The Effects of Substrate and Bias on CoNiCr/Cr Thin Films

Youping Deng and David N. Lambeth
Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

David E. Laughlin
Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, PA 15213

Abstract -- **The magnetic properties and microstructural characteristics of CoNiCr/Cr films with thin Cr underlayers prepared on both single crystal Si and glass substrates are discussed. It is found that {200} crystallographic texture is easily obtained for Cr films prepared on Si at room temperature. Substrate bias during the Cr deposition, however, changes the Cr {200} texture to {110}. Substrate bias during the CoNiCr deposition degrades the texture of the Cr underlayer.**

I. INTRODUCTION

In order to grow hexagonal Co alloy films with the c-axis oriented in the plane of the film a Cr underlayer having {200} crystallographic texture is desired [1]. This Cr {200} texture is often obtained by heating the substrate during the Cr deposition, or sometimes by epitaxial growth and even by bias sputtering [2-4]. It has also been found that substrate bias affects the magnetic properties and microstructure of the films [4-6]. Here, we report that high coercivity CoNiCr/Cr films with Cr {200} texture can be sputter deposited on a well-cleaned single crystal Si substrate even at room temperature. The films on Si substrates have low background noise in the x-ray diffraction spectra, and thus allow us to better investigate the effect of RF substrate bias on the crystallographic texture. The effect of RF bias on film growth for both Si and glass substrates is presented.

II. EXPERIMENTAL

$Co_{62.5}Ni_{30}Cr_{7.5}$/Cr thin films were RF sputter deposited on (100) single crystal Si and Corning 7059 glass substrates in an Leybold-Heraeus Z-400 sputtering system with a background pressure of 6×10^{-7} Torr and a sputtering pressure of 10 mTorr. The films were prepared at deposition rates of 30-120 Å/min. Following a solvent degrease and water rinse of both the Si and glass substrates, the Si substrate was immersed in a 10% HF solution for 60 seconds to remove the surface oxide, and blow dried without a water rinse. Both the Si and glass substrates underwent a low power *in-situ* plasma etching prior to the film deposition. The film thickness was determined by sputtering time which was calibrated by step profilometry. For the films studied, the CoNiCr was 300 Å thick giving an M_rt value of about 1.8 memu/cm^2. The Cr was 300 Å thick unless the Cr underlayer thickness was chosen as a variable. Magnetic properties and microstructural characteristics were studied by vibrating sample magnetometry, transmission electron microscopy and x-ray diffraction using Cu Kα radiation.

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III. RESULTS AND DISCUSSIONS

Fig. 1 shows the x-ray diffraction spectra for some of the films deposited on Si and on glass at room temperature without substrate bias. Apparently, the Cr {200} texture grows naturally on Si at room temperature resulting in the CoNiCr {11$\bar{2}$0} texture. On glass, however, the Cr {110} texture forms, and the CoNiCr forms with no clear texture. In spite of the growth of the {200} Cr on Si, ring patterns appeared in planar TEM Selected Area Diffraction, indicating that the Cr does not grow epitaxially on the Si. Therefore, the c-axes of the hexagonal CoNiCr are randomly oriented in the plane of the film.

Fig. 2 shows the coercivity vs. Cr underlayer thickness of the CoNiCr/Cr films with and without RF substrate bias during the Cr deposition. Without RF bias, the films both on Si and on glass show the same dependence of coercivity on Cr underlayer thickness, but have different textures as shown in Fig. 1. Our TEM studies reveal that without a Cr underlayer the CoNiCr films forms in the *fcc* phase, but that a 60 Å thick Cr underlayer is sufficient to change the

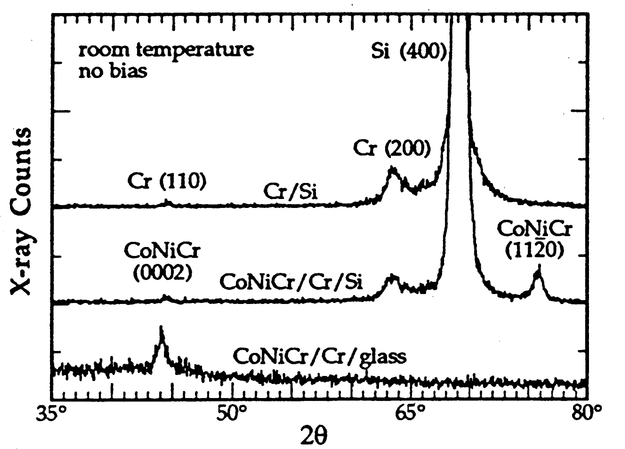

Fig. 1 Film x-ray diffraction spectra showing the substrate effect on Cr and CoNiCr textures.

