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Invited paper

Design and crystallography of multilayered media

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Abstract

In this paper several different schemes for multilayered longitudinal magnetic recording media are presented and discussed. We will focus the discussion on those schemes on which we have worked over the past several years, emphasizing the role of new underlayers, seed layers, intermediate layers and interlayers. In each case we discuss the role that each of the layers plays in determining the important magnetic properties and recording performance of the Co based hcp thin film media. Included in the paper is a review of the role of new underlayers (NiAl and MgO), seed layers (MgO), intermediate layers (Cr, Co alloys) and interlayers (Cr, Al, Cu and Ag). Throughout we discuss the role of epitaxy between the various layers and demonstrate that the resulting microstructure and crystallographic texture of the films depends strongly on such epitaxy. These characteristics, in turn, control the resulting magnetic properties of the Co based films such as in plane coercivity H_c and squareness ratio, S^*.

1. Introduction

In order to increase the density of longitudinal recording in thin film media, it is necessary to find ways of increasing the in plane coercivity of the media and at the same time decrease the media grain size in order to achieve acceptable levels of signal to noise ratios. The magnetic materials used as recording media are usually Co-based alloys with the hcp crystal structure. The various alloy additions to the Co (Cr, Ni, Ta, Pt etc.) change the *intrinsic* properties of the alloy. However the *extrinsic* properties of the alloys can be controlled by means of controlling their microstructure. The well known paradigm of Materials Science and Engineering is that the *extrinsic* properties of materials depend on their structure which in turn depends on the method by which materials were processed. This linkage between properties and processing gives us an important way to further develop alloys to be used in future magnetic recording devices.

As mentioned above, most of the media used for longitudinal magnetic recording are Co based hcp alloys. In this paper we will not emphasize the effects of alloy variations on properties. Instead, we focus on different ways of constructing thin film media so as to optimize their resulting magnetic properties. Hence we will be dealing with ways of changing the microstructure of the films, which will change their extrinsic magnetic properties. Features to be discussed include the grain size and crystallographic texture of the magnetic media.

When an hcp material such as Co or its alloys is sputter deposited on an amorphous substrate such as NiP or glass, the film usually takes on a crystallographic texture such that its *c* axis is perpendicular to the plane of the film. This is because the growing film seeks to minimize its surface free energy and the close packed planes (which have the lowest surface energy) of the hcp structure are the (0001) basal planes [1,2]. Because the *c* axis is the magnetic easy axis for hcp Co, this is ideal for perpendicular recording in which the magnetization should be perpendicular to the film. Different schemes have been devised to optimize the crystallographic texture of such films including the use of so called seed layers [3]. However for longitudinal recording it is necessary to have most of the magnetic grains with their easy axes of magnetization in or near the plane of the film. For hcp structures with their $(10\bar{1}0)$ or $(11\bar{2}0)$ planes parallel to the plane of the film the *c* axes will be in the film plane. If the $(10\bar{1}1)$ planes are in the film plane the *c* axis will be about 28° from the plane of the film [4]. Various ways have been devised to produce such hcp films.

The earliest methods were to sputter deposit Cr as an underlayer to the Co based alloy films. Since Cr is bcc, its closest packed planes are {110}, and thus its growth texture is [110] (see reference [2] for a discussion of the growth textures of various crystal structures). Also, the atomic size of Cr is very similar to that of Co (~ 0.125 nm). This combination allows for most of the grains of the growing Co based film to have their *c* axes lie at an angle of approximately 28°, due to the epitaxy of their $\{10\bar{1}1\}$ planes with the {110} planes of Cr.

The next advance in the construction of magnetic thin

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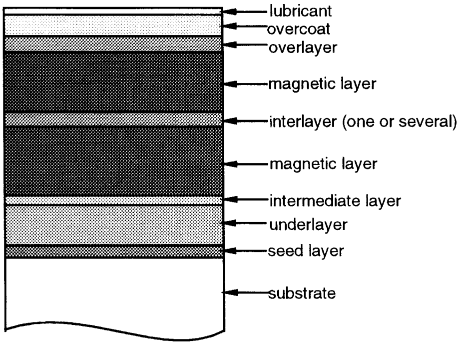

Fig. 1. Schematic of a multilayer film demonstrating the position of each of the kind of layer discussed in this paper.

films was to sputter deposit the Cr underlayers at elevated temperatures. This results in Cr underlayers with {002} crystallographic textures. By means of epitaxy it is possible to get the $(11\bar{2}0)$ Co planes to lie in the plane of the film, causing the closest packed planes of Co (the (0001) planes) to lie parallel to the closest packed planes of Cr (the {110} planes). This forces the *c* axes of these planes to lie in the plane of the film. Thus by suitable manipulation of the processing conditions (in this case the preheating temperature of the substrate) it is possible to obtain Co based thin films with most grains having their *c* axes in the film plane.

