The Properties of CoCrPt/CrMn/NiAl and CoCrPt/Cr/NiAl Films

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***Abstract*—In this study, the effects of CrMn/NiAl and Cr/NiAl underlayers on microstructure and magnetic properties of CoCrPt magnetic layers are compared. CrMn intermediate layers were found to induce better in-plane texture and magnetic properties in CoCrPt films than Cr. Significant improvement in magnetic properties was achieved by post-deposition rapid thermal annealing (RTA). The anisotropy did not decrease much while grain isolation in the CoCrPt layer was achieved by using RTA.**

***Index Terms*— CrMn, microstructure, annealing, anisotropy.**

I. INTRODUCTION

High density magnetic recording media must have high coercivities, low noise, and very smooth surfaces. One approach to achieve these properties is through the improvements of underlayers. Underlayers have significant influence on the texture and microstructure of Co alloy magnetic thin films via grain-to-grain epitaxy. NiAl, which can induce unicrystalline $(10\bar{1}0)$ Co texture and finer and more uniform Co grains, has been shown to be an excellent underlayer material [1,2]. An intermediate layer of Cr, Cr alloy, or other materials, between the NiAl underlayer and the Co alloy magnetic layer, was found to improve magnetic properties [3-5].

Co grain isolation is also critical in obtaining low noise and high coercivity media. Cr segregation at the grain boundaries is a widely adopted approach to achieve isolation for a variety of CoCrX alloys. However, a relatively high Cr concentration in CoCrX alloys is required for significant Cr segregation but the crystalline anisotropy energy decreases with increased Cr content [6]. Grain isolation can also be achieved by preferential interdiffusion of underlayer materials to the Co alloy grain boundaries [7]. Since grain boundary diffusion is known to have a lower activation energy than bulk lattice diffusion, under certain processing conditions, it is possible to diffuse sufficient underlayer materials to the grain boundaries while diffusing only small amounts into the bulk of the magnetic grains. Therefore, this may be a method of obtaining grain isolation with only a moderate decrease in the anisotropy energy density.

In this paper, the effects of CrMn/NiAl and Cr/NiAl underlayers on CoCrPt magnetic layer microstructure are compared and a significant improvement in magnetic properties, by post-deposition annealing, is reported.

II. EXPERIMENTAL

A 1000 Å thick NiAl underlayer, a CrMn or Cr intermediate layer with various thicknesses, a 300 Å thick CoCrPt magnetic layer, and an optional 200 Å thick CrMn or Cr overlayer were successively deposited onto glass substrates by RF diode sputtering without substrate preheating. The Ar sputtering pressure was 10 mTorr. Post-deposition annealing was performed at atmospheric pressure under Ar flow.

The composition of the CoCrPt films was Co-7at%Cr-16at%Pt, determined by energy dispersive x-ray spectroscopy (EDX). The in-plane magnetic properties of the samples were measured using vibrating sample magnetometry (VSM), torque magnetometry and alternating gradient magnetometry (AGM). Microstructural analyses were carried out by x-ray diffraction and transmission electron microscopy (TEM).

III. RESULTS AND DISCUSSION

Fig. 1 shows the x-ray diffraction spectra of three samples with (a) 100 Å CrMn, or (b) 100 Å Cr or (c) no intermediate layer. Inserting an intermediate layer between the NiAl underlayer and the CoCrPt magnetic layer increased the CoCrPt $(10\bar{1}0)$ peak. The sample with the CrMn layer exhibited a slightly higher CoCrPt $(10\bar{1}0)$ peak than Cr.

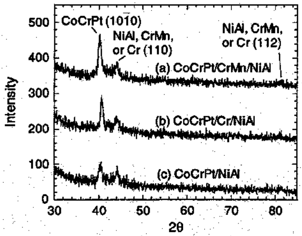

Fig. 1 X-ray diffraction spectra for samples: (a) CoCrPt/CrMn/NiAl, (b) CoCrPt/Cr/NiAl, and (c) CoCrPt/NiAl.

The magnetic properties of these three samples are shown in Table I. Consistent with the x-ray diffraction results, adding a CrMn or Cr intermediate layer increased the coercivity significantly. The CoCrPt magnetic film on the CrMn/NiAl underlayer structure had even higher coercivity and S value than Cr/NiAl.

