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# E-Beam Evaporated Co/Cr and Co/Mo Multilayer Thin Films

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**Magnetic properties and crystallographic structure of e-beam evaporated Co/Cr and Co/Mo multilayer thin films were investigated using VSM and XRD. Co/Cr and Co/Mo multilayer thin films are confirmed as an alternating layered structure. The structure of films with thicker Co layers than Cr and Mo layers are found to be a hcp structure with the c-axis perpendicular to the film plane. The direction of the film plane is the easy magnetization one. There is a no significant difference in shape of hysteresis loops between Co/Cr and Co/Mo multilayer films. It is found that Mo layer is more effective than Cr for preparing Co layer with c-axis normal to the film plane.**

## 1. Introduction

It has been well known that the CoCr thin film is accepted as a good medium for perpendicular magnetic recording because of its high perpendicular magnetic anisotropy [1]. The perpendicular magnetic anisotropy in CoCr thin films was related to a hcp crystallographic structure with its c-axis perpendicular to the film plane and Cr segregation near the grain boundaries. Magnetic properties and microstructures of CoCr films are strongly dependent upon the preparation method. This dependence in magnetic properties and microstructures are related to the segregation mechanism of Cr during film preparation. Co/Cr and Co/Mo multilayer have been studied for possible applications as the perpendicular recording media. Mo and Cr show same crystal structure (bcc) and a wide solubility range with Co. It was reported that saturation magnetization of Co in Co/Cr multilayer is considerably less than the bulk value, which indicates the occurrence of the interdiffusion [2, 3]. N. Sato has found that, for Co/Mo films, the Co layer being in contact with the Mo layer exhibits only small magnetization, which may be interpreted as the presence of a dead layer observed in Co/Cr multilayer [4]. In the paper, the crystallographic structure and magnetic properties of e-beam evaporated Co/Cr and Co/Mo multilayer films are presented.

## 2. Experimental Procedures

Co/Cr and Co/Mo multilayer films were prepared at room temperature by sequential deposition of Co and X (X=Cr, Mo) using e-beam evaporator. The films were deposited onto glass substrates (corning No. 2875) at room temperature to avoid interdiffusion of the constituents. The base pressure was below $3\times10^{-6}$ Torr. The deposition rate was controlled at 0.2~0.3 Å/s for Co and 0.1~0.2 Å/s for Cr and Mo layers. Co layer thickness was varied from 10 Å to 165 Å, while the thicknesses of Cr and Mo layer were fixed at 10 Å and 15 Å. The total thickness of Co/Cr and Co/Mo multilayer is in the range of 200~1800 Å.

Co/Cr and Co/Mo multilayer films contain totally 20 layers constituting 10/10 layers for Co/Cr and Co/Mo, respectively. Standard X-ray diffraction using CuKα radiation was used to study crystallographic structure of the films. The layered structure of the film was identified using a small-angle X-ray diffraction analysis. Magnetic properties such as saturation magnetization, coercivity were measured by VSM.

## 3. Results and Discussion

### 3.1. Crystallographic structure

Table 1. The thickness ratio and film thickness of Co/Cr and Co/Mo multilayer films

| Source \ Thickness ratio | 1/1 | | 1/3 | | 1/5 | | 1/7 | | 1/9 | | 1/11 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mo, Cr (Å) | 10 | 15 | 10 | 15 | 10 | 15 | 10 | 15 | 10 | 15 | 10 | 15 |
| Co (Å) | 10 | 15 | 30 | 45 | 50 | 75 | 70 | 105 | 90 | 135 | 110 | 165 |
| Total thickness (Å) | 200 | 300 | 400 | 600 | 600 | 900 | 800 | 1200 | 1000 | 1500 | 1200 | 1800 |

