Study of CoCrPt/NiAl thin films on (001) MgO single crystals

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(Received 5 April 1996; accepted for publication 11 June 1996)

The microstructure and in-plane magnetic properties of $Co_{72}Cr_{10}Pt_{18}$/NiAl thin films sputter deposited on (001) single crystal MgO substrates have been investigated. The orientation relationship between the NiAl underlayer and the MgO substrate is determined to be [001](100)NiAl//[001](110)MgO. The CoCrPt films grow in a fibrous manner on the (001) NiAl underlayer and the orientation relationship between the two layers is determined to be [$10\bar{1}1$]CoCrPt//[001]NiAl, and ($\bar{1}2\bar{1}0$)CoCrPt//(100)NiAl (variant 1), or ($\bar{1}2\bar{1}0$)CoCrPt//(010)NiAl (variant 2). The CoCrPt film has two sets of in-plane magnetization easy axes. The major easy axes are along the MgO[100] (i.e., NiAl[110]) and the MgO[010] (i.e., NiAl[$1\bar{1}0$]) directions and the secondary easy axes are along the MgO[110] (i.e., NiAl[100]) and the [$\bar{1}10$] (i.e., NiAl[010]) directions. © *1996 American Institute of Physics.* [S0003-6951(96)02134-1]

Co-based alloy thin films for longitudinal magnetic recording are usually sputter deposited on nonmagnetic underlayers. The role of the underlayers is to control the grain size, grain shape, grain separation, as well as to control the orientation of the magnetic layers. All of these features in turn strongly affect the magnetic and recording properties of the films. Of the many underlayers which have been developed, bcc Cr and CrX binary alloys (X=V, Ti) have received the most intensive investigation.[1–5] Various grain to grain epitaxial relationships between the bcc Cr underlayer and the hcp Co-based alloy thin films have been observed, such as

$$(11\bar{2}0)\text{Co}//(001)\text{Cr},\quad [0001]\text{Co}//[1\bar{1}0]\text{Cr};^{6-10}$$

$$(10\bar{1}1)\text{Co}//(110)\text{Cr},\quad [1\bar{2}10]\text{Co}//[1\bar{1}1]\text{Cr};^{8,11,12}$$

$$(10\bar{1}0)\text{Co}//(211)\text{Cr},\quad [0001]\text{Co}//[01\bar{1}]\text{Cr}.^{9,13}$$

Recently, Lee, Laughlin, and Lambeth[14] reported that NiAl with a B2 structure (which is a crystallographic derivative structure of bcc, a=2.89 Å) and an almost identical lattice constant of the bcc Cr (a=2.88 Å) could also be used as an underlayer for Co-based hcp magnetic thin film media. In contrast to Cr underlayers, for which the (001) texture can be achieved on preheated (~260 °C) NiP or glass substrates, attempts to grow (001) textured NiAl underlayers by means of substrate heating have so far been unsuccessful. On the other hand, similar to the Cr underlayers,[9,15] (001) textured NiAl underlayers grown on (001) textured MgO seed layers have been reported.[16] However, unlike the (001) Cr on (001) MgO which induces the ($11\bar{2}0$) texture in the CoCrPt layer[9,15] the texture of CoCrPt layer on (001) textured NiAl underlayer could not be determined in that study because x-ray peaks of the CoCrPt layer were not visible in the θ–2θ x-ray diffraction spectra. In this letter, we report the results of transmission electron microscopy (TEM) studies of the orientation relationship between CoCrPt and NiAl films sputter deposited on (001) MgO single crystal substrates. The correlation between the anisotropic in-plane magnetic properties of the CoCrPt and the determined CoCrPt/NiAl orientation relationship is also discussed.

An 80 Å thick MgO layer, a 1000 Å thick NiAl underlayer, and a 400 Å $Co_{72}Cr_{10}Pt_{18}$ film were sequentially deposited on a polished (001) MgO single crystal substrate by rf diode sputtering using a Leybold–Heraeus Z-400 system. The base vacuum was about 5×10^{-7} Torr. The Ar gas pressure was 10 mTorr and the sputtering power was 100 W for all the three layers. The substrate bias for the NiAl/MgO layers and for the CoCrPt layer were 0 and −100 V, respectively. The microstructure of the film was investigated using a θ–2θ x-ray diffractometer with a Cu $K\alpha$ radiation and by a Philips 420T transmission electron microscope. The in-plane magnetic properties of the magnetic film were measured using a vibrating sample magnetometer.

