DEVELOPMENT OF CRYSTALLOGRAPHIC TEXTURE IN RF SPUTTER DEPOSITED CoCrTa/Cr THIN FILMS

Y. C. FENG, D. E. LAUGHLIN and D. N. LAMBETH*,
Department of Materials Science and Engineering,
*Department of Electrical and Computer Engineering,
Data Storage System Center, Carnegie Mellon University, Pittsburgh, PA 15213

ABSTRACT

It is well known that Cr sputtered on glass or NiP/Al substrates has either the (002) or (110) crystallographic texture (depending on the substrate temperature) and that the Co-alloy layers which are deposited on the Cr underlayers have either the $(11\bar{2}0)$ or $(10\bar{1}1)$ textures respectively. However, the dependence of the crystallographic textures on other sputtering parameters is not clear. We report here on the study of the dependence of crystallographic textures of CoCrTa/Cr films on substrate bias. It is found that both Cr (110) and Cr (002) textures can form at elevated temperature, depending on the substrate bias. The development of the crystallographic texture is discussed with a model. It is also found that the epitaxy of CoCrTa layer depends on the sputtering conditions of both the Cr and the CoCrTa layers. The extrinsic magnetic properties (such as Hc, S and S*) of thin films with various textures are also presented. By controlling the sputtering procedure, the effects of crystallographic textures on magnetic properties were separated from the effects of film morphology.

I. INTRODUCTION

Sputtered CoCrTa thin films on Cr underlayers are one of the most promising candidates for longitudinal recording media,[1,2] due to their high in-plane coercivity and low recording noise.[3] It is believed that the Cr underlayer enhances the magnetic properties by facilitating the growth of Co-alloy grains with a crystallographic plane of either hcp $(11\bar{2}0)$ or $(10\bar{1}1)$ parallel to the film surface,[4] This causes the c-axis to lie nearly in the film surface. Therefore, understanding the dependence of crystallographic texture of CoCrTa/ Cr thin films on sputtering condition is of great importance.

Previous work regarding the crystallographic texture of Co-alloy/Cr has been summarized by T. Ohno *et al.*[5] It is well known that sputtered Cr thin films have either (110) or (002) texture,[5-7] depending on the substrate temperature. When deposited without substrate preheating, the Cr layers have the (110) texture, while when deposited at elevated temperatures they tend to have the (002) texture. However, the dependence of crystallographic texture on other sputter parameters is not clear. In this work, we have studied the dependence of the crystallographic texture of RF sputter deposited Cr underlayer on substrate bias. We find that when it is deposited at room temperature, the Cr layer always has the (110) texture and when deposited at elevated temperature, the Cr layer has either the Cr (002) or the Cr (110) texture depending on the substrate bias. The dependence of crystallographic texture of Cr on substrate bias is discussed with a model.[8]

It is also well known that when Co alloys are deposited on Cr with the (110) texture, they have the $(10\bar{1}1)$ texture and when they are deposited on Cr of the (002) texture, they have the $(11\bar{2}0)$ texture.[4,5] This is believed due to grain to grain epitaxy,[9,10] However, the effect of various sputtering conditions on this epitaxy has not been fully studied. In this work, we find that the epitaxy depends on the sputtering conditions of both the Cr and Co-alloy layer.

the other hand, in sample B, the Cr underlayer, which is deposited with -200 V substrate bias, has the (110) texture and the CoCrTa layer has the (10$\bar{1}$1) texture correspondingly. Comparing sample A and B, it seems that the substrate bias promotes the Cr (110) texture even at elevated substrate temperature. However, it is interesting to note that for sample C, for which the first 200 Å of Cr was deposited without applying substrate bias but the remainder 800 Å Cr was deposited with -200 V bias, the Cr underlayer has a very strong (002) texture, even stronger than that in the sample A. Comparing sample A and C shows that applying substrate bias for the remainder 800 Å Cr, promotes the continuation of the growth of the (002) texture. On the other hand, as seen by comparing sample A and D, applying substrate bias at the initial stage of film formation prevents the (002) texture formation and produces films with the (110) texture.

