THE DEVELOPMENT AND CHARACTERIZATION OF CRYSTALLOGRAPHIC TEXTURE IN THIN FILMS FOR MAGNETIC RECORDING

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ABSTRACT

The development of crystallographic texture in thin film longitudinal recording media is discussed. Polycrystalline thin films may obtain their crystallographic texture by means of a nucleation process such as epitaxial nucleation on a polycrystalline underlayer or by means of a process involving a preferred growth direction. In this paper we will discuss various epitaxial nucleation textures that are obtained in media produced for magnetic recording. We will discuss the way that the underlayer controls the crystallographic texture of the magnetic layer, as well as methods used to control the texture of the underlayer itself. We give a brief overview of some of our recent findings in the growth of NiAl and FeAl films used for underlayers. Finally we will briefly discuss what we have called the tilted electron beam technique. In this technique selected area electron diffraction patterns are obtained at different angles of tilt and the development of arcs in the patterns is analyzed so as to determine the type and amount of crystallographic texture which is present in the films.

1. INTRODUCTION

For the past decade the areal density of information stored on hard disks for magnetic recording has increased at an annual rate of approximately 60% (1). This increase in recording density has brought with it the need to continue to improve the properties of the magnetic films in which the information is stored. In particular, since the magnetized regions are getting smaller, the coercivity of the magnetic material has needed to increase as well, from under 1000 Oe (CoNiCr alloys), (2,3) to well over 2000 Oe (CoCrPt alloys), (4,5) during the last decade. Of course, the coercivity of the films should not be too large, in order to continue to be able to write the information on the films. The increase in the coercivity of the magnetic films has occurred either through changes in the chemistry of the magnetic films, which change intrinsic properties such as magnetocrystalline anisotropy or by the control of the crystallographic texture of the magnetic film (6-8).

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Another property that must be monitored is the signal to noise ratio. As the recorded bit size has decreased, so too has the number of grains of the magnetic phase that exist within the bit. This means that the noise of the media would have increased, unless offset by other microstructural changes such as smaller grain sizes of the magnetic films. The developments in this area are discussed below.

It should be pointed out that the films used for magnetic recording are polycrystalline in nature. Important microstructural features include the grain size, the grain shape and the crystallographic texture of the films. These are the features of the films that play an important role in controlling their extrinsic properties (9). In this paper we will emphasize methods used to control the crystallographic texture of the magnetic films.

The crystallographic texture of films can be described in terms of two important features, namely the plane of the film {hkl} and the direction perpendicular to the plane of the film, <uvw>. Two characteristic textures can be delineated: lamellar textures, which have specific planes parallel to the plane of the film, and fibrous textures which have a specific direction perpendicular to the film. In cubic crystals these distinctions are unnecessary since for all hkl, [hkl] is perpendicular to (hkl).

2. THE DEVELOPMENT OF TEXTURE IN MEDIA THIN FILMS

A schematic of a typical cross-section of magnetic media is shown in Figure 1.

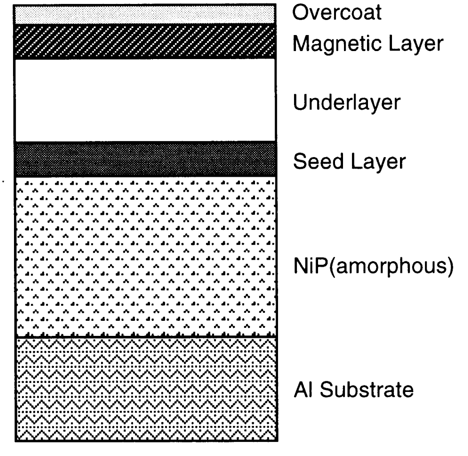

Figure 1. Schematic cross-section of longitudinal magnetic media.

The substrate may be either an Aluminum alloy or, for smaller diameter disks, they may be made of glass. Various layers are deposited on the substrate, the important ones for this paper being the seedlayer, the underlayer and the magnetic layer.

The control of the crystallographic orientation of the magnetic layer is done by controlling the crystallographic orientation of the underlayer. The polycrystalline magnetic layer is than grown epitaxially grain to grain on the underlayer (10). Thus the mechanism of producing the orientation of choice for the magnetic layer is "epitaxial" nucleation on the underlayer. Most underlayers that are currently in production are Cr or one of its substitutional solid solutions with a second element (e. g. V).

