

New Ni₅Al₃ Underlayer for Longitudinal Magnetic Recording Media

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Abstract—We describe a new Ni₅Al₃ underlayer for high-density longitudinal magnetic recording. The Ni₅Al₃ underlayer has the FCC derivative Ga₃Pt₅ structure. The Ni₅Al₃ (221) plane has good lattice match with the CoCrPt (10 $\bar{1}$ 0) plane. In addition, unlike the NiAl (112) plane, the Ni₅Al₃ (221) plane has the lowest surface energy. Hence, the Ni₅Al₃ thin film has a strong (221) texture and can induce CoCrPt (10 $\bar{1}$ 0) texture. The microstructure and magnetic properties of the CoCrPt–Ni₅Al₃ thin films are reported and discussed.

Index Terms—Co alloy magnetic film, epitaxial growth, lattice match, longitudinal magnetic recording thin film, NiAl underlayer, Ni₅Al₃ underlayer.

I. INTRODUCTION

TO ACHIEVE higher longitudinal magnetic recording density, the transition length of the media has to be reduced. This can be achieved by increasing the media coercivity. In order to achieve high coercivity and high k_u , we must obtain CoCrPt grains of such crystalline perfection that the CoCrPt magnetocrystalline anisotropy is maximized and not compromised by lattice strain and defects. This can be achieved by obtaining a strong CoCrPt crystallographic texture with the easy axes aligned in the thin film plane and with a minimum amount of misfit between the magnetic film and the underlayer.

The texture and grain size of the CoCrPt magnetic layer can be controlled by using underlayers. The currently popular NiAl (112) underlayer can be used to induce the CoCrPt (10 $\bar{1}$ 0) texture [1] with c axis aligned in the thin film plane. However, the NiAl (112) plane is probably not the lowest surface-energy plane and therefore a strong NiAl (112) texture cannot be easily obtained. High-resolution TEM has shown that a NiAl (112) texture is not usually obtained unless the NiAl underlayer obtained by our deposition system is thicker than about 80 nm [2]. As a result, the NiAl (112) texture does not usually induce strong CoCrPt (10 $\bar{1}$ 0) texture. In this paper, we introduce a new underlayer, with composition Ni₅Al₃ having a different crystal structure than the B2 NiAl. This new underlayer could induce a strong CoCrPt (10 $\bar{1}$ 0) texture and small CrCrPt grains.

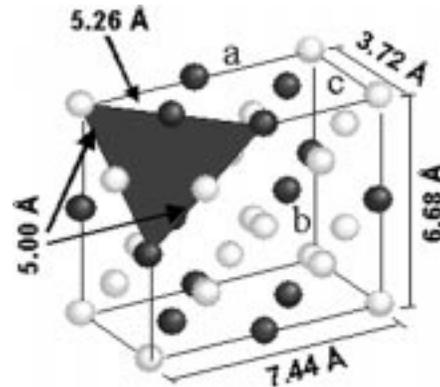


Fig. 1. Schematic of the Ni₅Al₃ unit cell and the Ni₅Al₃ (221) planes.

A. Ni₅Al₃ Phase and Epitaxial Relationship With Co-Alloy Magnetic Layer

The single phase region of the Ni₅Al₃ phase extends from about 64 at% to 68 at% of Ni below 700 °C [3]. Because the Ni₅Al₃ phase is stable at a room temperature, it is easy to obtain this phase by thin film deposition.

Ni₅Al₃ has the Ga₃Pt₅ structure, which is an FCC derivative structure with orthorhombic symmetry. The lattice parameters of the Ni₅Al₃ phase are $a = 7.44$ Å, $b = 6.68$ Å, and $c = 3.72$ Å, as shown in Fig. 1 [4]. The lattice parameters of the a and b axes are about twice as large as that of the c axis. Since the structure is an FCC derivative one, if atoms of the same type were placed on each site of this unit cell, it would become FCC structure. The (221) plane of the Ni₅Al₃ is equivalent to the close-packed (111) plane of the FCC. Thus, the Ni₅Al₃ (221) texture can be obtained right from the beginning of the Ni₅Al₃ deposition since the Ni₅Al₃ close-packed (221) planes have the lowest surface energy. Unlike the NiAl (112) texture, which is growth induced, a strong Ni₅Al₃ (221) orientation is obtained by deposition from the start.