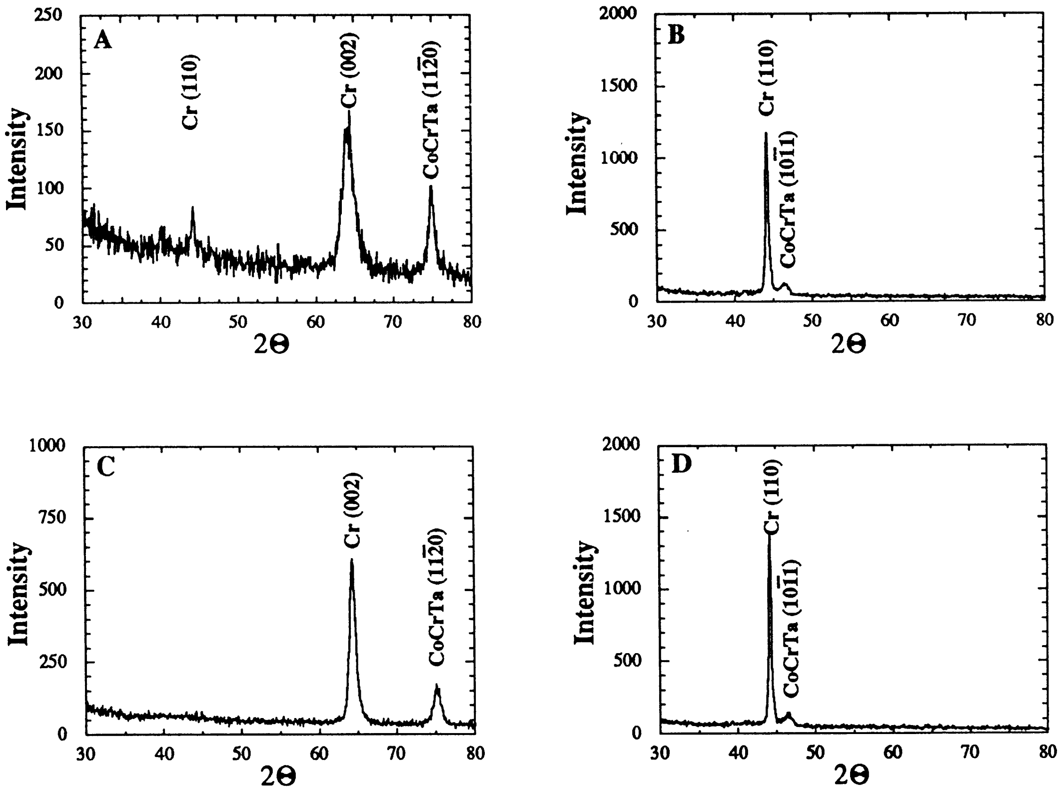

Figure 1, X-ray diffraction spectra of samples A, B, C and D

The films form by a nucleation and growth process. Based on the minimization of surface energy, we have proposed a model for the formation mechanism of crystallographic texture of sputter deposited Cr films.[8] From this model, the (002) and (110) textures are shown to form by different mechanisms. The (002) texture forms at the very beginning of the film deposition, when the "film" is composed of separated islands. Each single island prefers the (002) orientation, due to minimization of surface energy. On the other hand, the (110) texture is developed by a faster grain growth mechanism after the film become continuous. The higher the concentration of nucleation centers, the sooner the films become continuous. Therefore the (110) texture develop faster.

At room temperature, the nucleation rate is always high, so that the (110) texture always forms very early in the growth of the film. However, heating the substrate reduces the nucleation rate. The nucleation rate also depends on other sputtering parameters. Applying substrate bias increases the bombardment energy of the Ar^+ ions onto the substrate. At the initial stage of deposition, the concentration of nucleation centers increases with this bombardment because the sites of impingement will become sites for preferential nucleation.[13]

The extrinsic magnetic properties of thin films depend on their microstructure. To investigate the effects of each microstructural feature on the magnetic properties, it is critical to vary each microstructural feature independently. Y. Shen *et al.*[11] have tried to separate the effects of substrate heating, which has been thought to cause grain boundary segregation of Ta atoms, from the crystallographic texture effects. However, the substrate temperature also influences the morphology of the film.[12] In this work, the magnetic properties of films with various crystallographic textures are studied. By controlling the sputtering procedure, we try to separate the effects of crystallographic texture on the extrinsic magnetic properties from the effects of other microstructural features.

II. EXPERIMENTAL

CoCrTa/Cr thin films were RF sputter deposited on Corning 7059 glass substrates in an Leybold-Heraeus Z-400 sputtering system with a background pressure of $7.0X10^{-7}$ Torr. The composition of the CoCrTa layers is Co-12 at% Cr-2 at% Ta. The density of forward sputtering power was 1.6 Watts/cm^2 and the Ar pressure was 10 mTorr during the deposition of the film. The preheated substrate temperature, the Ar pressure and the substrate bias were varied, and will be specified in the text. The rate of deposition was determined by step profilometry measurements and these rates were used to calculate the various thicknesses of the films. The crystallographic texture was studied by x-ray diffraction using Cu K_a radiation. The magnetic properties of these films were measured using a Vibrating Sample Magnetometer.