The θ–2θ x-ray diffraction spectrum of the CoCrPt/NiAl/MgO/MgO(001) film is shown in Fig. 1. Except the strong (002) and (004) peaks no other MgO peaks are observed, indicating that the sputter deposited 80 Å thick MgO layer grows epitaxially on the (001) MgO single crystal substrate. Consequently, the (001) NiAl layer also seems to grow epitaxially on the (001) MgO layer, as inferred from the strong (001) and (002) NiAl peaks in Fig. 1. Epitaxial

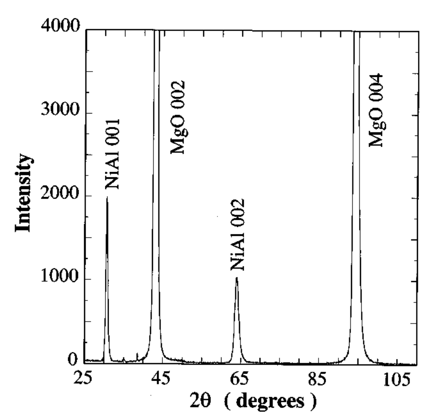

FIG. 1. The x-ray diffraction spectrum of the $Co_{72}Cr_{10}Pt_{18}$/NiAl/MgO/(001)MgO film.

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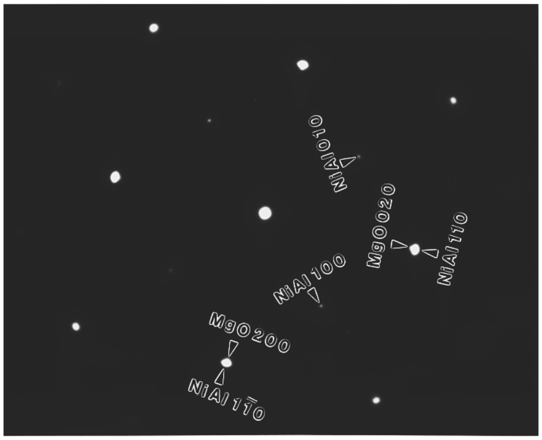

FIG. 2. [001]zone axis electron diffraction pattern of the NiAl/MgO/(001)MgO layers.

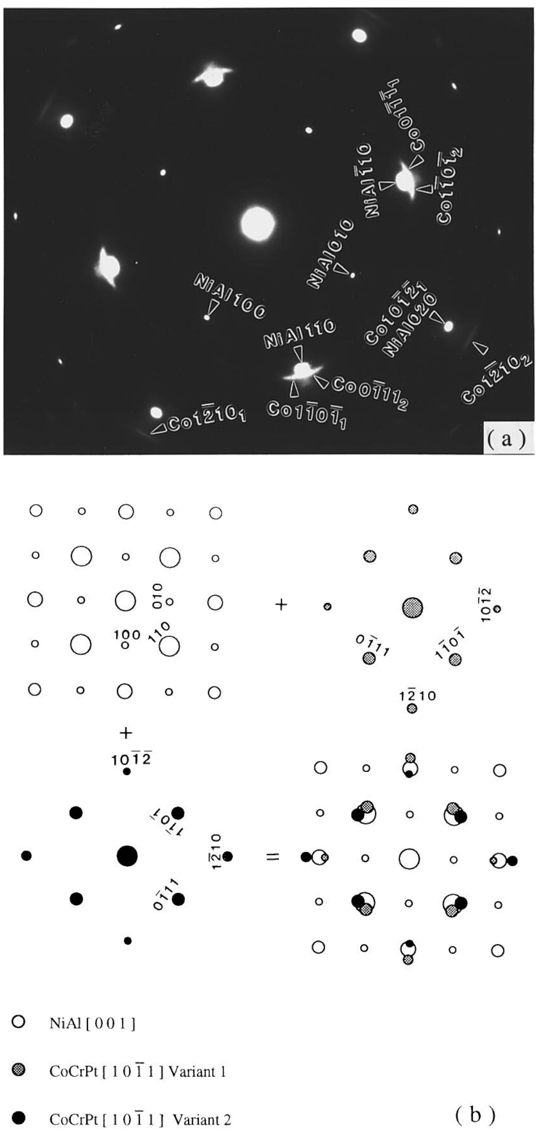

FIG. 3. (a) NiAl[001] zone axis electron diffraction pattern of the CoCrPt/NiAl bilayer, and (b) simulated [1011]CoCrPt//[001]NiAl, and (1210) CoCrPt//(100)NiAl, or (1210)CoCrPt//(010)NiAl, electron diffraction pattern.