TABLE I
MAGNETIC PROPERTIES OF SAMPLE (a), (b) AND (c)

Sample	(a)	(b)	(c)
Hc (Oe)	3390	2920	2310
Ms (emu/cc)	579	574	571
Mrt (memu/cm^2)	1.53	1.44	1.41
S	0.88	0.84	0.83
S*	0.91	0.90	0.82
δM peak	0.60	0.45	0.42

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The tilted electron diffraction technique was used to compare the quality of the CoCrPt texture on the above two underlayer structures [5,8]. Fig. 2 shows electron diffraction patterns for samples using a 1000 Å CrMn or Cr intermediate layer, tilted at about 0° and 60°, respectively. The $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ diffraction rings were found in the 0°-tilt electron diffraction patterns of both samples, which should not be present in purely $(10\bar{1}0)$ textured hcp Co-alloy samples. This implies that there exist at least some randomly oriented crystalline grains in addition to the $(10\bar{1}0)$ oriented CoCrPt grains when prepared on either CrMn or Cr intermediate layers. This is not totally unanticipated, as there is substantial lattice mismatch between the high Pt content Co alloy and the Cr or the CrMn intermediate layer [4]. However, the intensities of these two rings are weaker for the samples using CrMn/NiAl underlayers than for the Cr/NiAl, indicating that CoCrPt films on the former underlayer structure have a smaller portion of randomly oriented grains than the latter one. This is unanticipated as the lattice constant of Cr is changed little by the Mn addition.

Tilting the samples changes the normal ring patterns into arc patterns. The arc patterns of the 60°-tilt electron diffraction for the sample using CrMn/NiAl underlayers were obviously shorter and more concentrated in intensity, indicating a smaller CoCrPt $(10\bar{1}0)$ texture distribution angle, than when Cr/NiAl underlayers were used. The electron diffraction analysis is consistent with the magnetic measurements.

Plane-view TEM bright field images of the above two samples are shown in Fig. 3. The visually estimated average grain size of CoCrPt layer is about 16 nm on CrMn/NiAl, which is smaller than the 21 nm value obtained for the Cr/NiAl underlayer sample. The Co alloy grain sizes are also more evenly distributed visually for the former sample.

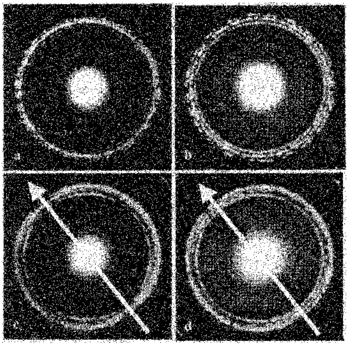

Fig. 2 Electron diffraction patterns of CoCrPt films. (a) & (c) are for samples using CrMn/NiAl underlayers; (b) & (d) for samples using Cr/NiAl underlayers. (a) & (b) are 0° tilt; (c) & (d) are 60° tilt. The arrows indicate the tilt axes. The three rings shown, from inside to outside diameter, are $\{10\bar{1}0\}$, {0002} and $\{10\bar{1}1\}$, respectively.

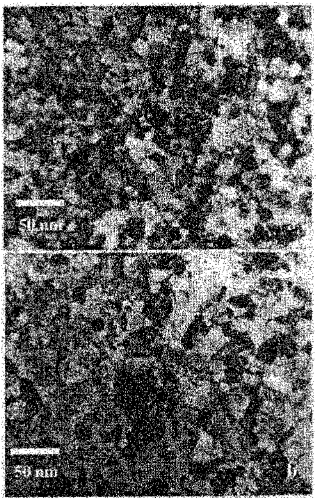

Fig. 3 Plane-view TEM bright field images of CoCrPt films on (a) CrMn/NiAl and (b) Cr/NiAl underlayers.

A series of repeated 1-minute post-deposition rapid thermal annealing (RTA), with increasing maximum temperature from 250 °C to 450 °C, were performed on the CrMn/CoCrPt/CrMn/NiAl and Cr/CoCrPt/Cr/NiAl films. CrMn and Cr overlayers were added to protect the Co-alloy magnetic layers from oxidization and to enhance the effects of interdiffusion. Fig. 4 shows the effects of the annealing temperature. For the samples using CrMn layers, the δM peaks and Ms decreased, while the coercivity increased with the higher annealing temperatures. At 450 °C, the δM peak value dropped to about 0.1, the coercivity increased by 40% to 4700 Oe, while the Ms decreased about 30%. The Cr/CoCrPt/Cr/NiAl films showed similar behavior except that the coercivity only increased up to 3400 Oe, a significantly smaller effect than for the CrMn layers.

By annealing the CrMn/CoCrPt/CrMn/NiAl films at an optimal condition of 400 °C for 8 minutes, the δM peak decreased to almost zero, Hc increased 38% to 4600 Oe, and Ms decreased only 15%. Since Hc is usually viewed as being proportional to Hk, and since $Hk = 2Ku/Ms$, only a portion of the Hc increase is due to the 15% Ms decrease. To account for the full 38% increase in Hc, either the Ku must have increased which will be shown later not to be the case, or the increase in Hc reflects a decrease in magnetic reversal via domain wall motion across grain boundaries due to a decrease in the granular exchange coupling. Comparing x-ray