In the remaining part of this paper we describe various methods utilized in our group to control the microstructure of media used for magnetic recording, with the goal of improving their recording performance. Our emphasis will be on the control of the grain size and of the crystallographic texture of the Co films by a series of innovations other than the processing techniques of the films.

Throughout the paper we will be using the terminology for the different layers as shown in Fig. 1. The names given to each of the layers are given in reference to their position with respect to the magnetic layer. Hence, the underlayer lies under the magnetic layer and interlayers lie within or in between two magnetic layers. The intermediate layer lies between the underlayer and the magnetic layer. It should be pointed out that the schematic is shown with many of the possible layers which we have utilized and does not represent any one configuration discussed in the paper.

2. NiAl underlayers

The intermetallic compound NiAl has the B2 crystal structure (space group $Pm\bar{3}m$; prototype CsCl) which is a derivative structure of bcc. Since its lattice parameter is nearly the same as that of bcc Cr, epitaxial relations that occur between Co based alloys and Cr should also occur between Co based alloys and NiAl [5]. We have sputter deposited NiAl on glass substrates and have obtained films with grain sizes that are nearly half the diameter of comparably sputtered Cr films. The subsequently deposited Co alloys should also have the smaller grain size. Measured values of the signal to noise ratio show promise as to the improvement due the smaller grain size. The coercivity values are about the same as those deposited on Cr underlayers. However when a small amount of Cr is deposited on top of the NiAl layer before the Co alloy is deposited, the subsequent coercivity greatly increases. This layer of Cr is called an intermediate layer, since it lies between the underlayer and the magnetic layer. The reason for its large effect on the coercivity is not fully understood at this time, but it may be related to its ability to interdiffuse into the magnetic layer thereby isolating the grains from each other. Thus, by using a different underlayer, the coercivity of the thin films can be increased as can the signal to noise ratio. It should be noted that combinations of Cr intermediate layers and FeAl underlayers have a similar effect on the magnetic properties of the magnetic layers as NiAl underlayers [6].

3. Intermediate layers

As mentioned above, the addition of a Cr *intermediate* layer to the NiAl underlayers greatly enhances the magnetic properties of the subsequently deposited Co based films. Another kind of *intermediate* layer has been developed by Fang and Lambeth [7]. They sputter deposited a thin layer of CoCrTa between a Cr underlayer and a CoCrPt thin film. This *intermediate* layer improved the lattice matching of the CoCrPt film and thereby improved the in plane magnetic properties of the CoCrPt film. This intermediate layer had the same structure as the magnetic film, while the Cr interlayer had a similar structure to the underlayer. However, since both are in between the underlayer and the magnetic layer they are both intermediate layers.

4. MgO seed layers

Nakamura et al. [8] have demonstrated that Cr films deposited on single crystals of [001] MgO are deposited with a [001] crystallographic texture. This occurs because of epitaxial atomic matching across the interface as illustrated in Fig. 2. We have extended this concept by sputtering MgO onto glass substrates obtaining a polycrystalline MgO film with a strong [001] crystallographic texture. This texture is expected as the MgO has the B1 crystal structure ($Fm\bar{3}m$: prototype NaCl) which has its {001} planes as the ones with lowest surface energy [9]. We have studied the texture of the MgO thin films by both X-ray diffraction and electron diffraction techniques. The MgO film shown in Fig. 3 was rf sputtered onto an oxidized (100) Si substrate without any preheating of the substrate. The resulting grain size of the film is approximately 45 nm as measured from the bright field image (Fig. 3a) at zero tilt. Fig. 3b, c and d are the diffraction patterns of the film

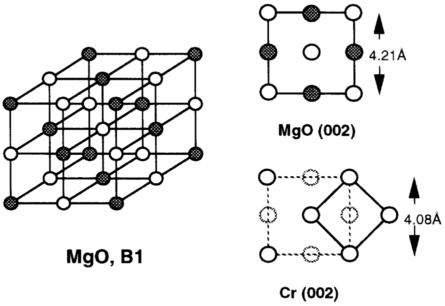

Fig. 2. Schematic of a (001) plane of MgO and its epitaxial orientation relationship of (001) Cr.

at 0, 35 and 56 degree tilt about the OT axis. From these patterns we can see that the film has the (001) crystallographic texture. The distribution angle for the [001] axis is measured to be about 14° [10].

