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Effects of layer thickness on orientation distribution and magnetic properties of CoCrTa/Cr films

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Evolution of orientation distribution of Co(110) crystal planes was determined by x-ray rocking curves. It has been found that: (i) The full-width at half maximum W of the Co(110) rocking curve decreases with both increasing Cr underlayer thickness d_{Cr}, and increasing CoCrTa magnetic layer thickness d_{Co}, especially in the thin layer regime. (ii) For the thin d_{Co} regime, the interlayer diffusion between the Cr underlayer and the magnetic layer affects the rocking curves and magnetic properties significantly. (iii) Film magnetic properties, e.g., a significant jump in coercivity with increasing magnetic layer thickness in the thin d_{Co} regime may be related in part to the evolution of the Co(110) orientation distribution. *© 1999 American Institute of Physics.* [S0021-8979(99)60608-9]

I. INTRODUCTION

Sputtered CoCrM (M=Ta, Pt, etc.) films with Cr underlayer (CoCrM/Cr) are the predominant longitudinal recording media today. It is well known that the Cr underlayer is extremely important for controlling the microstructure of the magnetic layer, including such features as the Co(110)/Cr(002) texture,[1–3] grain size, and the intergrain interaction,[4,5] and therefore the magnetic properties of films. Furthermore, since the magnetic layer thickness of films is getting thinner with increasing recording density,[6] studies on the correlation between microstructure and magnetic properties for very thin film media is of crucial importance in surveying the future ultrahigh-density-recording media. However, to our knowledge, thus far rather few works have been published to investigate these aspects.[7,8]

In this work, the orientation distribution of Co(110) crystal planes of the magnetic layer is studied by x-ray rocking curves,[9,10] which helps us to understand the evolution of the Co(110)/Cr(002) texture as a function of the Cr underlayer and the magnetic layer thickness, and the correlation between microstructure and magnetic properties of the thin film media.

II. EXPERIMENTS

CoCrTa/Cr films were deposited on the NiP/Al substrate by dc magnetron sputtering. Two series of films were prepared: series A with Cr underlayer thickness d_{Cr} varied from 0 to 805 Å and CoCrTa magnetic layer thickness d_{Co} fixed at 300 Å; and series B with a fixed $d_{\mathrm{Cr}}=350$ Å and d_{Co} varied from 46 to 823 Å. Magnetic properties were characterized by a vibrating sample magnetometer (VSM). Structural properties were studied by x-ray diffraction with a Cu $K\alpha$ target.

III. RESULTS AND DISCUSSION

A. Effects of layer thickness and interface on orientation of Co(110) planes

In order to understand the details of the Co(110)/Cr(002) texture, it is necessary to investigate the orientation distribution of Co(110) crystal planes. The conventional x-ray θ–2θ scan only offers information on crystal planes parallel to the film surface, while the x-ray rocking curve can provide an orientation distribution pattern of Co(110) crystal planes.

Evolution of the orientation distribution of Co(110) crystal planes as a function of Cr underlayer thickness d_{Cr} is shown in Fig. 1. For the film without Cr underlayer, no Co(110) peak is observable in the rocking curve. The full width at half maximum W of the rocking curve narrows with increasing d_{Cr} and the Cr layer thickness effect on W is plotted in Fig. 2(a). It is well known that the existence of a thin Cr underlayer (say 75 Å) is a necessary condition to epitaxially grow the Co(110)/Cr(002) texture. Figures 1 and 2(a) show that not only is the Co(110) plane intensity, but also its orientation are improved by increasing the Cr underlayer thickness d_{Cr}, especially in the case of very thin d_{Cr}.