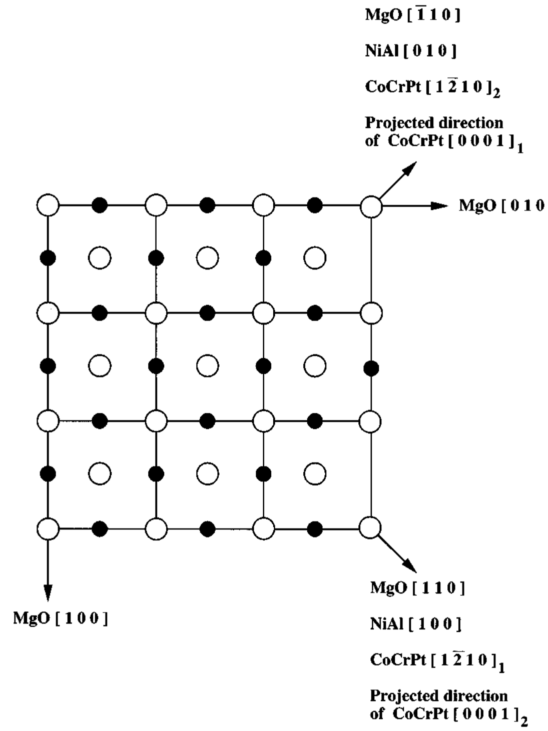

FIG. 4. Directional relationships between those of the CoCrPt/NiAl layers and those of the (001) MgO substrate.

growth is confirmed by the [001] zone axis electron diffraction pattern of the NiAl/MgO bilayer (Fig. 2) film. The orientation relationship between the NiAl layer and the MgO layer is determined to be: [001](001)NiAl//[001](110)MgO. This orientation relationship is the same as that for Cr on (001) MgO single crystals.[9] It is worth pointing out that no x-ray peaks of the CoCrPt layer are observed in Fig. 1. Nevertheless, epitaxy between the CoCrPt layer and the (001) NiAl layer obviously exists as can be seen from the NiAl [001] zone axis electron diffraction pattern [Fig. 3(a)] of the CoCrPt/NiAl bilayer. The CoCrPt spots in Fig. 3(a) can be indexed as diffraction spots from the [1011] zone axis of two variants. Figure 3(b) is the simulated [1011] CoCrPt (variants 1 and 2)//[001]NiAl electron diffraction pattern. From Figs. 3(a) and 3(b), the orientation relationship between the CoCrPt layer and NiAl layer can be written as: [1011]CoCrPt//[001]NiAl, and (1210)CoCrPt//(100)NiAl (variant 1), or (1210)CoCrPt//(010)NiAl (variant 2). Using the NiAl lattice constant $a=2.89$ Å as a standard and the (1210) and (1011) spots in Fig. 3(a) the lattice constants of the hcp CoCrPt film are determined to be $a=2.58$ Å and $c=4.20$ Å. The d-spacing mismatch between the CoCrPt (1210) plane and the NiAl(200) plane is 12% and that between the CoCrPt (1012) plane and the NiAl(200) plane is 6%. In addition, the d spacing and orientation mismatch between the CoCrPt (1101) and (0111) planes and the NiAl (110) plane is 3.5% and 4.5°, respectively. These mismatches are comparable with the mismatch (9%) between the CoCrPt (1100) plane and the NiAl (110) plane and that (3%) between the CoCrPt (0002) plane and the NiAl (110) plane if the CoCrPt would have grown with the (1120) plane parallel to the NiAl (001) plane. The reason why the CoCrPt film grows with the [1011] direction parallel to the NiAl [001]