III. RESULTS AND DISCUSSION

1. The crystallographic texture of the Cr underlayer

In this work, the Cr layers were deposited with various substrate biases on glass substrates at either room temperature or preheated to 260 °C. The films deposited at room temperature all show the (110) texture. However, films deposited at 260 °C have either the (002) or the (110) texture, depending on the substrate bias. To investigate the effects of applying substrate bias during the RF sputtering deposition at elevated temperature, four films were deposited, each with a 1000 Å Cr underlayer and 400 Å CoCrTa magnetic layer. For all four films, the CoCrTa layer was deposited with the same sputtering conditions, (forward sputtering power, 100 Watts; Ar pressure, 10 mTorr; preheating substrate temperature, 260 °C; substrate bias, -150 V) but the Cr underlayer was deposited with different biasing procedures, as listed in Table 1. Other sputtering parameters were fixed (100 Watts; 10 mTorr; 260 °C).

Table 1. Bias on the Cr underlayer of sample A, B, C and D

sample	bias on the first 200 Å Cr	bias on the remaining 800 Å
A	0 V	0 V
B	-200 V	-200 V
C	0 V	-200 V
D	-200 V	0 V

The X-ray diffraction spectra of these films are shown in Figure 1. In sample A, the (002) texture is dominant in the Cr underlayer, which was deposited without applying substrate bias, and the CoCrTa layer has the $(11\bar{2}0)$ texture. This is consistent with previous work.[5-7] On the other hand, in sample B, the Cr underlayer, which is deposited with -200 V substrate bias, has the (110) texture and the CoCrTa layer has the $(10\bar{1}1)$ texture correspondingly. Comparing sample A and B, it seems that the substrate bias promotes the Cr (110) texture even at elevated substrate temperature. However, it is interesting to note that for sample C, for which the first 200 Å of Cr was deposited without applying substrate bias but the remainder 800 Å Cr was deposited with -200 V bias, the Cr underlayer has a very strong (002) texture, even stronger than that in the sample A. Comparing sample A and C shows that applying substrate bias for the remainder 800 Å Cr, promotes the continuation of the growth of the (002) texture. On the other hand, as seen by comparing sample A and D, applying substrate bias at the initial stage of film formation prevents the (002) texture formation and produces films with the (110) texture.

