Substrate bias effects on composition and coercivity of CoCrTa/Cr thin films on canasite and glass

Y. Deng, D. N. Lambeth, and X. Sui
Department of Electrical and Computer Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

L.-L. Lee and D. E. Laughlin
Department of Materials Science and Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

CoCrTa/Cr thin films were prepared by rf diode sputtering onto canasite and glass substrates at various bias voltages from two targets of different compositions ($Co_{82.8}Cr_{14.6}Ta_{2.6}$ and $Co_{86}Cr_{12}Ta_2$). While Auger depth profile analysis indicates that there is some broadening at the CoCrTa-Cr interface, x-ray fluorescence spectroscopy reveals that changes in alloy composition due to the resputtering processes are even more prominent. For both targets, as the substrate bias increases the Co content in the films declines, and the magnetization decreases. The maximum film coercivity appears to correlate to the final film composition. By investigating the results from both targets, it is concluded that the coercivity reaches a maximum when the film composition is in the neighborhood of $Co_{84}Cr_{13}Ta_3$. Thus, to optimize the coercivity different bias voltages are required for each target. Excessive substrate bias, however, leads to films with low magnetization and coercivity.

I. INTRODUCTION

The effect of substrate bias on the magnetic properties of sputtered films has long been studied in terms of the film microstructure.[1-3] While the film microstructure undoubtedly plays an important role in determining the film coercivity, we have found that substrate bias can also change the composition of sputtered Co alloy films and that the magnetic properties of the films appear to correlate with the change in the film composition. These results are reported herein.

II. EXPERIMENTAL

CoCrTa/Cr films were rf sputter deposited onto Corning canasite and Corning 7059 glass substrates from two targets of slightly different compositions ($Co_{82.8}Cr_{14.6}Ta_{2.6}$ and $Co_{86}Cr_{12}Ta_2$) in a Leybold–Heraeus Z-400 sputtering system. The background pressure was 7×10^{-7} Torr and the sputtering pressure of the Ar gas was 10 mTorr. For all the films presented herein, the CoCrTa was 300 Å thick, and the Cr underlayer was 1000 Å thick. Since the film deposition rate varied when different rf substrate bias voltages were used, the sputtering time was adjusted to keep the same film thickness. For the two 3-in.-diam CoCrTa targets, the film deposition rates decreased monotonically from 120 to 30 Å/min as the substrate bias was increased from 0 to -300 V. Both canasite and glass substrates were cleaned with solvents and then rinsed with deionized water. Prior to the film deposition, a low power *in situ* plasma etching was performed to remove the residual surface contaminants and to improve film-substrate adhesion. Magnetic properties were measured by vibrating sample magnetometry, and the film composition was analyzed by energy dispersive x-ray fluorescence (EDXRF) spectroscopy and Auger depth profilometry.

III. RESULTS AND DISCUSSIONS

In order to accurately measure the CoCrTa film composition, CoCrTa films approximately 2000 Å thick were prepared directly on glass substrates (no Cr underlayers) at different rf substrate bias voltages. The composition of each of these films was measured by EDXRF spectroscopy. Figure 1 shows the elemental content versus substrate bias voltage for the sputtered CoCrTa films from the $Co_{82.8}Cr_{14.6}Ta_{2.6}$ and $Co_{86}Cr_{12}Ta_2$ targets. It is seen that the content of the magnetic element, Co, decreases with increasing substrate bias voltage, while the content of nonmagnetic elements, Cr and Ta, increases. It appears that the change in the composition of the bias sputtered films is caused by the resputtering process when bias is used. Since Co has a higher sputtering yield than either Cr or Ta,[4] the Ar ions impacting the substrate remove more Co from the CoCrTa film than Cr or, especially, Ta.

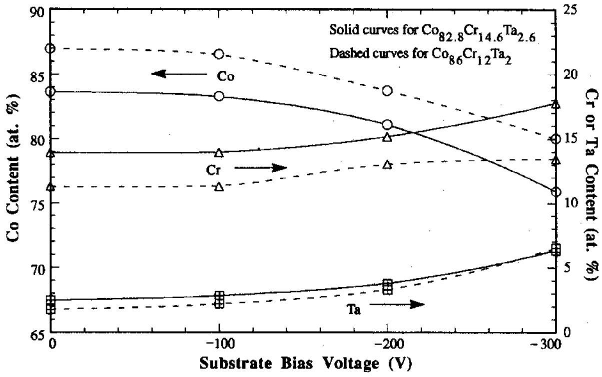

FIG. 1. Variations in the content of Co, Cr, and Ta with rf substrate bias voltages for the CoCrTa films (~2000 Å thick) sputtered on glass from the $Co_{82.8}Cr_{14.6}Ta_{2.6}$ and $Co_{86}Cr_{12}Ta_2$ sputtering targets.

0021-8979/93/105557-03$06.00

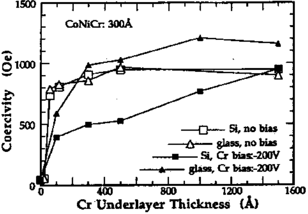

Fig. 2 Coercivity vs. Cr underlayer thickness.

