Cross-sectional structures of CoNiCr/Cr bilayer and multilayer thin films

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The cross-sectional structure of CoNiCr/Cr bilayer and multilayer thin films is investigated by HRTEM. Results showed that the orientation relationship between CoNiCr and Cr and the crystallographic orientation of CoNiCr is controlled by the orientation of the Cr column. Similar results are found for the multilayer film. The crystallographic orientation of the Cr interlayer and the second CoNiCr layer is identical to that of the Cr underlayer and the first CoNiCr layer. The misfit at the interface is partially relieved by misfit dislocations and the rest remains as elastic strain.

The use of a Cr underlayer is known to greatly enhance the coercivity of Co alloy (Co*) magnetic thin films.[1,2] Its importance lies in the fact that it reorients the Co*hcp *c*-axes into the plane of the film.[3–8] This suppresses the [0002] fibrous texture in the Co* film and leads to an enhancement in the in-plane coercivity. The application of an underlayer has also been found to stabilize the hcp structure.[3,9] This is essential because hcp Co* has a much higher magnetocrystalline anisotropy. Microdiffraction studies[9] on Co*/Cr bilayer films have revealed several grain to grain orientation relationships (ORs) between the Co* and the Cr grains. Moreover, preliminary high resolution transmission electron microscopy (HRTEM) studies on high coercivity CoNiCr/Cr films have revealed good lattice matching across the interface.[10] These results signify the importance of Cr in controlling the crystal structure and orientation of the Co* grains.

Recent studies on Co*/Cr media have shown that the coercivity and the noise characteristics can be improved by utilizing a multilayer structure.[11,12] This stems from a reduction in exchange coupling by partitioning the Co* film. However, little is known about the crystallographic orientation of the grains in the various layers. This is especially important because the in-plane anisotropy and the magnetostatic coupling between the Co* layers is sensitive to the orientation of the Co* grains.

The aims of the present study are twofold. First, the interfacial structure CoNiCr/Cr bilayer films is examined in detail. The effect of the Cr underlayer on the character of the CoNiCr grains is addressed. For the second part of this work, the orientation of the Cr and the CoNiCr grains in a multilayer film is characterized, with emphasis on the crystallographic orientation of the Cr interlayer grains and their effect on the alignment of the hcp *c*-axes in the second Co* layer.

The CoNiCr/Cr thin films were deposited onto Corning 0211 glass substrates at 260 °C by rf diode sputtering as presented previously.[13] The bilayer film is comprised of 400 Å CoNiCr/1000 Å Cr whereas the multilayer film is comprised of 200 Å CoNiCr/200 Å Cr/200 Å CoNiCr/600 Å Cr. The films were studied with a JEOL 4000EX high resolution electron microscope.

Three ORs were observed in the bilayer films. The first one is that of Pitsch–Schrader,[14] $(11\bar{2}0)_{\mathrm{CoNiCr}} \| (001)_{\mathrm{Cr}}$ and $[0001]_{\mathrm{CoNiCr}} \| [1\bar{1}0]_{\mathrm{Cr}}$ (see Fig. 1). The CoNiCr $(11\bar{2}0)$ and Cr (001) planes are approximately parallel to the interface. As a result of lattice matching, the hcp *c*-axis lies preferentially in the plane of the film. There is a noticeable misfit along Cr $[1\bar{1}0]$ and CoNiCr $[1\bar{1}00]$, circa 2.4%. This is compensated by edge dislocations (extra planes) situated in the Cr-underlayer (black arrows). The Burgers vector of the dislocation is $1/2[1\bar{1}0]$. The spacing between the dislocations was measured as 18 and 22 Cr (110) planes. According to Eq. (1)

$$P=\frac{d_2}{d_2-d_1} \tag{1}$$

the period P of the misfit dislocations is 17. Here d_1 and d_2 are the Cr $(1\bar{1}0)$ and CoNiCr $(1\bar{1}00)$ interplanar spacings. This discrepancy is most likely caused by other inherent lattice defects in the film created during deposition. Such defects would affect the local stress state at the interface and alter the misfit dislocation period.

From Fig. 1(a) one notes that the Cr [001] is not perpendicular to the interface but is tilted at 4°. In other words, it is not parallel to the film normal since the interface should be parallel to the film plane. Such rotation could play a role in the deterioration of the [001] fibrous texture in thick Cr underlayers.[13] Thus, if Cr (001) planes are not exactly parallel to the film surface, they may not grow as fast as those planes which are parallel to this surface, such as Cr (110) planes.