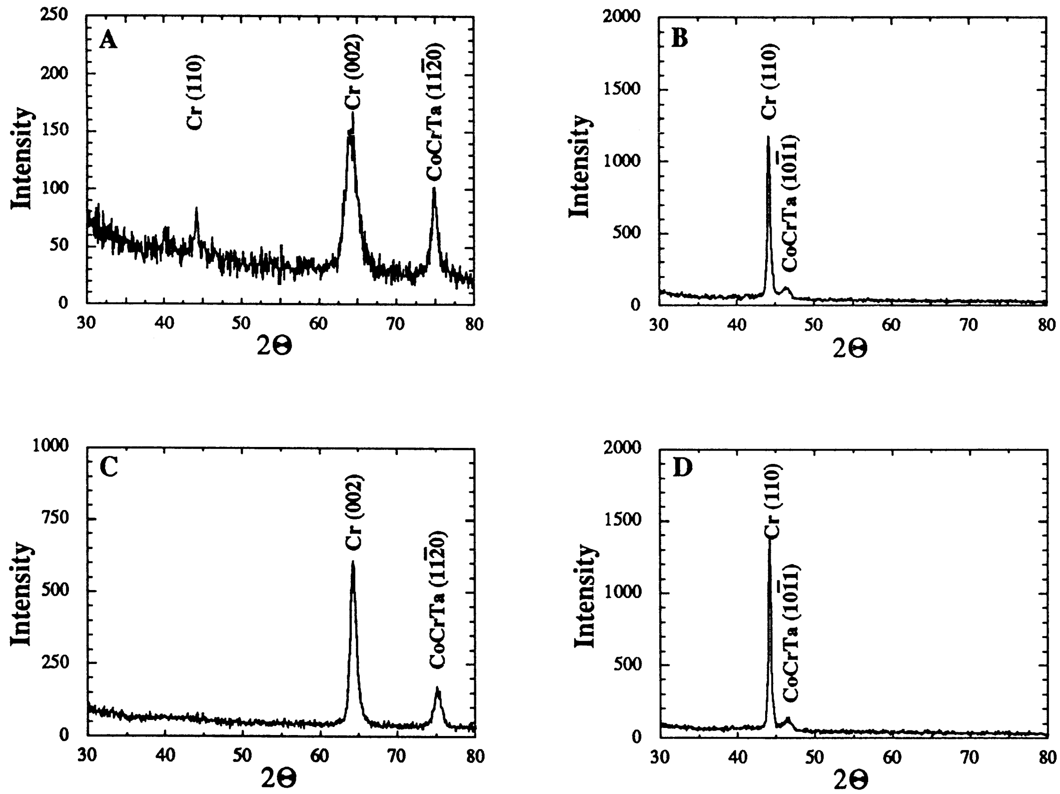

Figure 1, X-ray diffraction spectra of samples A, B, C and D

The films form by a nucleation and growth process. Based on the minimization of surface energy, we have proposed a model for the formation mechanism of crystallographic texture of sputter deposited Cr films.[8] From this model, the (002) and (110) textures are shown to form by different mechanisms. The (002) texture forms at the very beginning of the film deposition, when the "film" is composed of separated islands. Each single island prefers the (002) orientation, due to minimization of surface energy. On the other hand, the (110) texture is developed by a faster grain growth mechanism after the film become continuous. The higher the concentration of nucleation centers, the sooner the films become continuous. Therefore the (110) texture develop faster.

At room temperature, the nucleation rate is always high, so that the (110) texture always forms very early in the growth of the film. However, heating the substrate reduces the nucleation rate. The nucleation rate also depends on other sputtering parameters. Applying substrate bias increases the bombardment energy of the Ar^+ ions onto the substrate. At the initial stage of deposition, the concentration of nucleation centers increases with this bombardment because the sites of impingement will become sites for preferential nucleation.[13]

Thus, applying a substrate bias at the initial stage of deposition, promotes the (110) texture. On the other hand, applying substrate bias increases the mobility of surface atoms. When the film becomes continuous, bias promotes surface diffusion. This helps some grains to grow faster than others. Grains with low energy crystalline planes, such as (110) and (002), which are parallel to the film surface, grow faster than others. Therefore, applying substrate bias after the film become continuous promotes the growth of whichever texture is present initially.

2. The crystallographic texture of the CoCrTa layer

It is believed that Co-alloy layers grow epitaxially on the Cr underlayers. Therefore, the crystallographic texture of the Co-alloy layer depends only on the crystallographic texture of Cr underlayer. As shown in Figure 1, comparing spectra A and C, the intensities of the CoCrTa $(11\bar{2}0)$ peaks are proportional to the intensities of the Cr (002) peaks. Similarly, comparing spectra B and D, the intensities of the CoCrTa $(10\bar{1}1)$ peaks are seen to be proportional to the intensities of the Cr (002) peaks. However, these relationships are not always observed. For example, as shown in Figure 2, three films in which the Cr underlayer have similar crystallographic texture, have different crystallographic texture in their CoCrTa layers. The sputtering conditions of these films are listed in Table 2.

Table 2. Sputtering conditions of samples E, F and G

sample	Cr layer				CoCrTa layer			
	Ts (°C)	P (Watt)	Ar (mT)	Vb (V)	Ts (°C)	P (Watt)	Ar (mT)	Vb (V)
E	R.T	100	2	0	R.T	100	10	-150
F	R.T	100	10	-200	R.T	100	10	-150
G	260	100	10	-200	260°C	100	10	-150

Ts--substrate temperature, P--Sputtering power, Ar--Ar pressure, Vb--Substrate bias