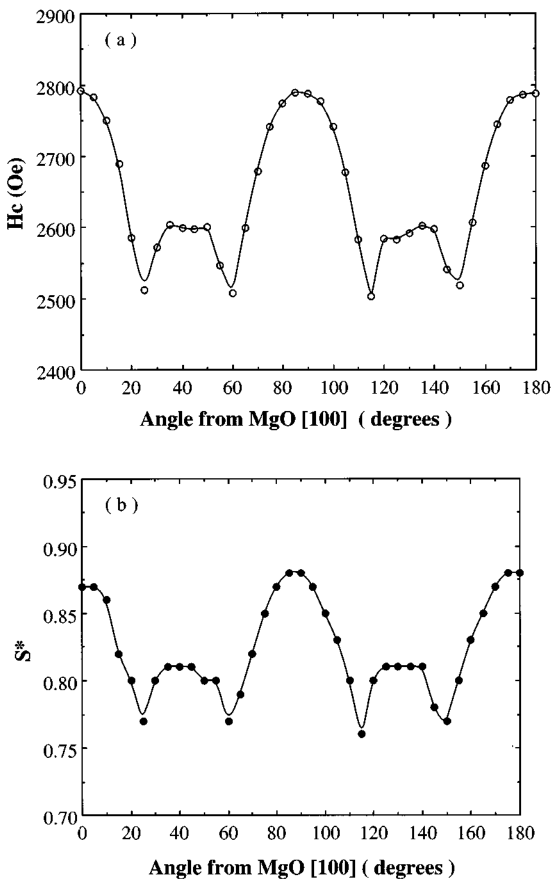

FIG. 5. Variation of (a) coercivity and (b) coercivity squareness of the CoCrPt film with the angle with respect to MgO [100] direction.

direction (i.e., fibrously oriented) instead with the $(11\bar{2}0)$ plane parallel to the NiAl (001) plane may be due to the reconstructed NiAl (001) surface. This topic is still a subject of intensive investigation.[17] It should be pointed out that the plane which the [1011] is normal to is (1 0 1 1.78) which in fact, is not a crystallographic plane in hcp lattice. Therefore, unlike the (001) NiAl and (001) MgO planes, this plane, which is parallel to the (001) NiAl and (001) MgO planes will not produce any diffraction in the θ–2θ x-ray diffraction spectrum since this technique only records diffraction from crystallographic planes which are parallel to the substrate surface. The (1 0 1 1.78) plane is approximately parallel to the (5 0 5 9) crystallographic plane. But the d spacing of the (5 0 5 9) plane, 0.3228 Å, is too small for the Cu $K\alpha$ radiation ($\lambda=1.54$ Å) to produce any diffraction (since $\lambda > 2d$).

Since the c axis, i.e., the magnetocrystalline easy axis of hcp Co-based alloys which makes an angle of 43° with the [1011] direction must lie in the {1120} planes, the projection of the c axis into the substrate surface, i.e., MgO (001), for CoCrPt variant 1 is along the NiAl [010] direction and for CoCrPt variant 2 is along the NiAl [100] direction (Fig. 4).

It can be noted from Fig. 4 that NiAl [100] and [010] directions are parallel to MgO [110] and $[\bar{1}10]$ directions, respectively. It is therefore expected that the in-plane effective magnetization easy axes of the CoCrPt film are along the MgO [100] and [010] directions.[18,19] The measurements of the in-plane coercivity, H_c, and coercivity squareness, S^*, of the CoCrPt film as a function of the angle between the MgO [100] direction and the in-plane applied magnetic field direction are shown in Figs. 5(a) and 5(b). It is noted that besides the major easy axes along the MgO [100] and [010] directions, as expected, there is a set of secondary easy axes along the MgO [110] and [110] directions. This set of secondary easy axes may arise from the exchange interaction within each of the variants or may be due to the imbalance in the fraction of the two crystallographic variants but further study is needed to elucidate the mechanism.

In summary, the orientation relationship between the CoCrPt film and NiAl underlayer grown on (001) MgO single-crystal substrates is determined to be [1011]CoCrPt//[001]NiAl, (1210)CoCrPt//(100)NiAl (variant 1), or (1210)CoCrPt//(010)NiAl (variant 2). The CoCrPt film has two sets of in-plane magnetization easy axes. The major axes are along the MgO [100] (i.e., NiAl [110]) and [010] (i.e., NiAl [110] directions and the secondary easy axes are along the MgO [110] (i.e., NiAl [100]) and [110] (i.e., NiAl [010]) directions.

This work is supported by the DSSC of Carnegie Mellon University under a NSF Grant, No. ECD-8907068. The government has certain rights to this material.

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