EFFECTIVE EPITAXIAL THICKNESS OF RF SPUTTERED CoCrTa / Cr FILMS

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Abstracts---A sequence of RF sputtered CoCrTa alloy films of different thickness were sputtered on 1000 Å thick Cr underlayers sputtered on glass with a (110) texture. The transmission electron diffraction pattern from a 100 Å CoCrTa film shows a mixture of (1010) and (1011) textures with a very small amount of (0002) texture. This result is evidence of " grain-to-grain epitaxy " of CoCrTa grains growing on Cr grains. However, the (0002) texture develops faster during film growth process and competes with the (1010) and (1011) textures. Accordingly, when CoCrTa films are thick enough, the (0002) texture will dominate other textures and the films will have perpendicular anisotropy. Because the textures caused by " grain-to-grain epitaxy " will be overwhelmed eventually, an " effective epitaxial thickness " is proposed to indicate a thickness when the (0002) texture starts to become discernible in the electron diffraction pattern and below that thickness (~ 400 Å ) the film has very little perpendicular oriented c-axis texture. The thickness dependence of the in-plane coercivity of RF sputtered CoCrTa/Cr thin films may be attributed to the change of crystalline orientation.

INTRODUCTION

High-coercivity and high-signal-to-noise-ratio thin films have been extensively investigated in recent years for possible application as the next generation of high-density longitudinal thin film rigid disk media. Cobalt-base alloy thin films with Cr underlayers have been proposed to be promising candidates for longitudinal thin film media,[1,2] although the sputtered cobalt-base alloys films tend to grow intrinsically in the [ 0001 ] direction with a thin transition layer and to have perpendicular anisotropy.[3,4] It is believed that the presence of well-textured Cr underlayers will cause the hcp c-axis of cobalt-base alloy grains to lie in the film plane direction because of the " grain-to-grain epitaxy " and to have a strong in-plane anisotropy.[5,6] Besides being composition dependent, the coercivity of sputtered Co alloy / Cr thin films is structure dependent and will vary for different deposition conditions. However, it was reported that the in-plane coercivity of the Co alloy / Cr media is also thickness dependent for DC magnetron sputtering [2] and S-gun sputtering.[6] Generally, the trend is that the in-plane coercivity decreases with increasing film thickness.

The purpose of this paper is to report the texture formation of CoCrTa films sputtered on (110) textured Cr underlayers and the structure dependence of the coercivity of the RF sputtered CoCrTa/Cr films. The crystalline structure was characterized by x-ray diffractometer and transmission electron diffraction. The mechanism of the change of textures during the growth process of films will be discussed.

EXPERIMENTAL

Thin films of Co-16 at% Cr- 4.5 at%Ta were deposited from a composite target using a Perkin-Elmer 2400 8SA RF diode sputtering system. The substrates were 18 mm X 18 mm Corning #2 cover glass. The background pressure was kept below 5 x 10^-7 torr. All of the Cr and CoCrTa films were deposited under the sputtering condition of 10 mtorr argon pressure, - 100 Volts substrate bias and 1000 W power. The thickness of the Cr underlayers was varied from 100 Å to 9000 Å while the thickness of the CoCrTa films was kept constant at 1000 Å.

Magnetic measurements were made using a vibrating-sample magnetometer (VSM) with 13 K gauss maximum applied field strength. A Siemens D500 x-ray diffractometer and A 100 KeV JEOL 100CX transmission electron microscope ( TEM ) were used to characterize the crystalline structures. Ion milling was used to remove the Cr underlayers and to thin down the CoCrTa layers in TEM sample preparation. The glass substrates were removed by chemical etching and CoCrTa/Cr films were glued to copper grids with CoCrTa faces attached to the grid and then thinned by ion milling from the the surface of the Cr layer. After ion milling, the TEM samples were semi-transparent.