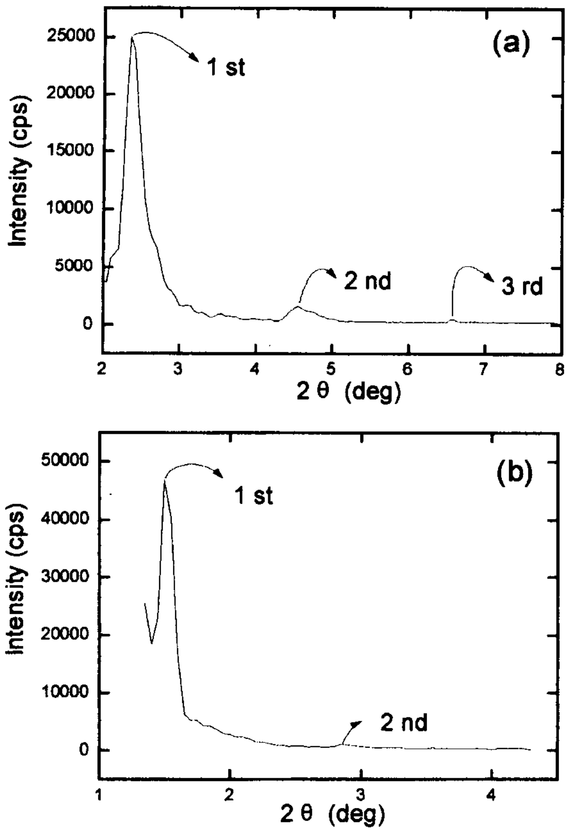


Fig. 1. Small-angle X-ray diffraction patterns for (a) (Co30 Å/ Mo10 Å)10 film (b) (Co45 Å/Cr15 Å)$_{10}$ film.

For almost all films except those with 1 : 1 thickness ratio of Co, and Cr or Mo, the presence of a layered structure was confirmed with small-angle X-ray diffraction analysis. The typical small-angle X-ray diffraction peaks are shown in Fig. 1 which are the case for (Co 30 Å/Mo 10 Å)$_{10}$ and (Co 45 Å/Cr 15 Å)$_{10}$ films, respectively. As shown in Fig. 1, in the case of Co/Mo films, peaks were observed at 2.35°, 4.54° and 6.55°. This indicates the layered structure was established. It was difficult to obtain small angle X-ray pattern for other Co/Cr films because of similarity of Co and Cr in interatomic distance.

The films with a small periodicity of Co (less than 30 Å) show no significant difference in periodicity between calculated and experimental value as shown in Fig. 2. These results suggest that the interdiffusion of Co and Cr or Mo at the interface between Co and Mo or Cr layers did hardly occur during evaporation. For thicker multilayer films, periodicity obtained from small-angle X-ray diffraction analysis is less than calculated value. This result indicates that for both of Co/Cr and Co/Mo film, the interdiffusion of Co and Cr (or Mo) may be occurred at the interface between two layers during evaporation. However, inaccuracy can be involved in measurement of the periodicity.

Large angle XRD data in Fig. 3 show that the intensity of Co (0002) peak increases with the increase in Co thickness. This result indicates (0002) plane of hcp Co layer is grown perpendicularly to the film plane. There will be a Cr (110)

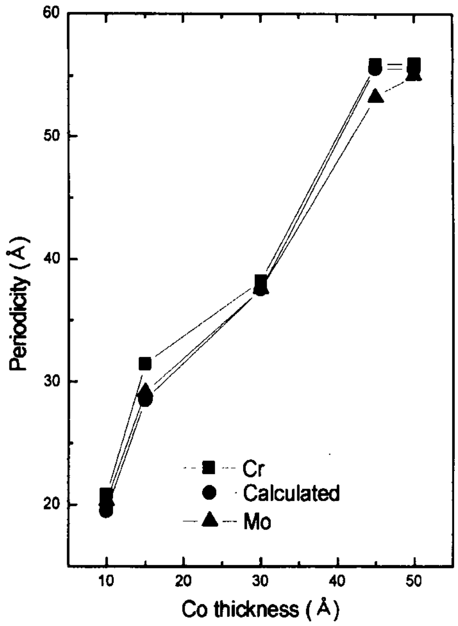


Fig. 2. Small-angle X-ray diffraction patterns for (a) (Co30 Å/ Mo10 Å) 10 film (b) (Co45 Å/Cr15 Å)$_{10}$ film.