When Cr is deposited on an amorphous substrate (such as NiP) at ambient temperature, it grows with a {110} crystallographic texture. This crystallographic texture develops because the {110} surfaces of the grains are closest packed, and hence should have the lowest surface energy. This makes them favorable over the other low index planes. When Co alloys are deposited on Cr underlayers with the crystallographic texture {110} the epitaxial relationship

$$(10\bar{1}1)_{Co} // (110)_{Cr} \text{ develops.}$$

See Figure 2. This has been discussed in detail in the literature (11,12).

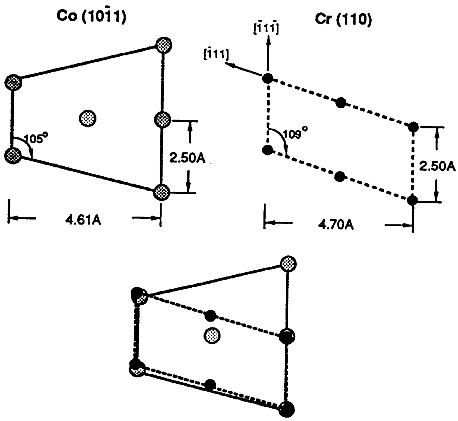

Figure 2. Schematic showing the epitaxial relationship of $(10\bar{1}1)_{Co} // (110)_{Cr}$

It can be seen that the crystallographic c axis is oriented at 28° to the plane of the film. This is not ideal for in plane magnetization. Therefore techniques were developed to obtain a crystallographic texture such that the c axis would lie in the plane of the film. This was done by heating the substrate during the deposition of the Cr underlayer. This gave rise to a [002] crystallographic texture of Cr, which by means of epitaxy gives rise to a lamellar $(11\bar{2}0)$ Co alloy texture. See Figure 3.

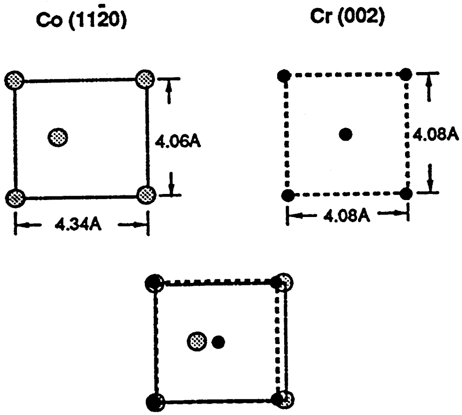

Figure 3. Schematic showing the epitaxial relationship of $(11\bar{2}0)_{Co}$ // $(002)_{Cr}$

In this case the full orientation relationship is given as:

$$(11\bar{2}0)_{Co} \;//\; (002)_{Cr} \text{ and } [0001]_{Co} \;//\; [1\bar{1}0]_{Cr}$$

Since the $[1\bar{1}0]$ direction is equivalent to the [110] in a cubic material, there are two ways that the magnetic layer can be oriented with respect to the underlayer, giving rise to a so called bicrystalline texture.

We have seen that the crystallographic texture of the magnetic layer of Co alloy films has been controlled by controlling the crystallographic texture of the Cr underlayer. The texture of the underlayer develops either because of a growth mechanism at low temperature, or by a nucleation mechanism at higher temperatures. See reference 13 for a more in depth discussion of this.

Recently, Lee *et al.* (14-16) have developed a new class of underlayers, namely those with the B2 structure. This structure is a crystallographic derivative of the bcc (A1) structure. Alloys with this structure and lattice parameters similar to bcc Cr give rise to similar orientation relationships with the magnetic layer. Two such alloys have been extensively studied in our group in the Data Storage System Center at Carnegie Mellon University, namely NiAl and FeAl. Figure 4 shows the B2 structure and compares it to the bcc Cr structure.