The Potter OR,[15] $(10\bar{1}1)_{\mathrm{CiNiCr}} \| (110)_{\mathrm{Cr}}$ and $[1\bar{2}10]_{\mathrm{CoNiCr}} \| [1\bar{1}\bar{1}]_{\mathrm{Cr}}$ is also observed between CoNiCr and Cr (see Fig. 2). In this OR, Cr (110) and CoNiCr $(10\bar{1}1)$ are parallel to the interface and cause the hcp [0002] to be situated at an angle of 28° with respect to it. Good atomic matching can be observed across the interphase boundary with the Cr $(\bar{1}10)$ and CoNiCr $(01\bar{1}\bar{1})$ planes connecting at the interface. Although the period of the extra $(01\bar{1}\bar{1})$ plane should be 19 according to Eq. (1), only one misfit edge dislocation can be depicted in the image (arrow). This implies that the misfit strain at the interface has not been completely relieved.

Finally, the Burgers OR,[16] $(11\bar{2}0)_{\mathrm{CoNiCr}} \| (111)_{\mathrm{Cr}}$, $[0001]_{\mathrm{CoNiCr}} \| [10\bar{1}]_{\mathrm{Cr}}$ is also observed (see Fig. 3). The atomic matching across the interface is worse than the two previous examples. This is due to the larger misfit in this

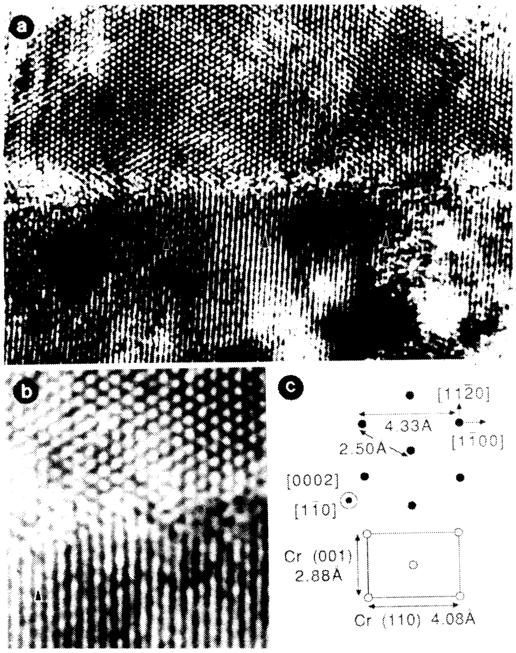

FIG. 1. HRTEM image of the cross section of a CoNiCr/Cr bilayer thin film. The OR between the grains is that of Pitsch–Schrader.

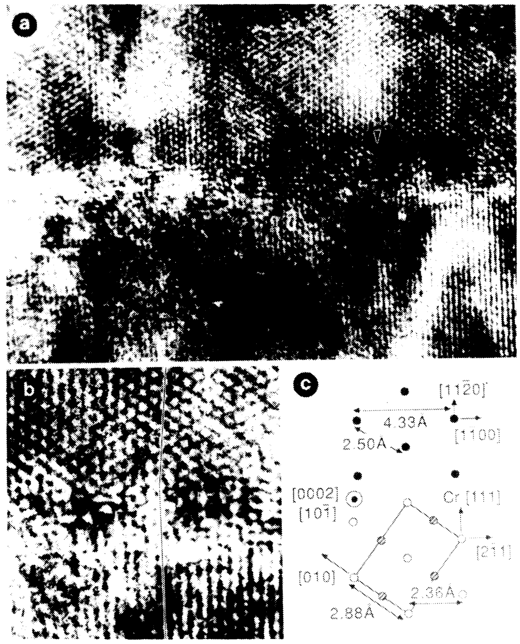

FIG. 3. HRTEM image of the cross section of a CoNiCr/Cr bilayer thin film. The OR between the grains is that of Burgers.

OR. The CoNiCr $(11\bar{2}0)$ and Cr (111) planes are almost parallel to the interface. The CoNiCr $(1\bar{1}00)$ planes are rotated by 6.5° with respect to the Cr $(\bar{2}1\bar{1})$ planes [Fig. 3(b)]. This may have been induced by the surface roughness of the Cr column.

In the three ORs examined, misfit dislocations are only found near the center of the grain. Since the system under consideration is not infinite (grain size = 350 Å), misfit can be partially relieved by the free surface near the grain/column boundaries and the balance can remain as elastic strain. This strain probably leads to the obtuse contrast observed at the interfaces. On the other hand, similar contrast can be caused by an oxide layer at the interphase boundary. However, the epitaxial growth between Cr and CoNiCr indicates that the amount of oxide at the interface is minimum. Thus, the contrast is mainly due to the elastic strain present as the interface.