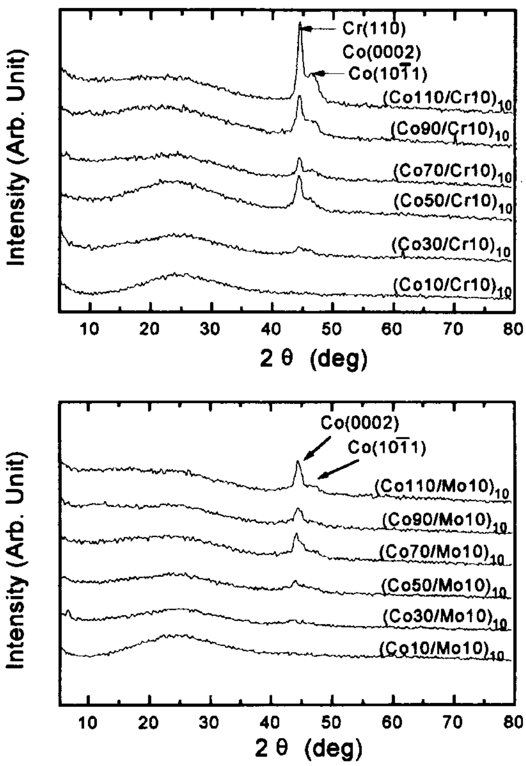


Fig. 3. Large-angle X-ray diffraction patterns for (a) Co/Cr (b) Co/Mo multilayer films with different Co layer thickness ratio.

contribution to (0002) peak intensity. In the films with a small periodicity of 20 Å, no X-ray diffraction peak was observed. This indicate that Co was not grown on the Cr layer epitaxially. For Co/Mo films, there is small intensity of the peak of Co (10$\bar{1}$1) plane, which is observed in Co/Cr films. The peak position change of Co (0002) plane with increasing Co thickness is shown in Fig. 4. In Co/Mo multilayers, it is found that Co (0002) peak shifts toward much

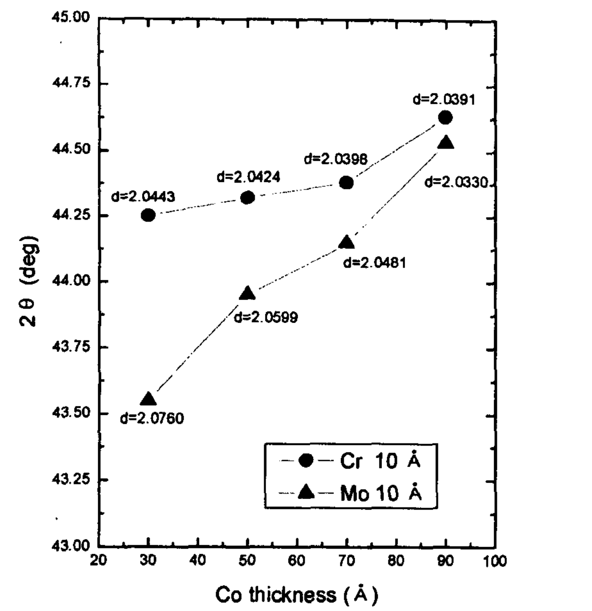

Fig. 4. Large-angle X-ray peak position of Co(0002) plane and d-values for Co/Cr and Co/Mo films with various Co layer thickness ratio.

lower angle with the decrease of Co layer thickness, indicating a larger lattice parameter.

For small Co thickness film, there is a significant difference in Co (0002) plane peak position between Co/Cr and Co/Mo multilayers. It is noticed that the Co peak moves toward lower angle in Co/Mo film comparing to Co/Cr film, representing larger lattice parameter effect of Mo on peak shifts of Co (0002) plane. This result is consistent with other researcher's finding [4]. However, there is no significant change in d-value for Co/Cr films. It is suggested that the epitaxial growth and defect within each grain cause this small lattice parameter increase. As Co thickness increases, d-value of Co (0002) plane of Co/Cr and Co/Mo film approaches to that of bulk Co. The position and intensity of a (0002) diffraction peak are influenced strongly by Co thickness as shown in Fig. 5. It is observed that the peak intensity in Co $(10\bar{1}1)$ plane increases with the increase in Co thickness for Co/Cr films, while there is no significant increase in Co $(10\bar{1}1)$ peak intensity for Co/Mo film. By comparing to relative peak intensity of Co(0002) plane in the both Co/Mo and Co/Cr films, the same result can be obtainable.