Evolution of the orientation distribution of Co(110) crystal planes as a function of the magnetic layer thickness d_{Co} is shown in Fig. 3. As d_{Co} increases from 93 to 823 Å, W decreases accordingly, which indicates that the Co(110) planes are becoming more parallel to the film surface as the magnetic layer becomes thicker. The W value increases appreciably with decreasing d_{Co} from 186 to 93 Å [see Fig. 2(b)], i.e., there are more out-of-plane Co(110) components

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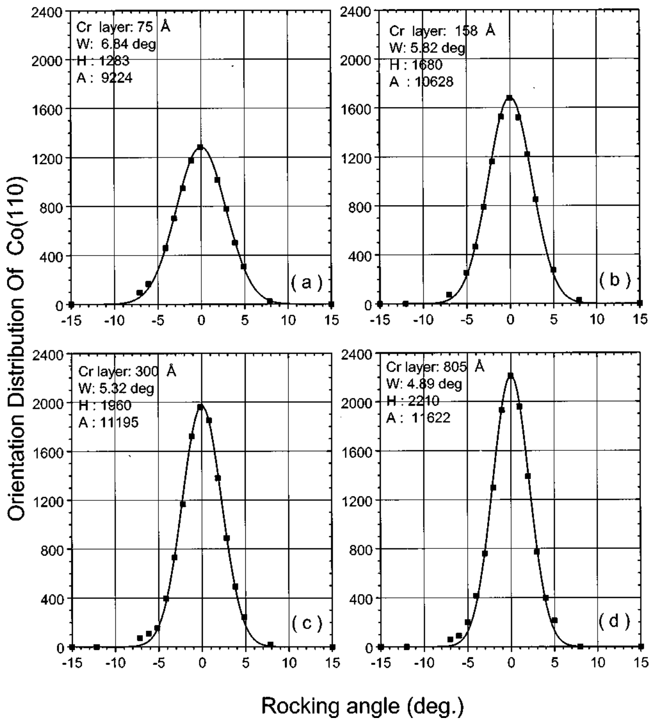

FIG. 1. X-ray rocking curves of Co(110) crystal planes as a function of Cr underlayer thickness: (a) $d_{Cr}=75$ Å, (b) $d_{Cr}=158$ Å, (c) $d_{Cr}=300$ Å, and (d) $d_{Cr}=805$ Å (The rocking curves were taken in the circumferential direction on the disk films hereafter.)

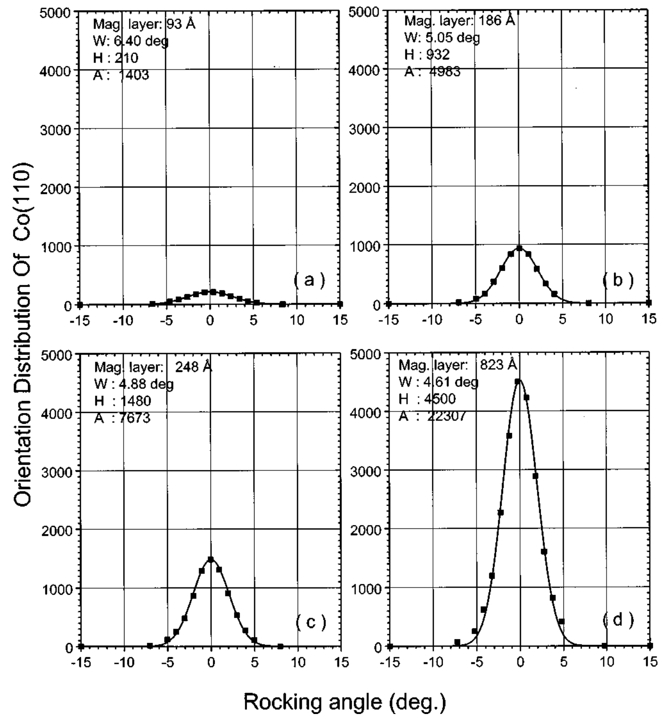

FIG. 3. X-ray rocking curves of Co(110) crystal planes as a function of magnetic layer thickness: (a) $d_{Co}=93$ Å, (b) $d_{Co}=186$ Å, (c) $d_{Co}=248$ Å, and (d) $d_{Co}=823$ Å.

as d_{Co} decreases. This behavior is related to the interface effect in the thin d_{Co} case.