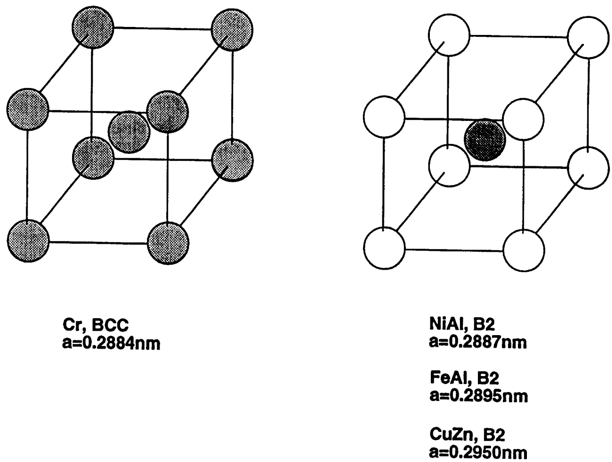

Figure 4. Comparison of the bcc structure and the CsCl structure (B2).

Although the B2 structure is similar to the A2 one, for reasons not completely understood, a new crystallographic texture can be obtained with them, namely the {211} texture. This texture allows for the orientation relationship:

$$(10\bar{1}0)_{Co} \; // \; \{211\}_{B2}$$

See Figure 5, for a schematic of this orientation relationship.

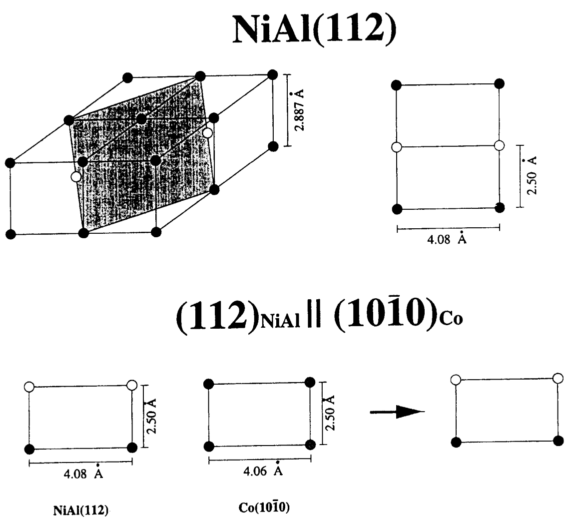

Figure 5. Schematic showing the $(112)_{NiAl}$ planes and their epitaxial relationship with the $(10\bar{1}0)_{Co}$ plane.

However, it may still be desired to obtain the [002] texture for the NiAl underlayer so that the bicrystal magnetic layers can be obtained. We were unable to grow NiAl films with this texture. Therefore we looked for a material that had a four fold symmetry axis and atomic spacings such that the (002) planes of NiAl would form parallel to the plane of the substrate. Figure 6 shows a schematic of the MgO crystal structure (17,18).

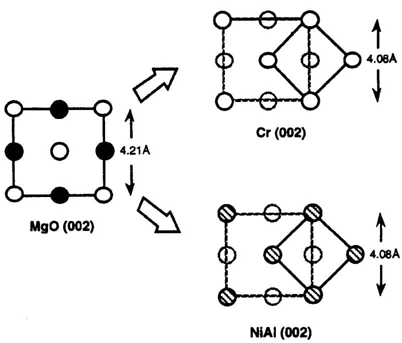

Figure 6. Schematic of the MgO structure, showing how Cr or NiAl can have (002) in plane texture when deposited on MgO seed layer.

It can be seen that if we could deposit MgO films with a [002] texture we would be able to obtain the desired [002] NiAl texture. Figure 7 shows the x-ray scans of films with the following structure:

CoCtPt / NiAl / MgO

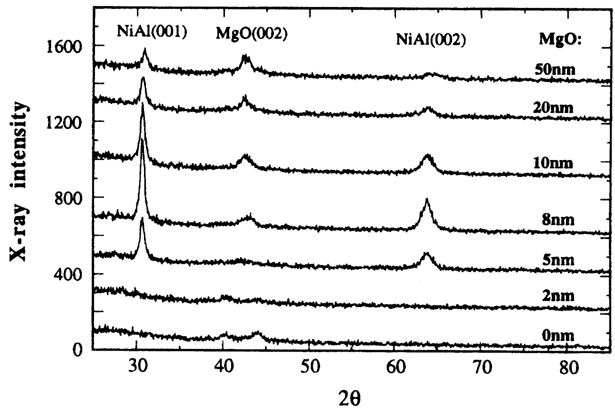

Figure 7. X-ray scans of samples with varying MgO seedlayer thickness.

