High Coercivity Co-Alloy Thin Films on Polymer Substrates

Bo Bian, James A. Bain, Soon-Ju Kwon, and David E. Laughlin

***Abstract*—Films of $(10\bar{1}0)$ textured CoCrPt have been sputtered on polymer substrates for use as thin film tape media. Underlayers of NiAl combined with various intermediate layers were employed to obtain this orientation without thermal damage to the polymer. It was found that NiAl underlayers sputtered on tape substrates have a (112) growth texture, like they do on glass. Film coercivity varied as a function of intermediate layers used, with the highest value of coercivity (3800 Oe) being obtained with a composite intermediate layer of CrMn\CoCrMn. TEM observation showed that the CoCrMn component of these intermediate layers was hexagonal with a $(10\bar{1}0)$ texture and low stacking fault density. The CoCrPt layers deposited on these CoCrMn layers had uniform grains with a lower stacking fault density, possibly due to grain-to-grain epitaxial growth of CoCrPt on CoCrMn.**

***Index Terms*—Co-alloy thin films, coercivity, polymer substrates, sputtering, tape recording.**

I. Introduction

FUTURE higher density recording tape media will require thinner magnetic layers. With present dual-coating technology for particulate media, it is challenging to make defect-free magnetic layers with thicknesses below 100 nm. Sputtering offers an alternative method for fabricating thin, magnetically bi-directional, smooth layers of magnetic media, and is universally employed in the fabrication of rigid disk media. However, concerns over thermal damage to fragile polymer substrates (like PET) and low deposition rates have historically hindered pursuit of this solution to the tape-coating problem. It has been reported that using a higher sputtering pressure and substrate cooling can solve the problem of substrate damage [1]. However, controlling the texture and grain size of the magnetic layers is still a challenge. In order to get acceptable magnetic properties in longitudinal tape media, it is necessary to get hexagonal close-packed (hcp) Co-alloy films with in-plane orientation of the c-axis.

Previously it has been reported that the application of a (112) textured NiAl\Cr bilayer on aluminum or glass substrates leads to a $(10\bar{1}0)$ texture of Co-alloy films [2], [3]. In this study, we have applied NiAl underlayers and various Cr containing intermediate layers on PET substrates to get the $(10\bar{1}0)$ texture of CoCrPt without thermal damage to the polymer.

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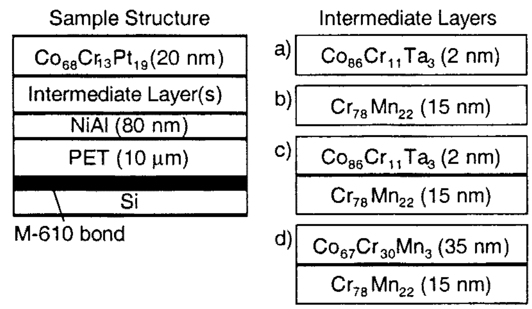

Fig. 1. Structure of the four complete stacks studied in this work. Each of the intermediate layers indicated (a)–(d) was inserted into the sample stack at the indicated location to form the four structures studied in this work. Partially complete versions of these samples were also examined.

II. Experimental

Coupons of 36-gauge PET (10 μm thick) were cut and bonded to untreated Si (100) substrates with M-610. The four sample structures shown in Fig. 1 were then deposited each in a single pumpdown without breaking vacuum. Partially complete structures were also examined. Depositions were done by RF diode sputtering in a Leybold-Heraeus Z-400 system. Textures and microstructures of the films were examined by x-ray diffraction (XRD) and transmission electron microscopy (TEM). The in-plane magnetic properties of sputtered tape media were measured using vibrating sample magnetometry and alternating gradient magnetometry.

III. Results

TEM observation of a 80 nm thick NiAl layer deposited on PET substrates showed well-defined grains with an average grain size of 12 nm and similar (112) texture as those of NiAl layers on untreated Si or glass substrates. The XRD spectra of NiAl layers and NiAl\CrMn bilayers showed that the (112) textures of NiAl films improved with film thickness and that CrMn layers had a (112) texture as well.

Fig. 2 shows the XRD profiles of four sample structures deposited on PET substrates. The coercivity of each sample is indicated on the Figure. All the peaks located at 2θ of 40.1° correspond to $(10\bar{1}0)$ CoCrPt reflections whereas those with 2θ of 44.4° are (110) peaks of the NiAl and CrMn layers. It is clear from these spectra that high coercivity is associated with CrMn in the underlayer and with the strong $(10\bar{1}0)$ texture in stacks b, c, and d. The CoCrPt layer deposited on a CoCrTa intermediate layer (structure a in Fig. 1) has both $(10\bar{1}0)$ and

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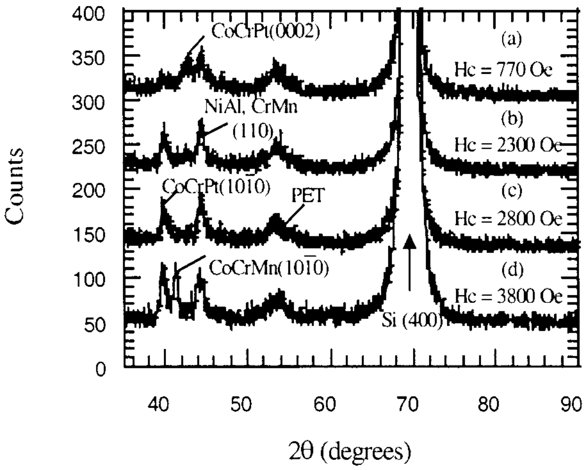

Fig. 2. XRD spectra of the four complete stacks. The textures and magnetic coercivities of these layers are strongly dependent on intermediate layers, as labeled in the figure. Refer to Fig. 1 for structure identities.