The Ni₅Al₃ (221) planes have a small misfit with CoCrPt (10 $\bar{1}$ 0) planes, as shown in Fig. 2. Consequently, a strong Ni₅Al₃ (221) texture is expected to induce a strong CoCrPt (10 $\bar{1}$ 0) texture by means of epitaxy.

II. EXPERIMENTS

All the films discussed in this paper were deposited on Corning 7059 glass substrates at 25 °C by RF diode sputtering in a Leybold–Heraeus Z-400 system. The base pressure was 5×10^{-7} mtorr. The CoCrPt films were deposited with a fixed argon pressure of 10 mtorr, RF sputtering power of 2.3 W/cm², and substrate bias voltage of –100 V. The composition of the CoCrPt thin films deposited at the substrate bias voltage

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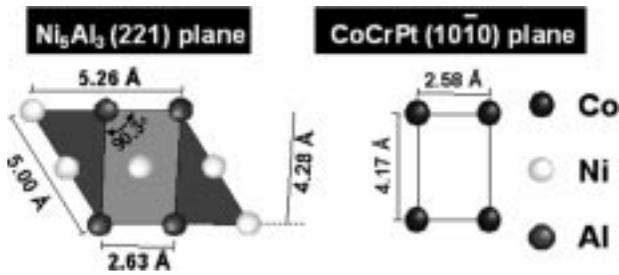


Fig. 2. Schematic of the lattice match of the Ni_5Al_3 (221) and CoCrPt ($10\bar{1}0$) planes.

of -100 V was 78.5 at% Co, 9 at% Cr, and 12.5 at% Pt by inductively coupled plasma (ICP) analysis. The thicknesses of the Ni_5Al_3 and CoCrPt films were fixed at 100 and 40 nm, respectively. *This CoCrPt thickness is greater than that used in current longitudinal recording media for the purpose of observing CoCrPt texture change.* The Ni_5Al_3 films were deposited from either a Ni_1Al_1 or a Ni_5Al_3 target at 10 mtorr and 2.3 W/cm^2 . If the Ni_1Al_1 target was used, various substrate bias voltages were used in order to achieve the composition of Ni_5Al_3 . The thickness of the NiAl thin films deposited with various substrate voltages were fixed at 100 and 400 nm. This is because the NiAl (112) texture is easily observed at the thick 400-nm NiAl thin film. The intermediate Cr and NiAl layers were deposited at a fixed argon pressure of 10 mtorr and RF sputtering power of 2.3 W/cm^2 . The thicknesses of the intermediate Cr and NiAl layers were both fixed at 100 nm. Thin film texture characterization was carried out by using the Rigaku X-ray diffractometer (XRD) with $\text{Cu } K\alpha$ radiation. A Philips EM 420 T transmission electron microscope (TEM) was used to observe microstructure. A vibrating sample magnetometer (VSM) with fields up to 10 kOe was used to measure magnetic properties.

III. RESULTS AND DISCUSSIONS

A. Ni_1Al_1 Target With High Substrate Bias Voltage

Our initial attempts at making Ni_5Al_3 underlayers were performed by using a Ni_1Al_1 target with a substrate bias voltage applied. With no substrate bias voltage, XRD scans in Fig. 3(a) shows that the 100-nm NiAl thin film is (110) textured. For the 400-nm-thick NiAl thin film, both (110) and (112) peaks are observed in Fig. 3(b). If a low substrate bias voltage such as -100 V is applied, a very strong NiAl (110) texture is obtained and the NiAl (112) texture disappears in both the 100- and 400-nm-thick films as shown in the XRD spectra (see Fig. 3). Substrate negative bias voltage attracts some positive argon ions to bombard the substrate surface. The atoms that are loosely bonded to neighboring atoms can be easily removed from the thin film by the bombarding argon ions. *Consequently, the crystallographic texture in the NiAl thin film shifts to a texture with closer packed plane if the substrate bias voltage is applied.* Since the NiAl (110) plane is the closest-packed plane for the B2 structure, (110) is expected to be the strongest XRD peak when the bias voltage of -100 V is used. In addition, it is observed that the intensity of the NiAl (110) peak is strongest at a

