the Cr thin films was studied by TEM. For the 120-nm-thick film deposited on glass without substrate preheating, the grains are elongated [Fig. 4(a)]. The average length-to-width ratio is roughly 4:1 and the average width is about 8 nm. For film of the same thickness prepared with the substrate preheated to 260 °C [Fig. 4(b)], the grains are more equiaxed and the grain size is about 30 nm. For the 400-nm-thick film prepared without substrate preheating [Fig. 5(a)], both elongated and equiaxed grains are seen. The grain size is about 28 nm. For the 400-nm-thick film prepared with the substrate preheated to 260 °C [Fig. 5(b)], the grains are equiaxed and about 58 nm in size. Thus, for Cr films deposited on glass substrates at smaller $d_{\rm Cr}$ and at lower T_S, the grains are elongated. As $d_{\rm Cr}$ and T_S increase, the grains become more equiaxed. The grain size increases with increasing film thickness and substrate temperature. The larger grain size at higher substrate temperature may be related to the higher mobility of the adatoms on the substrate surface.

We also studied the microstructure of Cr thin films deposited on NiP-coated Al substrates. For a 70-nm-thick film, the grain size was 19 nm when the substrate was not preheated and 32 nm when the substrate was preheated to

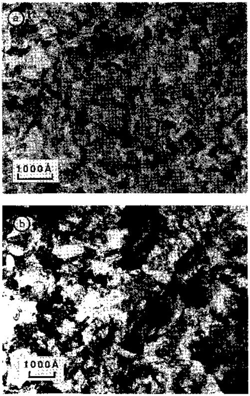

FIG. 4. Bright-field TEM images taken from the top of 120-nm-thick films deposited on glass (a) without substrate preheating and (b) with substrate preheated to 260 °C.

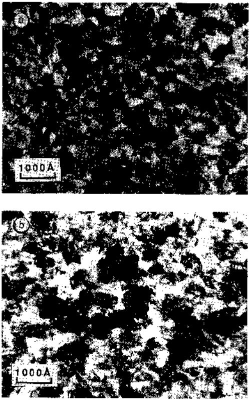

FIG. 5. Bright-field TEM images taken from the top of 400-nm-thick films deposited on glass (a) without substrate preheating and (b) with substrate preheated to 260 °C.

260 °C. These are of the same order of magnitude as the grain sizes of Cr films deposited on glass substrates. The grain size of Cr deposited on NiP/Al also increases with increasing substrate temperature. However, for Cr deposited on NiP/Al at higher T_S, the grains become more elongated rather than equiaxed as in Cr/glass.

IV. CONCLUSIONS

The growth characteristics of Cr thin films sputtered on glass substrates were studied. For Cr deposited on glass substrates without substrate preheating, only the Cr {110} x-ray diffraction peak was observed for film thicknesses between 60 and 400 nm. As the substrate temperature before deposition, T_S, was increased (by substrate preheating), the Cr {200} peak became visible with increasing intensity. As T_S was increased from 105 to 200 °C, the texture of the 170-nm-thick films changed from {110} to {100}. Even in films prepared at high substrate temperatures ($T_S \geqslant 200$ °C), the intensity of the {110} peak increases with film thickness and presumably would dominate the texture at sufficiently large thickness. As T_s increases a larger film thickness is required for the {110} texture to dominate. The grain size of the Cr films deposited on glass increases with film thickness and also increases substantially with substrate temperature T_S. For Cr deposited on NiP-coated Al substrates, the grain size also increases with increasing substrate temperature.

ACKNOWLEDGMENT

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