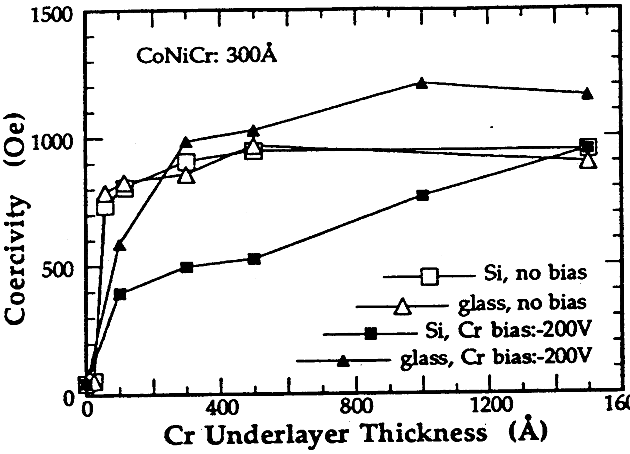

Fig. 2 Coercivity vs. Cr underlayer thickness.

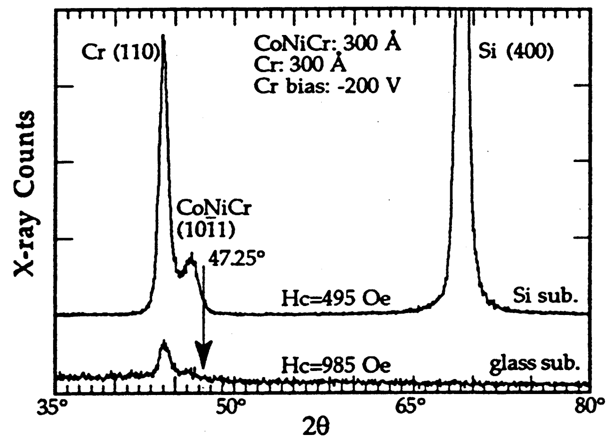

Fig. 3 Film x-ray diffraction spectra showing the Cr {110} texture resulted from the substrate bias sputtering.

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.

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.

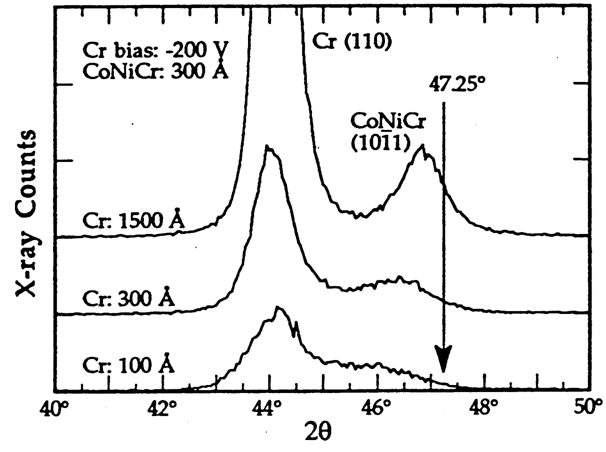

Fig. 4 Film x-ray diffraction spectra showing the effect of thickness of the bias deposited Cr underlayer.

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	2θ(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.

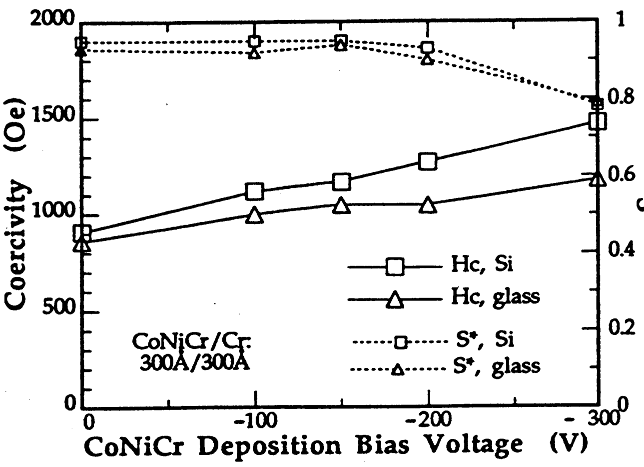

Fig. 5 Coercivity and coercive squareness S* vs. CoNiCr deposition bias voltage.

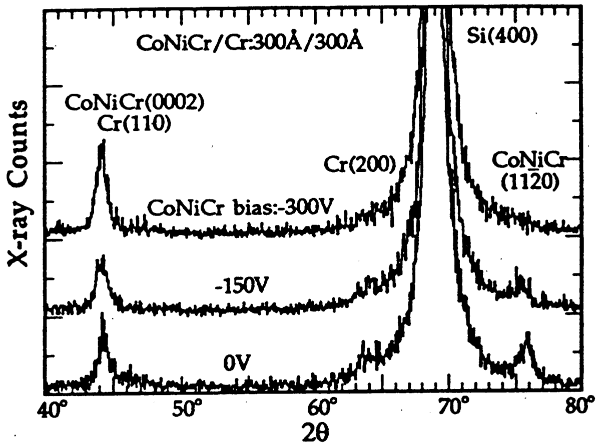

Fig. 6 Film x-ray diffraction spectra showing that bias sputtering of CoNiCr changes the Cr texture.

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