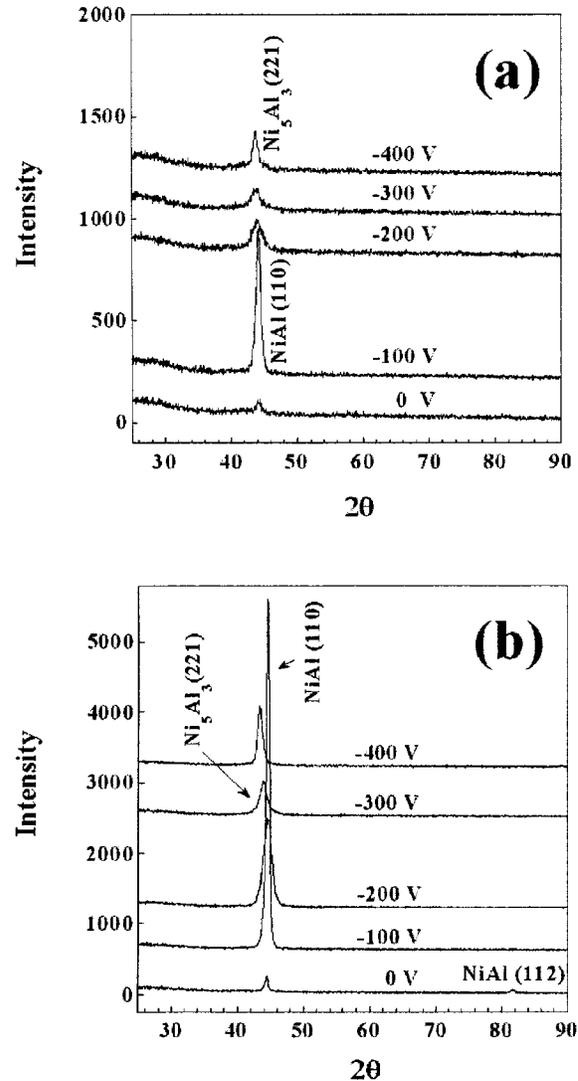


Fig. 3. X-ray diffraction spectra of the NiAl (a) 100-nm and (b) 400-nm thin films deposited with various substrate bias voltages.

substrate bias voltage of -100 V and becomes weaker with increasing substrate bias voltages in Fig. 3(a) and (b). The position of this peak (2θ) also decreases about 1° in both XRD spectra of the 100- and 400-nm-thick NiAl films as the substrate bias voltage is increased to -300 V. This peak position shift implies a lattice parameter change either due to the occurrence of a new phase, composition change, or stress resulting from the substrate bias voltage.

The electron diffraction pattern (EDP) of the 100-nm NiAl thin film at a substrate bias of -300 V shows a ring pattern resulting from the Ni_5Al_3 phase [Fig. 4(b)]. This pattern is different from the EDP of the B2 structure NiAl thin film obtained for the sample without substrate bias voltage applied [Fig. 4(a)]. *No NiAl ring was found in the Ni_5Al_3 diffraction pattern shown in Fig. 4(b). This Ni_5Al_3 (221) ring does not contain the NiAl (110) ring, although this ring appears to be thick.*

The Ni_5Al_3 (221) X-ray diffraction peak position (2θ) is at 43° , which is 1° less than the NiAl (110) peak. The peak shift *as well as the weakening of the NiAl (110) peak at high substrate*