CoNiCr from the *fcc* phase to the *hcp* phase. The *hcp* phase has a high uniaxial magnetocrystalline anisotropy, yielding a sharp increase in the coercivity.

As shown in Fig. 2, with RF bias the Cr thickness required to achieve the same coercivity as obtained without bias is greater. For the films on glass this is a relatively small increase in Cr thickness, however, for the films on Si this is quite dramatic. At the same time, the x-ray diffraction spectra in Fig. 3 show that the Cr on Si has a {110} texture when bias is applied. Furthermore, the diffraction peak intensity for Cr on Si is significantly higher than that for Cr on glass indicating a much stronger Cr {110} texture on Si. Contrary to these results, Pressesky *et al*. found that for CoCrTa/Cr sputtered on NiP at high temperature (230°C), RF bias prepared films showed both {110} and {200}, but predominantly a {200}, Cr texture.

The decrease in the coercivity for thin Cr underlayers when bias is used is consistent with the Yogi *et al*.'s study on CoPtCr [6]. In that work it was found that high atomic mobility was caused by the combination of an elevated substrate temperature (150°C), substrate bias (-85 V), and low sputtering pressure. This yielded a dense and continuous Cr film as exhibited by a lower coercivity and a higher intergranular exchange coupled media noise. A high δM value and a high coercivity squareness obtained on our films imply a strong exchange coupling. This was especially true for the Cr films prepared on Si with bias. This is also indicative of a more continuous CoNiCr film.

A picture, consistent with Yogi *et al*.'s findings and our data, would be that an oxide-free smooth Si surface would promote a high degree of Cr atomic mobility even at room temperature allowing a high quality {200} texture to develop, while the reactivity of Cr with the oxygen of a glass substrate would limit the mobility. The introduction of bias implies that Ar^+ striking the substrate promotes dense Cr and CoNiCr films (lower coercivity and higher media noise) and the strong Cr {110} texture. A hint that higher Cr deposition rates limit the atomic mobility is shown in Fig. 6, where no bias was applied to the Si substrate during Cr deposition but some Cr (110) texture has appeared. These Cr films were deposited at approximately twice the deposition rate of those in Fig. 1.

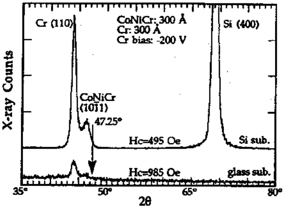

Fig. 3 Film x-ray diffraction spectra showing the Cr {110} texture resulted from the substrate bias sputtering.

The x-ray spectra in Fig. 3 also reveal that the diffraction peak of the CoNiCr (10$\bar{1}$1) is shifted to lower 2θ values, relative to the value obtained from the target alloy. (47.25°, indicated by an arrow). This shift is dependent on the thickness of the Cr underlayer (see Fig. 4). We fit the Cr (110) peak and the CoNiCr (10$\bar{1}$1) peak with Gaussian distributions and calculated the "true" angle for the weak CoNiCr (10$\bar{1}$1) peak (see Table I). From the table it can be seen that the d-spacing of the (10$\bar{1}$1) planes decreases towards its equilibrium value as the Cr underlayer thickness increases. We are uncertain as to the cause of this peak shift, though it has been attributed to the unequal thermal expansion of the substrate and the bi-layer film [7]. Since the two identically prepared films in Fig. 3, one on glass and the other on Si, have considerably different coercivities but identical shifts in the (10$\bar{1}$1) peak, we do not think that the d-spacing strongly correlates to the coercivity.

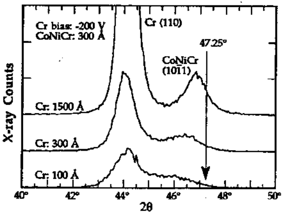

Fig. 4 Film x-ray diffraction spectra showing the effect of thickness of the bias deposited Cr underlayer.

Table I
Values for 2θ and d-spacing of the CoNiCr (10$\bar{1}$1) planes for the three samples in Fig. 4 and the CoNiCr sputter target

Cr Thickness	$2\theta_{(10\bar{1}1)}$	$d_{(10\bar{1}1)}$
100 Å	46.10°	1.968 Å
300 Å	46.50°	1.952 Å
1500 Å	46.90°	1.936 Å
sputter target	47.25°	1.923 Å

As shown in Fig. 5, RF bias applied during the CoNiCr deposition (but not during the Cr deposition) increases the film coercivity. While the coercivity increases with increasing bias voltage, the value of the coercive squareness S* decreases, implying that grain isolation may be increased. X-ray diffraction spectra in Fig. 6 indicate that both the {11$\bar{2}$0} texture in the CoNiCr and the {200} texture in the previously deposited Cr underlayer, diminish as the bias voltage increases. All three Cr underlayers were sputtered under the same conditions, and thus should be the same in terms of the film texture. Therefore, it is conjectured that bombardment by highly energized backward sputtered Ar^+ ions causes disruption of the interface and possibly interdiffusion of Cr and CoNiCr at the CoNiCr/Cr interface.