Because of the atomic interdiffusion between Cr and Co alloy magnetic layers, the interface region of the magnetic layer is enriched with Cr atoms, which causes lattice strain and composition inhomogeneity because more Cr atoms diffuse along the grain boundaries.[11] Figure 4 shows the magnetic layer thickness effect on magnetization for our films. We found that the magnetization decreases significantly in the thin d_{Co} regime [Fig. 4(a)] and the so-called ‘‘dead layer’’ [12] thickness is 23 Å [Fig. 4(b)]. This implies that the interface region may extend to a significant thickness of the magnetic layer if it is weakly magnetic. The thinner the d_{Co},

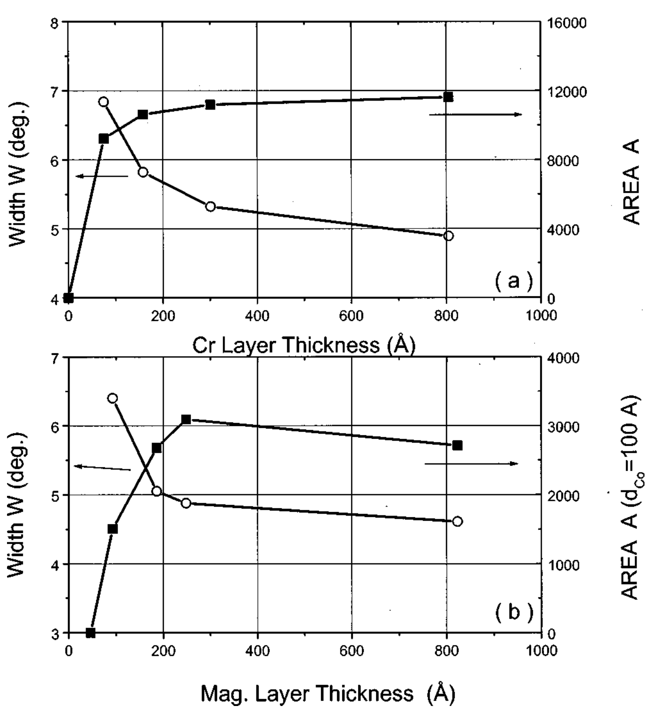

FIG. 2. A summary of *W* and *A* as a function of Cr underlayer thickness (a) and magnetic layer thickness (b).

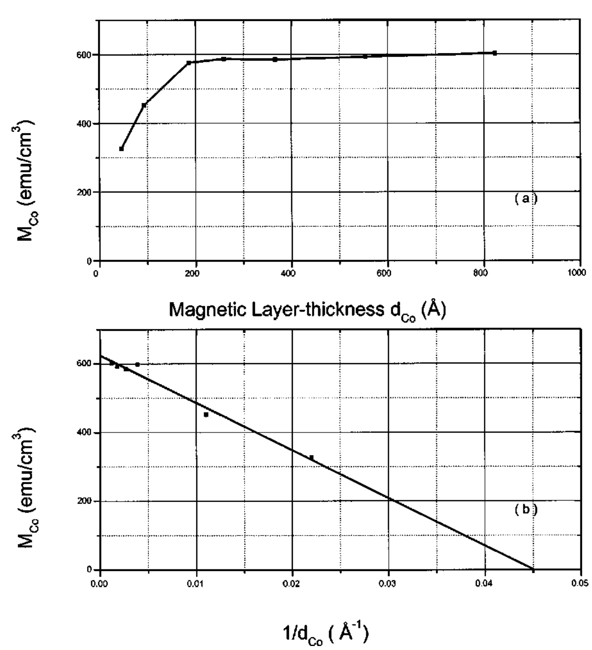

FIG. 4. Saturation magnetization of Co alloy layer M_{Co} as a function of magnetic layer thickness d_{Co} (a) and M_{Co} vs $1/d_{Co}$ (b).