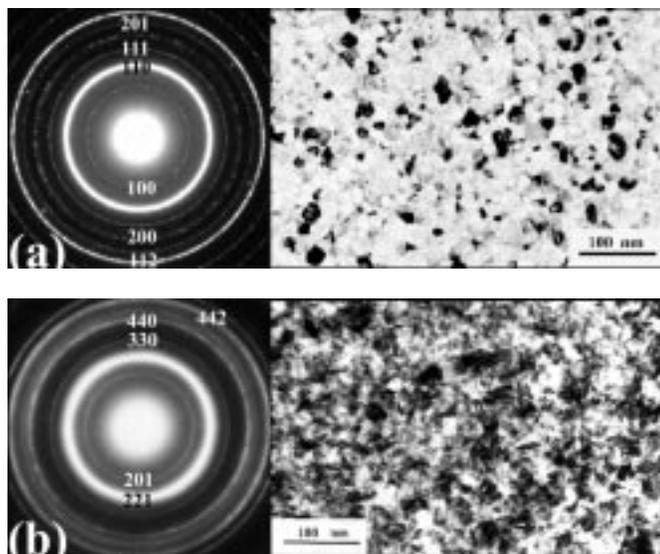


Fig. 4. TEM selected area diffraction and bright field image of the NiAl 100-nm thin film deposited with (a) 0 V and (b) -300 V substrate bias voltage. The TEM diffraction rings in Fig. 4(a) and (b) result only from NiAl and Ni₅Al₃ phase, respectively.

bias voltage in the XRD spectra can be explained by the formation of the Ni₅Al₃ phase at the bias voltages of -300 V. With substrate bias voltage applied, the Al atoms are more easily removed by the argon ion bombardment than the Ni atoms. Hence, we observed a Ni rich phase, i.e., Ni₅Al₃, to form.

The XRD spectra of the 40-nm CoCrPt-100-nm NiAl with various substrate bias voltages during NiAl deposition are shown in Fig. 5(a). The CoCrPt (10 $\bar{1}$ 0) peaks are observed when the CoCrPt films are deposited onto the NiAl underlayers prepared at 0 and -300 V. As shown by the inserted XRD slow scan with 2 θ from 80° to 84° [Fig. 5(a)], the NiAl (112) texture is obtained only when no substrate bias voltage is applied. This NiAl (112) texture obtained at 0 V is observed to induce the CoCrPt (10 $\bar{1}$ 0) texture. At the substrate bias voltage of -300 V, no NiAl (112) peak is observed in the XRD slow scan. Here, it is the Ni₅Al₃ (221) texture that induces the CoCrPt (10 $\bar{1}$ 0) texture due to the small misfit of the Ni₅Al₃ (221) and CoCrPt (10 $\bar{1}$ 0) planes, as shown in the CoCrPt and Ni₅Al₃ epitaxial relationship in Fig. 2.

The magnetic properties of the 40-nm CoCrPt-100-nm NiAl thin films prepared with various substrate bias voltages are shown in Fig. 5(b). The coercivity and squareness are highest at zero bias voltage and decrease with increasing bias voltage due to the weakened NiAl (112) texture. The coercivity and squareness increase again at a bias voltage of -300 V because of the reappearance of the CoCrPt (10 $\bar{1}$ 0) texture induced by the Ni₅Al₃ (221) texture.

B. Ni₅Al₃ Alloy Target

The EDP and bright field image of a 100-nm Ni₅Al₃ thin film deposited from a Ni₅Al₃ target are shown in Fig. 6(a) and (b), respectively. Due to the strong Ni₅Al₃ (221) fiber texture, the (021), (440), and (442) reflections are observed in Fig. 6. In addition, the (221) rings are also observed, which indicates that