RESULTS AND DISCUSSIONS

Magnetic Properties

Figure 1 shows the thickness dependence of the coercivity and squareness. Both of them decrease with increasing CoCrTa thickness. The in-plane...
coercivity reaches its maximum of about 1650 Oe at the thickness of 200 Å and decreases to 740 Oe at 9000 Å monotonically. The in-plane squareness is about 0.93 at the thickness of 100 Å and is 0.25 at 9000 Å. The change of the coercivity is very rapid below 400 Å. It is believed that the presence of the Cr underlayer will cause the hcp c-axis of the CoCrTa grains to lie in the film plane such that the CoCrTa film will have strong longitudinal anisotropy. Fig. 2 shows the hysteresis loops from 200 Å and 9000 Å films measured in the in-plane and perpendicular direction. The hysteresis loop from the 9000 Å film measured in the perpendicular direction shows very square shoulder, which is commonly seen in good perpendicular media. This result seems to imply that the Cr underlayer does not have a strong effect on very thick CoCrTa films which tends to have large perpendicular anisotropy. Fig. 3 shows a very different behavior when CoCrTa films were sputtered on glass substrates only. The in-plane coercivity increases with increasing CoCrTa thickness.

Crystal structure Analysis by X-ray Diffraction

Figure 4 is a 2θ/θ X-ray diffraction pattern of the Cr films used in this experiment, which shows a b.c.c. (110) texture and Fig. 5 is a 2θ/θ X-ray diffraction pattern of a CoCrTa film sputtered on a bare glass substrate, which shows a (0002) texture. Unfortunately, the (0002) peak is located almost at the same angle as the Cr (110) peak and they cannot be separated in analyzing the diffraction patterns of CoCrTa/Cr films.
Figure 6 shows a series of X-ray diffraction patterns from several CoCrTa films of different thickness. If there is a change in the c-axis orientation of CoCrTa grains, we should be able to observe new peaks and the (0002) peak from the CoCrTa film should decrease or disappear. However, for films thinner than 200 Å, no new peaks are shown in the X-ray pattern because the penetration depth of the X-rays is about 1 μm. A film 200 Å thick is too thin to give enough contribution to constructive interference. If there are new peaks, they are very likely to be overwhelmed by the background noise. For films thicker than 400 Å, (1010) and (1011) peaks start to be discernible. But in the pattern from a 9000 Å thick film, (1010) and (1011) peaks are gone and a very strong (0002) peak dominates. This implies that there is a change in the distribution of orientation while the film gets thicker. In our analysis of the X-ray diffraction pattern, the overlap of the Cr (110) and the CoCrTa (0002) peak makes the evidence of the orientation change of the c-axis more obscure. Accordingly, X-ray diffractometry does not provide an unambiguous interpretation of to what extent the c-axis orientation is changed.

**Crystal Structure Analysis by TEM Electron Diffraction**

In order to obtain more information in determining the orientation of the c-axis of CoCrTa films, TEM electron diffraction was used in our study.

If a polycrystalline film has a (1010) texture, the diffraction rings can be identified as [1010] zone rings because these rings are diffracted from the planes whose zone axis is [1010]. From X-ray diffraction data, we know that (1010), (0002), (1011) peaks are the three main peaks. A summary of the relation between textures (or zone axes) and diffraction rings is listed in table 1. The table shows that the (0002) ring is an indicator for a (1010)
texture, while the (1010) ring is for a (0002) texture and the (1011) ring is for a (1011) texture.

<table>
<thead>
<tr>
<th>zone axis</th>
<th>(1010)</th>
<th>(0002)</th>
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<td>(1010)</td>
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<td>X</td>
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<td>(0002)</td>
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<td>(1013)</td>
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<td>(2020)</td>
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<td>(1122)</td>
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Tab.1 Relation between textures (zone axes) and diffraction rings

Figure 7 shows a series of transmission electron diffraction patterns from several CoCrTa films of different thickness. The TEM diffraction pattern from a 100 Å film shows that there is a mixture of [1010] zone and [1011] zone rings and the [0002] zone rings are very weak. This implies that the presence of Cr underlayer causes epitaxial coherent growth of CoCrTa grains, such that the c-axis is oriented in-plane or tilted by an angle. For thicker films, the [0002] zone rings become more intense. The [0002] zone becomes clearly discernible in the 400 Å film. The [1010], [1011] and [0002] zones are about the same intensity in the 1000 Å film. The [0002] zone rings are more intense compared with the other two zones in the 2000 Å film. In the 4000 Å film, the [1010] zones are very weak but the [1011] zone rings are still visible. Finally, [0002] zone rings dominate in the 9000 Å film and the c-axis is perpendicular to the plane.