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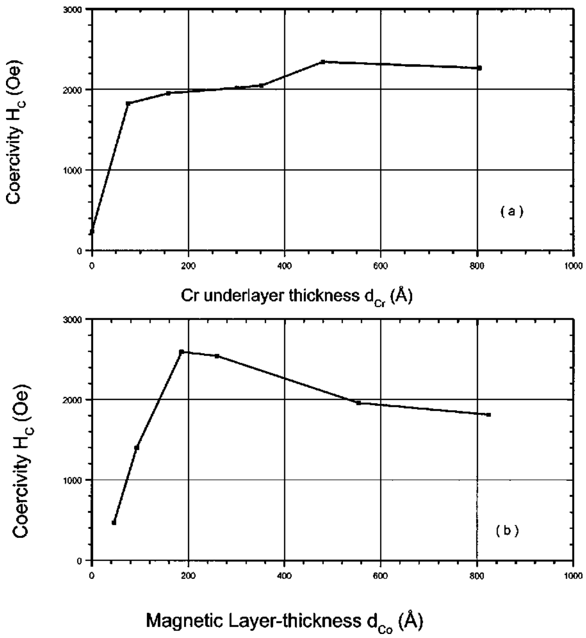

FIG. 5. Coercivity H_c as a function of Cr underlayer thickness (a), and H_c as a function of magnetic layer thickness (b).

the stronger the effect of the interface on the perfection of the Co(110)/Cr(002) texture and the magnetic properties. The interface does have the Co(110)/Cr(002) texture, but it is less perfect than that of the interior of the magnetic layer.

The area *A* under the rocking curve (see Figs. 1 and 3) is associated with the preferred orientation of Co(110) planes and the grain size. In general, *A* tends to increase as the grain size or the preferred orientation of the Co(110) planes increases. The decrease of the grain size (volume) together with the deterioration of the Co(110)/Cr(002) texture with decreasing d_{Co} leads to a rapid drop of the *A* value as seen in Figs. 2(b) and 3. Since the magnetic layer thickness is becoming thinner for future ultrahigh-density-recording media, it is essential to improve the Co(110)/Cr(002) texture and magnetic properties in the thin d_{Co} regime.

B. Effect of layer thickness on coercivity behavior

Coercivity is essential in high-density recording and its characteristics are correlated with many factors including the Co(110)/Cr(002) texture. Coercivity H_c as a function of the Cr underlayer thickness is demonstrated in Figs. 5(a). This behavior may be associated with the evolution of the orientation distribution of Co(110) crystal planes as a function of d_{Cr} as shown in Fig. 1 and 2(a). The significant jump in H_c as d_{Cr} varies from 0 to 75 Å is related to the onset of the Co(110)/Cr(002) texture, which is confirmed by the fact that *W* decreases and *A* increases drastically in this region. As d_{Cr} changes from 75 to 805 Å, the slow increase in coercivity is related to the decrease of *W* and the increase of *A*.

Figure 5(b) shows the magnetic-layer-thickness dependence of coercivity. For thin magnetic layers, H_c increases dramatically from 460 to 2600 Oe as d_{Co} increases from 46 to 186 Å. This feature may be connected in part with the evolution of the orientation distribution of Co(110) planes as shown in Figs. 2(b) and 3. It is clearly seen in Fig. 2(b), that *W* decreases (*A* increases) significantly in this d_{Co} range. The slight decrease in H_c as d_{Co} varies from 248 to 823 Å may be related to the increase of the intergrain interaction with increasing d_{Co}.

Besides texture, coercivity behavior is affected by many other parameters such as intergrain interaction, anisotropy, grain volume, magnetization, etc.,[13] and all these parameters change their characteristics with changing d_{Cr} and d_{Co}, especially in the thin layer region. As an Example Fig. 4 shows the magnetic-layer-thickness effect on magnetization.

In summary, not only the intensity of the Co(110) planes, but also its angular distribution is improved with increasing layer thickness of d_{Cr} and d_{Co}, especially in the thin layer region. For thin d_{Co} films, the interfacial magnetism is of importance in affecting the magnetic properties. The fact that the orientation of the Co(110) planes and the magnetic moment are more scattered in the thin magnetic layer region is an important concern in the design of future ultrahigh-density recording media.

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