IV. SUMMARY

A very thin Cr underlayer can produce *hcp* CoNiCr films having a high in-plane coercivity for either Si or glass substrates. Even at room temperature, Cr {200} texture forms on Si resulting in a {11$\bar{2}$0} in-plane texture in the CoNiCr film. On glass, however, Cr {110} texture forms and the CoNiCr film has no single dominant texture. RF substrate bias applied during the Cr underlayer deposition leads to Cr {110} and CoNiCr {10$\bar{1}$1} textures for both Si and glass substrates. With Cr prepared using RF bias the coercivity for films on Si is significantly reduced. This decrease may be attributed to the intergranular exchange interactions in the more continuous CoNiCr films. RF substrate bias applied during the CoNiCr deposition degrades the (200) Cr interface but improves the coercivity.

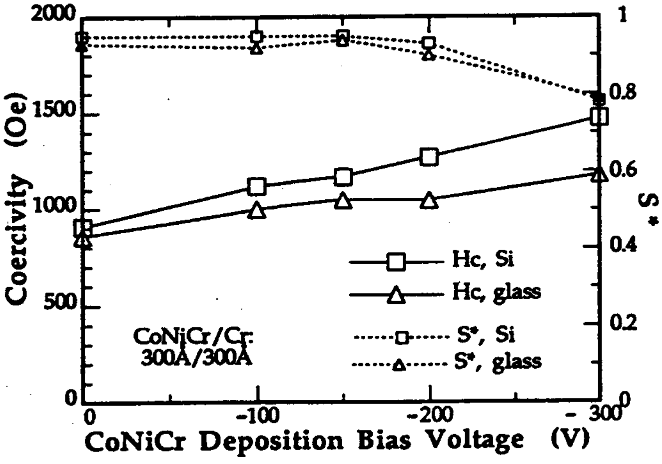

Fig. 5 Coercivity and coercive squareness S* vs. CoNiCr deposition bias voltage.

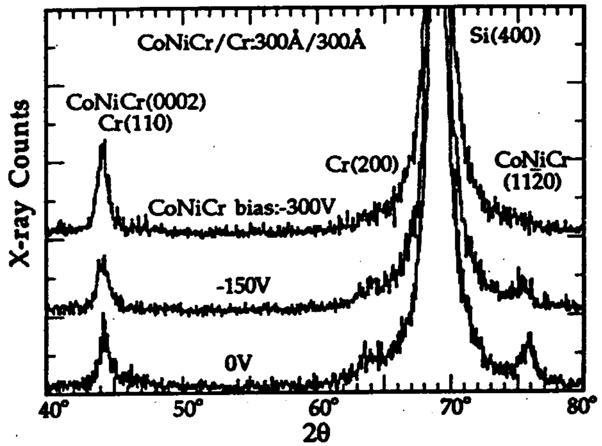

Fig. 6 Film x-ray diffraction spectra showing that bias sputtering of CoNiCr changes the Cr texture.

ACKNOWLEDGMENTS

We would like to thank Mr. Yongchang Feng, Mr. Li-Lien Li, and Drs. David J. Rogers, Yong Shen, Bunsen Y. Wong, and E.M.T. Velu of Carnegie Mellon University for stimulating discussions. We also wish to thank Mr. Philip Frausto of and TOSOH SMD, Inc. for supplying the sputtering targets.

REFERENCES

1 D. E. Laughlin and B. Y. Wong, "The crystallography and texture of Co-based thin film deposited on Cr underlayers," *IEEE Trans. Magn.*, Vol. 27, No. 6, pp. 4713-4717(1991).
2 S. L. Duan, J. O. Artman, B. Y. Wong, and D. E. Laughlin, "The dependence of the microstructure and magnetic properties of CoNiCr/Cr thin films on the substrate temperature," *IEEE Trans. Magn.*, Vol. 26, No. 5, pp.1587-1589 (1990).
3 J. Daval and D. Randet, "Electron microscopy on high-coercive-force Co-Cr composite films", *IEEE Trans. Magn.*, Vol. 6, No. 4, pp.768-773 (1970).
4 J. Pressesky,S.Y. Lee,S. Duan, and D.Williams, "Crystallography and magnetic properties of CoCrTa films prepared on Cr underlayers with different substrate bias conditions", *J. Appl. Phys*, Vol.69, No.8, pp.5163-5165 (1991).
5 N. Toni, M. Hashimoto, M. Ishikawa, Y. Ota, K. Nakamura, and A. Itoh, "Increase of coercive force in sputtered hard disk,"*IEEE Trans. Magn.*,Vol. 26, No.4 pp.1282-1285 (1990).
6 T. Yogi, T. A. Nguyen, S. E. Lambert, G. L. Gorman, and G. Castillo, "Role of atomic mobility in the transition noise of longitudinal media", *IEEE Trans. Magn.*, Vol. 26, No. 5, pp.1578-1580 (1990).
7 M. Lu, J. H. Judy, and J. M. Sivertsen, "Effects of RF bias on the texture, magnetics, and recording properties of RF sputtered CoCr/Cr longitudinal thin film media", *IEEE Trans. Magn.*, Vol. 26, No. 5, pp.1581-1583 (1990).