It can be seen from the plots that the (002) planes of MgO are diffracting as are the (001) and (002) planes of NiAl. This means that we were successful in obtaining the desired crystallographic texture for the NiAl underlayer.

3. THE DEVELOPMENT OF TEXTURES IN FeAl AND NiAl THIN FILMS

We have produced NiAl and FeAl films under various sputtering conditions in order to ascertain what are the controlling parameters in the development of crystallographic texture in these alloys. In particular we have varied the thickness, sputtering power, bias, and Argon pressure. Our results are to be published elsewhere. The following is a summary of them.

A very strong (110) texture was found in NiAl and FeAl underlayer deposited at -200 V bias. This was also found in Cr thin films (13). The (110) planes in these structures are the most closely-packed planes. When applying bias voltage during deposition, the atoms that are weakly bound to the growing thin film are easily removed. Therefore a more compact thin film is formed resulting in the (110) crystallographic texture. Figure 8.

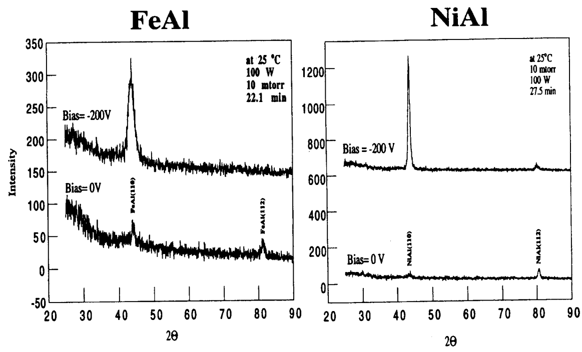

Figure 8. X-ray scans of NiAl and FeAl films with and without bias.

Preliminary work has shown that these strong (110) textured NiAl films yield magnetic films that have the $(10\bar{1}0)$ crystallographic texture. This will be discussed in a subsequent paper.

If NiAl and FeAl thin films are deposited at room temperature, FeAl thin films have stronger (112) x-ray reflections than the NiAl thin films. However, substrate heating during deposition of the thin films promotes the (112) texture.

Interestingly enough, under certain conditions with very high Argon pressure, NiAl thin films have displayed (110), (112) and (111) reflections, indicating a more random distribution of crystallographic orientations of the grains. However, with high Argon pressures under certain conditions we found that the FeAl thin films change their texture into (200). This is the crystallographic texture found in Cr films grown at high temperature. Until this discovery, we had not been able to grow this texture in NiAl films without epitaxial nucleation on a seedlayer. In the case of high sputtering power both NiAl and FeAl thin films are strongly (112). See Figure 9.

Thus, we are able to obtain either very strong (110) texture (high bias), strong (112) texture (high sputtering power), a (200) texture (high Argon pressure) or a random distribution of the FeAl grains in the thin films. This means that we can better control the texture of the subsequently sputtered magnetic films, which means that we can better control their extrinsic properties.

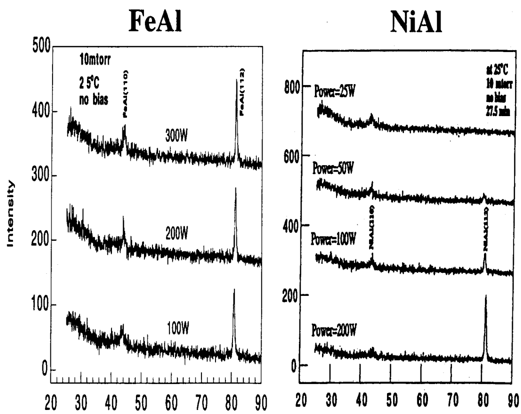

Figure 9. X-ray scans of FeAl and NiAl films produced with various amounts of power.