This strongly textured MgO then can act as a seed layer for the growth of a highly textured Cr underlayer. Of interest here is that the (002) Cr crystallographic texture can be obtained without preheating of the substrate. This scheme can also be used for preparing NiAl underlayers on MgO seed layers yielding subsequent magnetic films with superior magnetic properties (see Table 1). Thus, MgO may be either a new underlayer or it may be used as a seed layer to produce highly textured underlayers of Cr or NiAl. For NiAl layers grown on MgO seed layers we have been able to enhance the crystallographic texture of the subsequently deposited magnetic film by use of this new layer.

Table 1
In plane magnetic propeties of CoCrPt(40 nm)/NiAl(100 nm) films with various MgO seed layer thicknesses

MgO seed layer	H_c (Oe)	S^*	S
0 nm	1860	0.87	0.84
5 nm	3420	0.89	0.85
20 nm	3300	0.83	0.85

5. Interlayers

Another kind of layer that can be added to the thin film multilayer is an *interlayer*. As shown in Fig. 1, an inter-

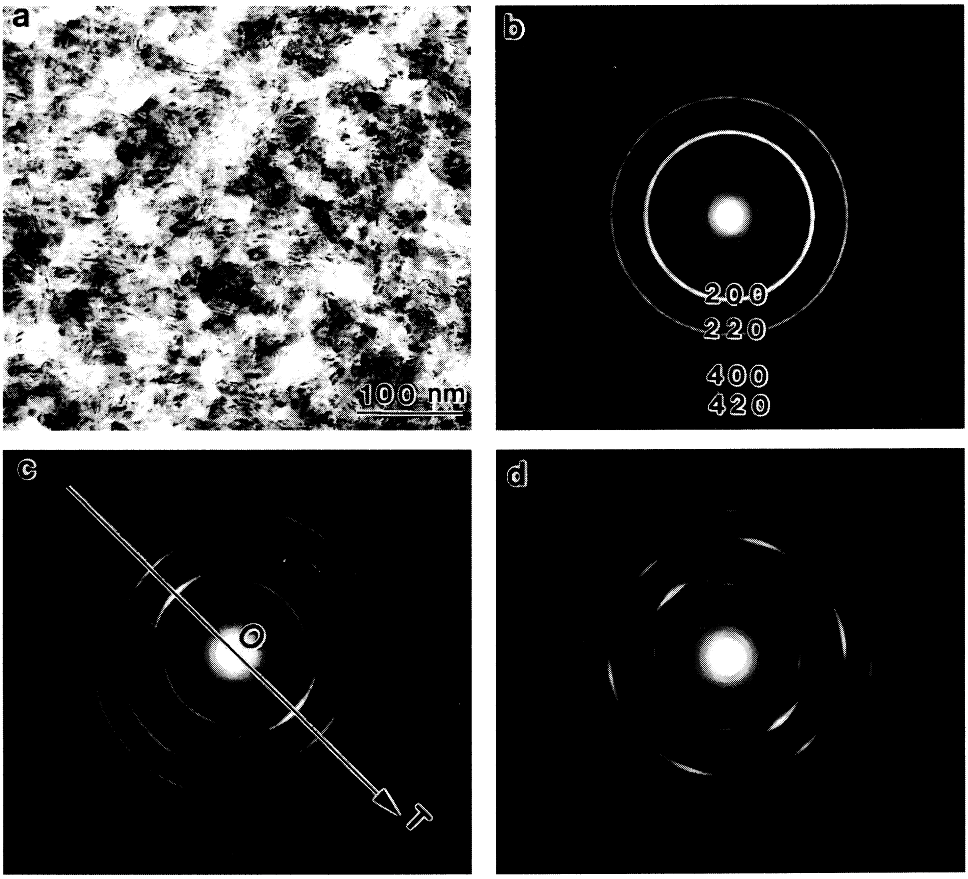

Fig. 3. (a) Bright field TEM image of a MgO film at zero tilt and diffraction patterns at (b) 0°, (c) 35° and (d) 56° tilt.

layer is a thin non-magnetic layer that is placed between two magnetic layers. Cr interlayers have been the subject of research since 1990 [11–13]. It has been shown that Cr interlayers do indeed increase the signal to noise ratios of magnetic media [11–13]. In our investigations we have looked at the effect of several other non-magnetic materials (Ag, Al and Cu) and compared them with the effect of Cr interlayers [14–17]. Only a very brief overview of this work can be presented here.

One of the purposes of an interlayer is to increase the signal to noise ratio of the magnetic media by decreasing the size of the magnetic grains. Another purpose of an interlayer is to promote interdiffusion into the magnetic layer grains thereby increasing magnetic isolation within each magnetic layer. This too should help the noise properties of the media. We chose to look at Al, Ag and Cu interlayers in addition to Cr, because of their low melting temperatures and hence greater diffusivity. Ag and Cu are immiscible with Co. Also, the three elements gave a spectrum of lattice misfit compared to Cr. Al and Ag fit very well ([100] rotated 45 with respect to Cr) and Cu has a large misfit [16].