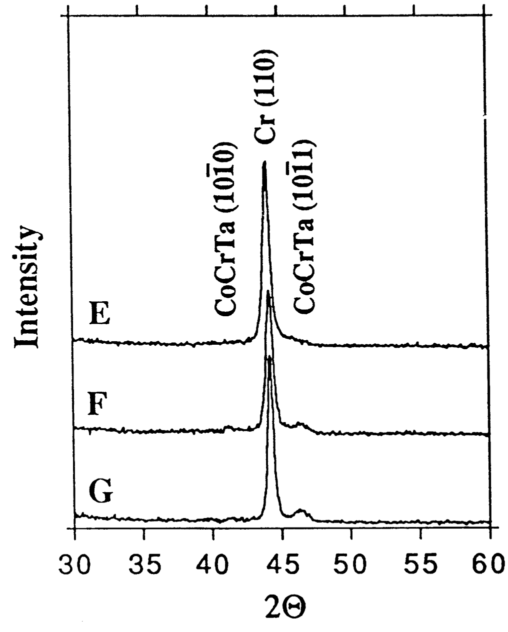

Figure 2, X-ray diffraction spectra of samples E, F and G

Comparing samples E and F, their CoCrTa layers were deposited with the same conditions, but the Cr underlayer of sample E was deposited without applying substrate bias and the Cr underlayer of sample F was deposited with -200 V substrate bias. As shown in Figure 2, the spectrum E does not show clearly any peaks from the CoCrTa layer, while in the spectrum F does show the $(10\bar{1}1)$ and $(10\bar{1}0)$ peaks from CoCrTa layer, even though spectra E and F show similar Cr (110) textures. The $(10\bar{1}1)$ texture is believed due to the epitaxial growth of Co-alloy on the Cr (110) plane, but it is not clear how the $(10\bar{1}0)$ texture develops.[4] Comparing samples F and G, both of which were deposited with the same conditions except for the substrate temperature, it can be seen that sample G, which was deposited at elevated temperature, shows stronger $(10\bar{1}1)$ texture and less $(10\bar{1}0)$ texture than F. This means that epitaxial growth at elevated temperature is easier. From these results, it is seen that elevated substrate temperature and applying substrate bias during the deposition of Cr underlayer promotes epitaxial growth.

3. Magnetic properties and crystallographic texture

The extrinsic magnetic properties of magnetic thin films depend on their microstructure. The crystallographic texture describes the orientation of the grains and the surface roughness describes the surface morphology of the film. By applying a substrate bias, we can obtain either the (110) or the (002) texture at the same elevated temperature. On the other hand, applying substrate bias also changes the film morphology. Due to resputtering, when the film is deposited with applied substrate bias, the film is denser (lesser voids between the grains) and its surface is smoother.[12] By controlling the sputtering process, we try to separate the effects of crystallographic texture from that of surface morphology. The magnetic properties and microstructure features of samples A, B, C and D are listed in Table 3.

Table 3. The magnetic properties and microstructure features of samples A, B, C and D

	Hc (Oc)	S	S*	Texture (CoCrTa/Cr)	Roughness
A	1950	0.79	0.78	$(11\bar{2}0)/(002)$	large
B	1550	0.74	0.74	$(10\bar{1}1)/(110)$	small
C	1790	0.76	0.85	$(11\bar{2}0)/(002)$ (strong)	small
D	1570	0.72	0.76	$(10\bar{1}1)/(110)$	large

Hc--Coerciverty, S--Remanence squareness, S*--Coercivity squareness

Comparing samples A and D, which have different crystallographic textures but may have similar morphology because they were deposited with the same conditions except for the first 200 Å Cr, the Hc and S of sample A are larger than those of sample D. This is understood because the CoCrTa layer of sample A has the $(11\bar{2}0)$ texture, which brings the c-axis into the plane of the film, while the CoCrTa layer of sample D has the $(10\bar{1}1)$ texture, for which the c-axis is 28° out of the film surface. Similarly, comparing B and C, which may have similar morphology but different type of texture, sample C, which has the $(11\bar{2}0)$ texture, has the larger Hc and S.

Comparing samples A and C, which have the same type of texture but may have different morphologies, the Hc of sample A is larger, even though sample C has a stronger $(11\bar{2}0)$ texture. This may due to their different morphologies. The Cr layer of sample A was deposited without applying substrate bias, therefore, the surface of the Cr layer is rougher due to the effects of shadowing.[12] This rough surface helps to separate the CoCrTa grains which grow on that surface. The related smaller S* of sample A supports this argument.[14]

IV. SUMMARY

1) The dependence of crystallographic texture of CoCrTa/Cr thin films deposited by RF sputtering on deposition conditions has been investigated. Cr layers deposited without preheating have the (110) texture. However, when Cr is deposited at elevated temperatures, the texture of the Cr layer depends on the substrate bias. Either the (110) or the (002) texture can be obtained at elevated temperature. We explain this by a simple model.

2) For the CoCrTa layers, the epitaxial growth depends on the microstructure of the Cr layer and the deposition conditions of CoCrTa layer. Applying substrate bias during the deposition of the Cr layer and increasing the substrate temperature during the deposition of CoCrTa promotes epitaxial growth.

3) By controlling the sputtering procedures, the crystallographic texture and morphology can be varied independently. The extrinsic magnetic properties depend on the crystallographic texture and the morphology of the CoCrTa films.

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