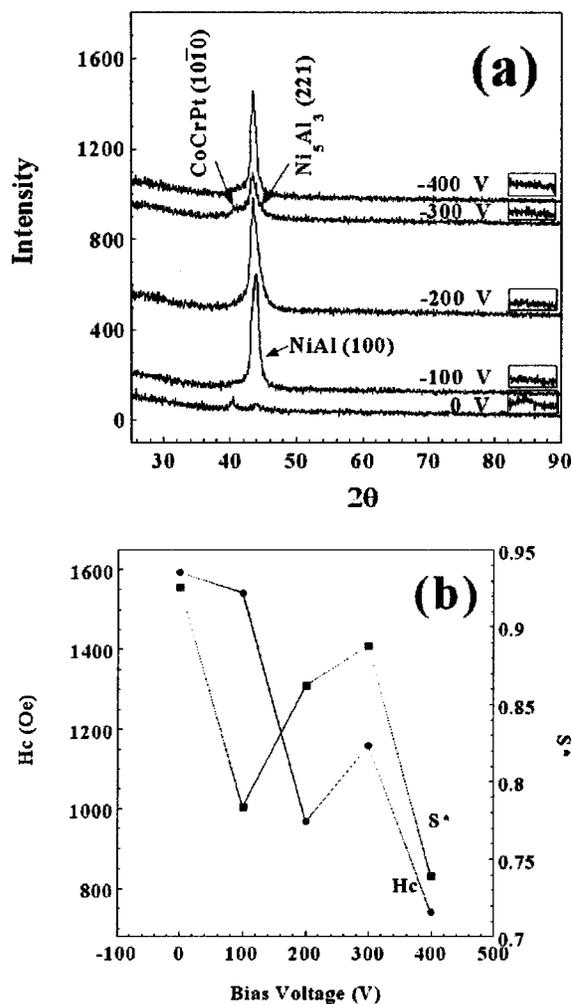


Fig. 5. (a) X-ray diffraction spectra and (b) magnetic properties of the 40-nm CoCrPt-100-nm NiAl thin films deposited with various substrate bias voltages.

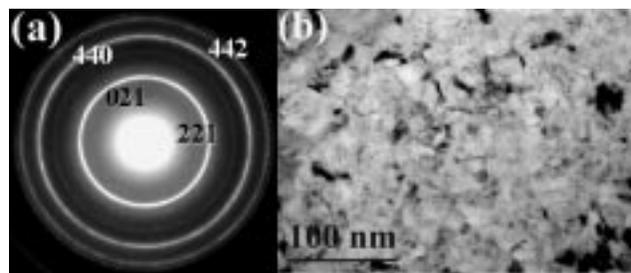


Fig. 6. TEM selected area diffraction and bright field image of the Ni₅Al₃ 100-nm thin film directly deposited from the Ni₅Al₃ alloy target.

some of the Ni₅Al₃ grains are not (221) textured. The Ni₅Al₃ grain size is about 10 nm.

The XRD spectra of the CoCrPt magnetic layer deposited onto the Ni₅Al₃ underlayer directly from the Ni₅Al₃ targets with the use of the Cr and NiAl intermediate layer are shown in Fig. 7(a). A strong Ni₅Al₃ (221) peak is observed, consistent with the Ni₅Al₃ (221) plane having the lowest surface energy. The CoCrPt (10 $\bar{1}$ 0) peak is observed, indicating that the Ni₅Al₃ texture induces the CoCrPt (10 $\bar{1}$ 0) texture.

The in-plane magnetic properties of the films are shown in Fig. 7(b). Introducing a 100-nm Cr intermediate layer between