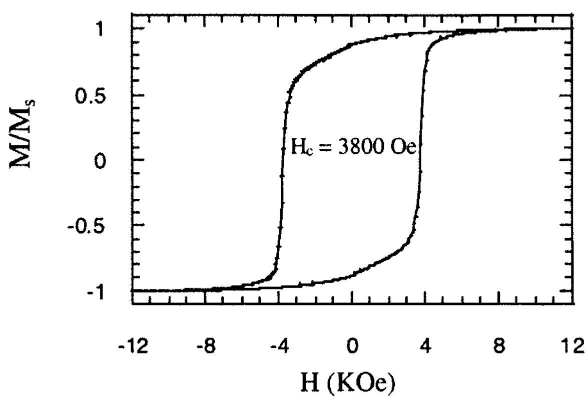

Fig. 3. In-plane magnetic hysteresis loop of the NiAl\CrMn\CoCrMn\CoCrPt tape medium (structure d). The coercivity of this medium is around 3800 Oe.

(0002) textures, which is most likely responsible for its low coercivity (770 Oe). It is interesting to note, that among the samples that all display a (10$\bar{1}$0) texture (structures b, c and d), rather significant differences in coercivity can be seen, ranging from 2300 Oe to 3800 Oe. These will be discussed below. The hysteresis loop for the highest coercivity sample (structure d) is shown in Fig. 3.

IV. Discussion

There appear to be at least three mechanisms contributing to the variation in coercivity seen among the four sample structures studied in this work. First, and most obvious, is the texture issue discussed above. Since the CoCrPt layers deposited on CoCrTa (sample a) and CrMn/CoCrTa (sample c) intermediate layers are expected to have similar anisotropy constants and saturation magnetizations, the difference in (10$\bar{1}$0) and (0002) textures of the CoCrPt films should be responsible for the significant difference between the magnetic coercivities of samples a and c. Although all the samples with a CrMn underlayer (structures b, c and d) had a (10$\bar{1}$0) texture, our electron diffraction experiment by tilting the specimens showed that the CoCrPt layer in structure c had slightly better (10$\bar{1}$0) texture than those in structures b and d.

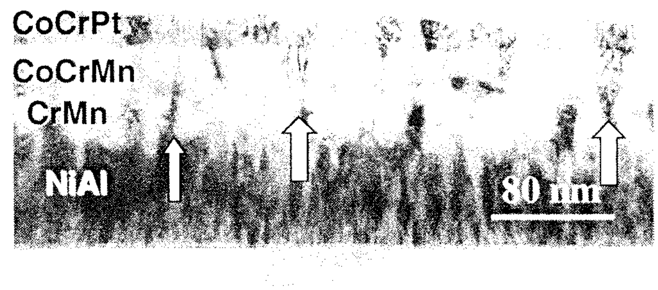

Fig. 4. Cross-sectional TEM image of NiAl\CrMn\CoCrMn\CoCrPt films (structure d). Although grain-to-grain growth penetrates all the layers (see arrows), the CoCrMn/CoCrPt interface shows better epitaxial growth.

Second, comparisons of samples b and c using TEM suggest that the application of the composite intermediate layer of structure c (CrMn/CoCrTa) reduced the stacking fault density in the CoCrPt layers, as compared to the CrMn underlayer alone (structure b). We believe that stacking faults may reduce the anisotropy of the magnetic alloy, thus reducing the coercivity. Generally CoCrTa films have lower stacking fault density as compared with that of CoCrPt layers. Since the 2 nm thick CoCrTa layer in sample c possesses the same symmetry as the CoCrPt magnetic layer, it may reduce the tendency for the CoCrPt to form stacking faults. In related work, our study on stacking faults in unicrystal Co thin films showed that stacking faults in Co and Co alloy thin films significantly, and negatively, affected the anisotropy [4].

Although a CoCrTa intermediate layer offers the possibility of fewer stacking faults, it may have costs as well. Since it is very likely that the CoCrTa is exchange coupled with the CoCrPt layer, the lower anisotropy constants of CoCrTa may detract from the improvement associated with varying more grains with fewer defects.