The hysteresis loop of the films with Al interlayers indicate two distinct switching field distributions [16]. This may due to the formation of Al–Co intermetallic compounds at the Al/Co interface. Hence, the second Co alloy layer could not duplicate the microstructure of the first Co alloy layer by epitaxy.

Studying the dependence of magnetic properties on the thickness of Cu, Ag and Cr interlayers, we found that the coercivities of the films with the Cu interlayer decrease most significantly (fastest) as the interlayer thickness increases [16]. We believe that this is because the large misfit between Cu and Co alloys lattices. Hence, further work has been focused on comparing the films with Ag interlayers to those with Cr interlayers [17].

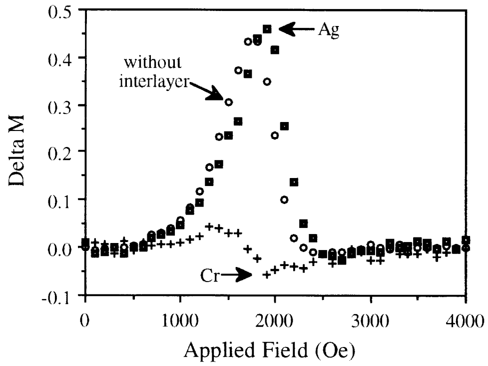

Fig. 5. ΔM curves of films with Ag, Al and Cr interlayers.

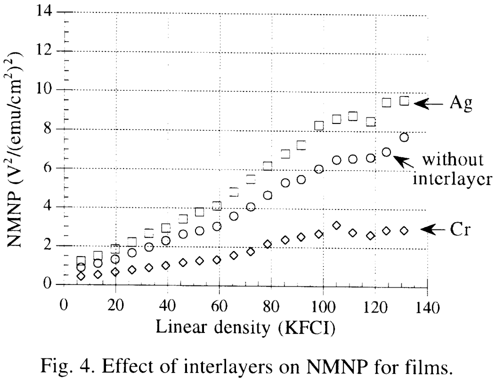

Fig. 4. Effect of interlayers on NMNP for films.

In order to make media suitable for MR read heads, the total thickness of CoCrTa layers were chosen to be 200 Å. The H_c and S^* decreased rapidly when a Cr interlayer was introduced. On the other hand, H_c and S^* increased when a thin Ag interlayer was used, but decreased as the interlayer thickness further increased [17].

Fig. 4 shows the Normalized Media Noise Power (NMNP) versus linear recording density for films with Cr and Ag interlayers, as well as for a film with no interlayer. It can be seen that consistent with previous work [11–13] the Cr interlayer improves the noise properties. However, the films with Ag interlayers have worse noise properties. This may be understood by investigating the role of interlayers on magnetic coupling in these films. To study the magnetic interactions, we performed ΔM measurements on the films. The results are displayed in Fig. 5. It can be seen that the ΔM curve of the film with a Ag interlayer displays a much higher positive peak than does the ΔM curve of the film with a Cr interlayer. This indicates a stronger exchange coupled interaction in the film with a Ag interlayer. The possible mechanism of the enhanced coupling in the film with the Ag interlayers may be due to RKKY interaction [18]. This coupling could be between two magnetic layers (Fig. 6a) or among grains within the same magnetic layer (Fig. 6b). However, the fact that the disk with a Ag interlayer has greater noise than that without an interlayer can only be understood if the Ag

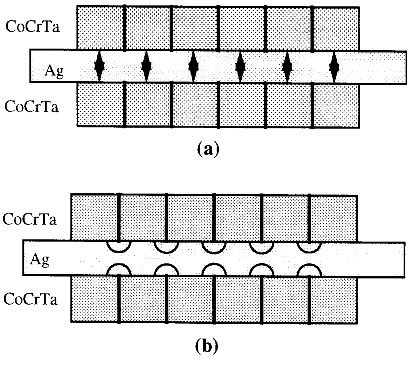

Fig. 6. Schematic showing possible RKKY coupling through a Ag interlayer; (a) between two magnetic layers, (b) among the grains within the magnetic layers.

interlayer enhances the exchange coupling among grains within a magnetic layer.

6. Summary

We have presented various schemes that we have utilized to control the magnetic recording properties of thin film recording media. These include new underlayers, intermediate layers, seed layers and interlayers. Other schemes include combinations of each. For example, a MgO seed layer could be used to produce a NiAl underlayer with stronger [001] texture. A Cr intermediate layer should then be placed on top of the underlayer before the magnetic layer is deposited. In each case the structure of the film becomes more complex which will make them more difficult to produce.

Acknowledgements

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