4. THE CHARACTERIZATION OF TEXTURE IN FILMS BY ELECTRON DIFFRACTION

The crystallographic texture of thin films can be determined in a semi-quantitative way by means of electron diffraction. Recently, Tang and Laughlin (19,20) have developed a method using tilted electron diffraction patterns to gather information about the type and amount of crystallographic textures in layered thin films. Figure 10 shows diffraction patterns taken from a thin film of Cr that has a [001] texture. Figure 10a shows the electron diffraction pattern obtained when the normal to the foil is parallel to the incident electron beam. A characteristic ring pattern is obtained, which shows that the thin film is randomly oriented within the plane of the film. However, it can be seen that the (211) ring is missing from the pattern. This means there is a texture. As the sample is tilted it can be seen that the diffraction pattern changes from the ring pattern to patterns exhibiting arcs at various positions around the rings. This only occurs because the film is textured. The arcs arise because the reciprocal space of a highly textured film consists of an array of circles at the various higher order Laue zones. These reciprocal circles are not intersected by the reflection sphere when the normal to the foil is parallel to the incident electron beam, but are intersected after various amounts of tilt. From the length of the arcs as well as from the angles of tilt that the various arcs appear quantitative information about the texture can be ascertained. See (19,20). It should also be pointed out that the use of electron diffraction allows us to investigate the crystallographic texture of samples consisting of more than one type of film. Figure 11 shows a pattern taken from a sample consisting of CoCrTa film deposited on a Cr underlayer. Rings from each of the phases can be distinguished, and the texture of the two films can be determined.

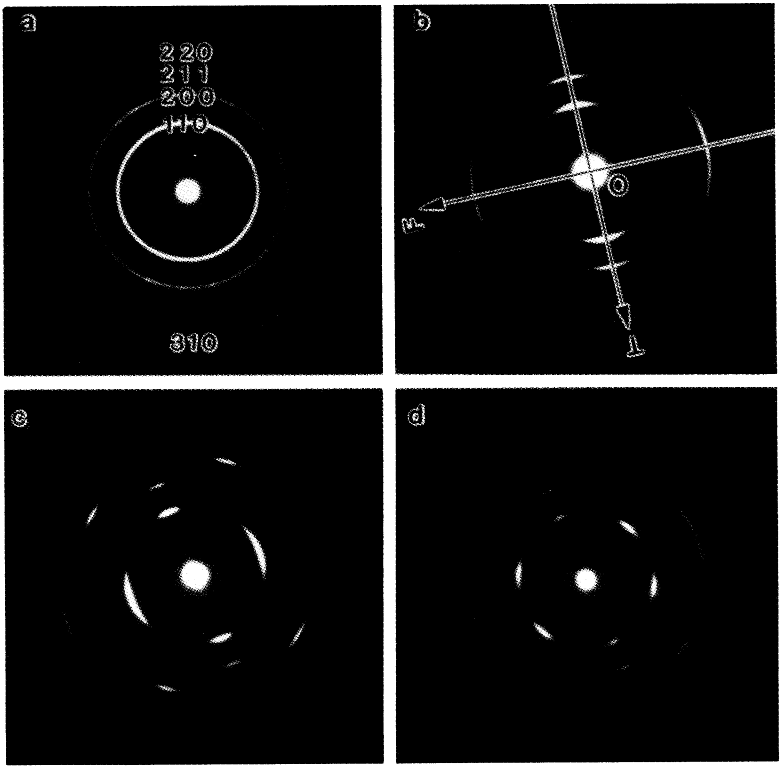

Figure 10. Electron diffraction patterns of a [001] textured Cr films at various tilts: (a) 0°, (b) 21°, (c) 45°, (d) 55°.

Figure 11. Indexed electron diffraction pattern of $(11\bar{2}0)_{CoCrTa}$ // $(002)_{Cr}$ bilayer film at 60° tilt. From (20).

5. SUMMARY

We have discussed the way that the crystallographic texture of magnetic tin films used for longitudinal magnetic recording can be controlled during their production. The key is to develop the proper underlayer texture so that the desired planes of the magnetic Co alloy will form epitaxially on the grains of the underlayer. Sometimes the underlayer texture is enhance or changed by sputtering a seedlayer prior to the underlayer. In this paper we have reviewed some of our recent work on novel underlayers as well as our new technique of characterizing the crystallographic texture by electron diffraction.

ACKNOWLEDGMENTS

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