The above images show that the choice of OR is governed by the crystallographic orientation of the Cr column. The two layer *ABAB* stacking of the Cr atomic planes is

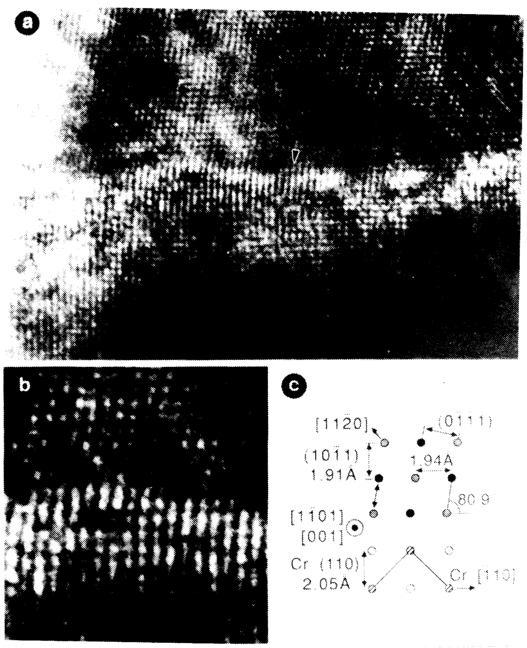

FIG. 2. HRTEM image of the cross section of a CoNiCr/Cr bilayer thin film. The OR between the grains is that of Potter.

FIG. 4. Cross-sectional TEM image of a CoNiCr/Cr multilayer thin film. (a) Bright field and (b) dark field.

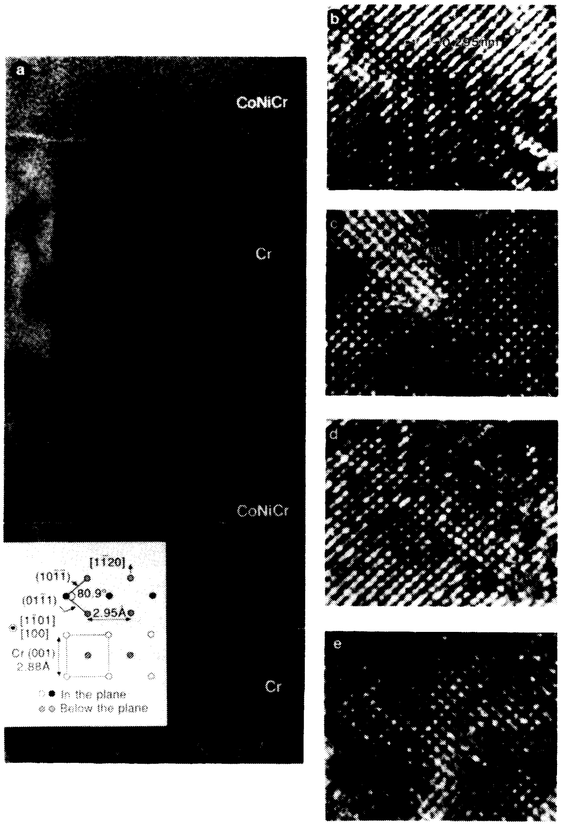

FIG. 5. HRTEM image of the cross section of a CoNiCr/Cr multilayer thin film. The OR between the grains is that of Pitsch–Schrader.

preserved by hcp CoNiCr in all the three ORs studied. This shows the atomic matching is better between hcp CoNiCr and bcc Cr and this is one of the main reasons behind the selective nucleation and growth of hcp CoNiCr, instead of fcc CoNiCr, on bcc Cr. The favorable lattice matching has also been shown by modeling studies of the interfacial structure.[17]

Figure 4 shows the bright field (BF) and the dark field (DF) images of the multilayer specimen. The interface between the Cr interlayer and the second CoNiCr layer is rougher than that between the Cr underlayer and the first CoNiCr layer. No morphological separations between columns was found. In the BF image, a continuous columnar contrast extending across the interfaces can be observed. Two such columns are diffracting in the DF image and this implies a correlation in the crystallographic orientation between the grains in each layer.

The HRTEM studies on the multilayer specimen have revealed that the Cr interlayer grain and the Cr underlayer grain, which are in the same grain column, have the same crystallographic orientation. Similarly, the orientation of the CoNiCr interlayer grain and the CoNiCr overlayer grain are identical. The HRTEM image of one of these grain columns is shown in Fig. 5. The OR between the grains is Pitsch–Schrader. The magnified images from the various layers display a correspondence in the crystallographic orientation between them. The above results demonstrate that the crystallographic orientation of the grains in the two magnetic layers have not been altered despite the use of a Cr interlayer. Hence, the in-plane anisotropy is preserved.

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