The above results show that when the film is thin, most of the c-axis is oriented in-plane or close to the plane. When it is thick, more and more perpendicularly oriented grains exist in the film. Therefore, the longitudinal magnetic anisotropy decreases with increasing thickness. Because the [0002] zone rings do become very weak in thin films, it is clear that the Cr underlayers cause the c-axis of the CoCrTa films lie in the plane of the film by grain-to-grain epitaxial growth. As the film gets thicker, the diffraction intensity from [1010] zone decreases quickly, while the diffraction intensity from [1011] grains still survive even when the film is 4000 Å thick. At the same time the diffraction intensity of the [0002] zone rings increase with increasing the CoCrTa film thickness.

CoCrTa films, like CoCr films, have a columnar structure with a [0002] texture when sputtered on glass substrates with proper sputtering conditions.[3,4] The formation of the [0002] texture can be explained in terms of a surface energy minimization model. From the Wulff plot,[7] the [0002] plane has the lowest surface energy, so it will dominate other textures after a transition layer. When a Cr film, which has a bcc ([110]) texture, is used as an underlayer, the surface energy at the interface (1010) and (1011) planes have small lattice misfit and will grow coherently on the Cr underlayer by grain-to-grain epitaxy. From the electron diffraction pattern of a 100 Å CoCrTa film, it shows very intense diffraction from (1010) and (1011) textures and very weak (0002) texture. However, the (0002) grains have the lowest surface energy intrinsically at the top surface of the CoCrTa film and it will dominate other textures as the film grows thicker. From the diffraction patterns, the (0002) texture starts to be discernible, which implies the epitaxy effect competes with the fast growth process of the (0002) texture. A term of "effective epitaxial thickness" is proposed to indicate a thickness when the (0002) texture starts to become discernible in the electron diffraction pattern and below that thickness the film have very little perpendicular oriented c-axis components.

The change of the c-axis texture will have an effect on the in-plane coercivity. The in-plane coercivity will be high when the c-axis lies in the film plane direction.[8] In our experiment, the c-axis of the CoCrTa/Cr films is oriented in plane or close to the plane when films are thin (~200 Å). Then some of the grains start to have perpendicular orientation in thicker films. Or, we may say that the distribution of the c-axis becomes more random (~1000 Å) because there are three textures developed evenly in the film. Eventually, the perpendicular orientation dominates when the film is very thick (~9000 Å). Thus, we can propose that during the growth process of CoCrTa films, the distribution of the c-axis is more in-plane at the initial stage, then random, and then perpendicular. Gordon F. Hughes [9] showed that 2D (planar) random easy axis distribution will have
higher Hc (//) compared with 3D random distribution. The relation between the thickness dependence of Hc (//) and the change of orientation shows fairly good agreement with the modeling. The decreasing of the in-plane squareness for thicker films is a direct result of the decreasing of the in-plane c-axis components.[10]

Another important factor affecting the coercivity is the stress caused by the coherent growth at the interfaces. Because of the lattice misfit and the strain at the interfaces, the stress will impede the wall motion, which will occur if the grains are not magnetically isolated completely and the exchange coupling interaction still exist. This is very possible when the film is thin because the precipitation process does not have enough time and thermal energy to complete. However, the relaxation of the coherent stress at the interfaces is very fast as the distance from the interfaces increases.[11,12] This could be the reason for the rapid change of the in-plane coercivity below 400 Å.

CONCLUSIONS

(1) Cr underlayers cause the CoCrTa films to form (1010) and (1011) textures, so the direction of the c-axis is in-plane or tilted by an angle with respect to the plane. A reduction of (0002) plane has been clearly observed by using transmission electron diffraction on films below 400 Å thick.

(2) A change of the crystalline texture for increasing film thickness has been observed. This could be explained by a surface energy minimization model. A term of "effective epitaxial thickness" is proposed to indicate a thickness when the (0002) texture starts to become discernible in the electron diffraction pattern and below that thickness the film has very little perpendicular oriented c-axis components.

(3) The thickness dependence of the in-plane coercivity and squareness of RF sputtered CoCrTa/Cr films can be related to the change of the crystalline textures.

(4) The relaxation of the stress at the interfaces of Cr and CoCrTa films could be the reason for the rapid change of the in-plane coercivity below 400 Å.

ACKNOWLEDGEMENT

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REFERENCES
[7] Swalin, Thermodynamics of solids, chap. 10