Previously, it has been reported that the application of a hexagonal (11$\bar{2}$0) textured $Co_{63}Cr_{37}$ intermediate layer between Cr and CoCrTa layers improved the (11$\bar{2}$0) texture and increased the coercivity of CoCrTa films [5]. However, the $Co_{63}Cr_{37}$ intermediate layer is not applicable to sputtered tape media with polymer substrates, as it requires a substrate heating at temperature above 200°C to get the (11$\bar{2}$0) texture of the $Co_{63}Cr_{37}$ layer. It has been reported that $Co_{65}Cr_{31}Mn_4$ deposited on glass substrates around 200°C has an hcp structure with both (10$\bar{1}$0) and (11$\bar{2}$0) textures [6]. From both plan-view and cross-section electron diffractions of the layered structure d, it was confirmed that the CoCrMn layer deposited on the CrMn film had an hcp structure and a (10$\bar{1}$0) texture. The grain-to-grain growth at the NiAl\CrMn, CrMn\CoCrMn and CoCrMn\CoCrPt interfaces can be seen by cross-sectional TEM image as shown in Fig. 4. The CoCrMn layer appears to have a lower density of stacking faults.

The atomic registry across the CoCrMn\CoCrPt boundary is evident in the TEM image. In fact, our plan-view TEM observations showed that CoCrPt deposited on the CrMn\CoCrMn intermediate layer exhibited lower stacking fault density as compared with CoCrPt layers deposited on other intermediate layers. This indicates that this intermediate layer is in fact superior to others in its ability to suppress stacking faults while having the desirable property of being nonmagnetic.

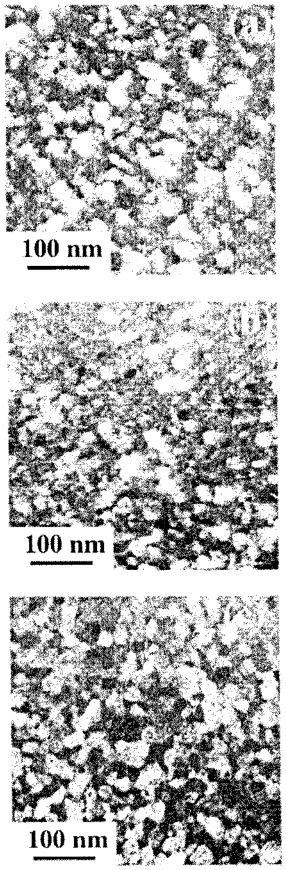

Fig. 5. Plan-view dark-field TEM images of CoCrPt films in the NiAl\CrMn\CoCrPt (a), NiAl\CrMn\CoCrTa\CoCrPt (b) and the NiAl\CrMn\CoCrMn\CoCrPt (c) tape media. The CoCrPt films in both NiAl\CrMn\CoCrPt and NiAl\CrMn\CoCrTa\CoCrPt tape media contain many grains with size less than 8 nm whereas the CoCrPt grains in the NiAl\CrMn\CoCrMn\CoCrPt tape medium are more uniform in size.

Fig. 5 shows the plan-view dark-field TEM images of CoCrPt films in the tape media with (a) CrMn, (b) CrMn\CoCrTa and (c) CrMn\CoCrMn intermediate layers. The average grain sizes of the three CoCrPt films were 13 nm (a), 11 nm (b) and 14 nm (c), respectively. The CoCrPt layers with CrMn or CrMn\CoCrTa intermediate layer contained many tiny grains with grain size less than 8 nm whereas the CoCrPt film on NiAl\CrMn\CoCrMn had fewer CoCrPt grains with such small size. The smaller average grain size of CoCrPt on CrMn\CoCrTa resulted from epitaxial growth of CoCrPt on tiny CoCrTa grains. The CoCrPt grains on NiAl\CrMn\CoCrMn were well-defined and uniform in size.

We believe this to be one of the advantages offered by the CoCrMn, and the third mechanism influencing the coercivity: an absence of exchange coupling to the intermediate layer and possibly less exchange coupling among CoCrPt grains. The CoCrPt film on the CoCrMn intermediate layer contains less tiny grains with size smaller than 8 nm, which are probably exchange-coupled to other grains. We believe the CoCrMn intermediate layer offers hexagonal symmetry to promote $(10\bar{1}0)$ texture and reduce stacking fault density, but is nonmagnetic, so that it does not compromise the anisotropy of the CoCrPt. It also offers two mobile atoms (Cr and Mn) that may be segregating to the grain boundaries of magnetic layers [7].

V. Conclusion

Underlayers of NiAl and Cr containing intermediate layers have been sputtered on polymer substrates to induce $(10\bar{1}0)$ texture in CoCrPt films without thermal damage to the polymer. A cubic Cr containing phase, like CrMn on the NiAl appears necessary to induce strong $(10\bar{1}0)$ texture in the CoCrPt. Additionally, the inclusion of a hexagonal layer (like CoCrTa or CoCrMn) in the intermediate layer is effective in reducing the density of stacking faults in the CoCrPt. This leads to higher coercivity in the magnetic film. Finally, it appears that the CoCrMn hexagonal intermediate layer offers superior performance to the CoCrTa layer, because it has stacking fault suppression capability and uniform grain size. It also may offer an advantage because it is nonmagnetic and does not couple to the CoCrPt, reducing its anisotropy. By application of the CrMn\CoCrMn bilayer intermediate layer, sputtered tape media with coercivity around 3800 Oe was obtained.

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