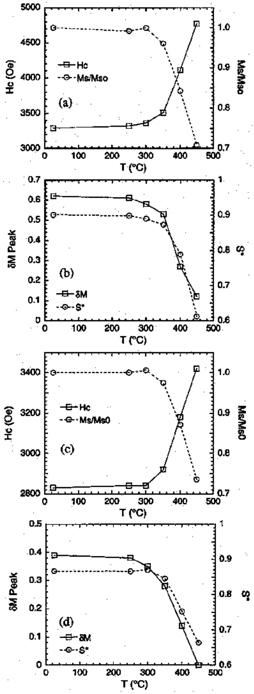

Fig. 4 The magnetic properties vs. annealing temperature for (a) & (b) CrMn/CoCrPt/CrMn/NiAl and (c) & (d) Cr/CoCrPt/Cr/NiAl films. Mso is the Ms value prior to the RTA treatment.

diffraction data of all layers and TEM images of the CoCrPt layer with and without the RTA treatment, there was no apparent change in grain size or texture after the RTA treatment under these conditions.

Table II compares the anisotropy energy density Ku, measured by the out-of-plane torque method in a field of 20 KOe and the Miyajima analysis (45°-torque) method using fields from 10 to 20 KOe [9,10], for the 400°C/8-minute annealed and unannealed samples. These two methods assume 2-D in-plane random distribution of uniaxial easy axes. Because our samples did not have a perfect in-plane Co texture, the Ku values obtained by these measurements may be smaller than the actual values. Since there was no significant change in Co alloy texture, these methods are valid to study the effects of RTA. The CoCrPt films on CrMn/NiAl underlayers exhibited a higher Ku value than those prepared on Cr/NiAl. This is consistent with the observed better CoCrPt in-plane texture. Both types of samples show only marginal decreases in Ku after annealing, which may suggest grain boundary diffusion dominates. In this sense, since the Co alloy anisotropy energy density decreases rapidly with the increasing Cr concentration [6], a well-controlled interdiffusion maybe more beneficial for achieving grain isolation than the conventional approach of Cr segregation via high-Cr-content CoCrX alloy films. The 15% decrease in Ms may be due to diffusion of nonmagnetic materials into the bulk of the CoCrPt grains, which is not severe enough to significantly decrease the Ku; or the decrease in Ms may only reflect the decrease in magnetic moment at the grain boundaries and there maybe no significant bulk diffusion at the annealing conditions.

TABLE II
ANISOTROPY ENERGY DENSITY MEASUREMENTS

Intermediate & over layers		Ku (10^6 erg/cc)	
		Out-of-plane torque	Miyajima
CrMn	Orig.	4.3	4.7
	RTA	4.1	4.7
Cr	Orig.	3.0	3.5
	RTA	3.0	3.5

IV. CONCLUSIONS

CrMn/NiAl underlayers induce better CoCrPt $(10\bar{1}0)$ texture and magnetic properties than Cr/NiAl. CoCrPt films on the former underlayer structure also have smaller and more evenly distributed grain sizes. Hc increased 38% to 4600 Oe, Ms decreased 15%, and the δm peak decreased to almost zero by using post-deposition RTA. CoCrPt films on CrMn/NiAl underlayers exhibit higher anisotropy, obtained by out-of-plane torque and Miyajima method, than on Cr/NiAl. Both showed limited decrease in anisotropy after annealing. Post-deposition RTA appears to be a promising technique to achieve Co alloy grain isolation.

REFERENCE

[1] L.-L. Lee, D. E. Laughlin, and D. N. Lambeth, *IEEE Trans. Magn.*, vol. 30, pp 3951-3 (1994).
[2] J. Li, M. Mirzamaani, X. Bian, M. Doerner, T. Arnoldussen, S. Duan, and K. Tang, to be published on *J. Appl. Phys.*
[3] L.-L. Lee, D. E. Laughlin, L. Fang, and D. N. Lambeth, *IEEE Trans. Magn.*, vol. 31, pp 2728-30 (1995).
[4] J. Zou, D. E. Laughlin, and D. N. Lambeth, *IEEE Trans. Magn.*, vol. 34, pp 1582-4 (1998).
[5] B. Lu, D. E. Laughlin, D. N. Lambeth, S. Z. Wu, R. Ranjan, and G. C. Rauch, to be published on *J. Appl. Phys.*
[6] N. Inaba, M. Futamoto, and A. Nakamura, , *IEEE Trans. Magn.*, vol. 34, pp 1558-60 (1998).
[7] J. Zou, D. E. Laughlin, and D. N. Lambeth, *MRS Symp. Proc.*, v. 517, pp 217-22 (1998).
[8] L. Tang, Y. C. Feng, L.-L. Lee and D. E. Laughlin, *J. Appl. Cryst.* 29, 419-26 (1996).
[9] H. Miyajima and K. Sato, *J. Appl. Phys.*, vol 47, pp 4669-71 (1976).
[10] H. N. Bertram and J.-G. Zhu, *IEEE Trans. Magn.*, vol. 27, pp 5043-5 (1991).