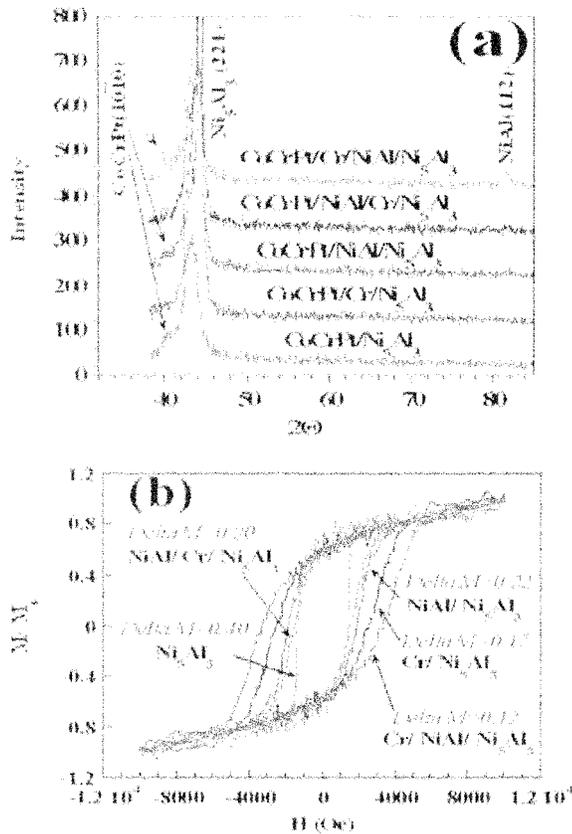


Fig. 7. (a) X-ray diffraction spectra and (b) magnetic properties of the CoCrPt 40-nm- Ni_5Al_3 100-nm thin films.

the CoCrPt and Ni_5Al_3 layers decreases the CoCrPt ($10\bar{1}0$) peak intensity. However, the coercivity increases from 1440 to 2530 Oe. The peak δM value for the CoCrPt- Ni_5Al_3 thin film is 0.4 and that of the CoCrPt-Cr- Ni_5Al_3 thin film is 0.17. The exchange coupling is reduced by the Cr intermediate layer, which is most likely due to Cr diffusion from the intermediate layer to the CoCrPt grain boundaries [5]. The increase of the in-plane coercivity is mainly due to the reduction of the exchange coupling.

Adding a 100 nm NiAl film between the CoCrPt and Ni_5Al_3 thin films can induce a NiAl (112) texture and hence an improved CoCrPt ($10\bar{1}0$) texture. The in-plane coercivity of the CoCrPt-NiAl- Ni_5Al_3 thin film is about 1790 Oe. The coercivity of the CoCrPt-NiAl- Ni_5Al_3 thin film is larger than that of the CoCrPt- Ni_5Al_3 thin film due to an enhanced CoCrPt ($10\bar{1}0$) texture. The δM peak intensity is about 0.22, indicating stronger exchange coupling than that of the CoCrPt-Cr- Ni_5Al_3 thin film.

TABLE I
SUMMARY OF THE MAGNETIC PROPERTIES OF THE VARIOUS FILM STRUCTURES

Film structure	Hc (Oe)	S*	Delta M
CoCrPt/ Ni_5Al_3	1440	0.8419	0.40
CoCrPt/Cr/ Ni_5Al_3	2530	0.4267	0.17
CoCrPt/NiAl/ Ni_5Al_3	1790	0.5024	0.22
CoCrPt/NiAl/Cr/ Ni_5Al_3	1650	0.4806	0.20
CoCrPt/Cr/NiAl/ Ni_5Al_3	3380	0.5945	0.12

The CoCrPt-NiAl-Cr- Ni_5Al_3 thin film does not show the CoCrPt ($10\bar{1}0$) and NiAl (112) peaks, indicating that the Cr layer does not grow epitaxially onto the Ni_5Al_3 layer. The in-plane coercivity is about 1650 Oe and δM peak value is 0.2.

A CoCrPt-Cr-NiAl- Ni_5Al_3 thin film shows strong CoCrPt ($10\bar{1}0$) and NiAl (112) peaks as seen in Fig. 7(a). This indicates that the Ni_5Al_3 (221) texture can induce the NiAl (112) and CoCrPt ($10\bar{1}0$) texture. The in-plane coercivity is approximately 3380 Oe and δM is about 0.12. The high coercivity may be due not only to the good texture but also to the small exchange coupling as indicated by δM peak value. *The details of the magnetic properties of the various film structures discussed in this paper are listed in Table I.*

IV. CONCLUSION

We have shown that a Ni_5Al_3 underlayer not only induces the CoCrPt ($10\bar{1}0$) texture, but also the NiAl (112) texture. The Ni_5Al_3 improves the NiAl and CoCrPt texture and maintains a small grain size. Adding a Cr intermediate layer between the CoCrPt and Ni_5Al_3 layers was shown to effectively reduce the media exchange coupling. This new media structure has the potential to yield a high coercivity and low noise magnetic recording media.

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