### 3.2. Magnetic properties

Fig. 6 gives the hysteresis loops for typical film exhibiting ferromagnetism in in-plane direction and perpendicular direction. Both films show in-plane easy axes and none of the perpendicular loops achieved saturation. As for the in-plane magnetization curve, the multilayer films shows small

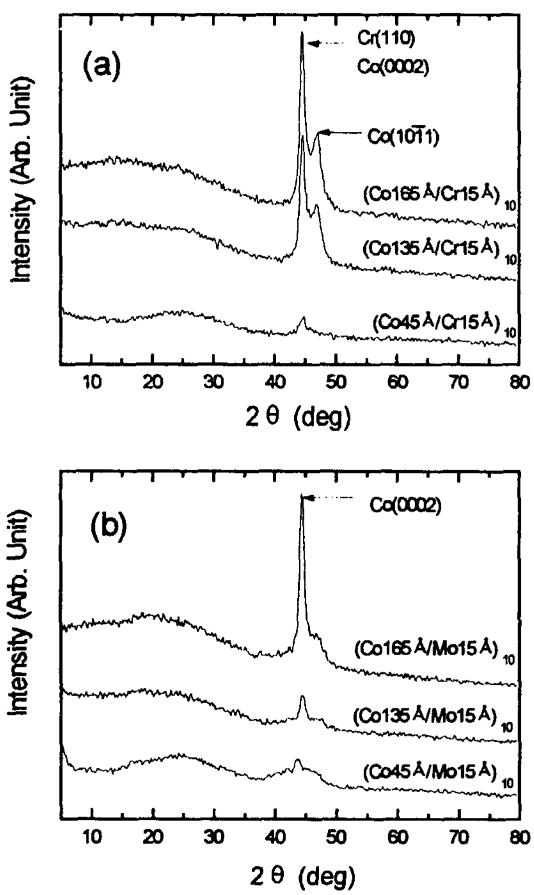

Fig. 5. Large-angle X-ray diffraction patterns for the film with (a) 15 Å Cr and (b) 15 Å Mo layer thickness.

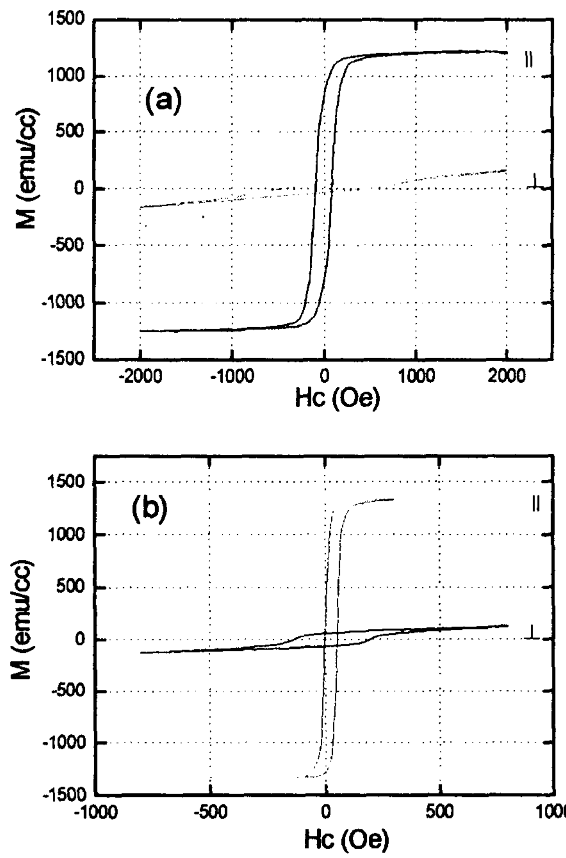

Fig. 6. Magnetic hysteresis loops for (a) $(Co75\ Å/Cr15\ Å)_{10}$ (b) $(Co75\ Å/Mo15\ Å)_{10}$ films. ⊥ and ∥ indicate the perpendicular and in-plane hysteresis loops, respectively.

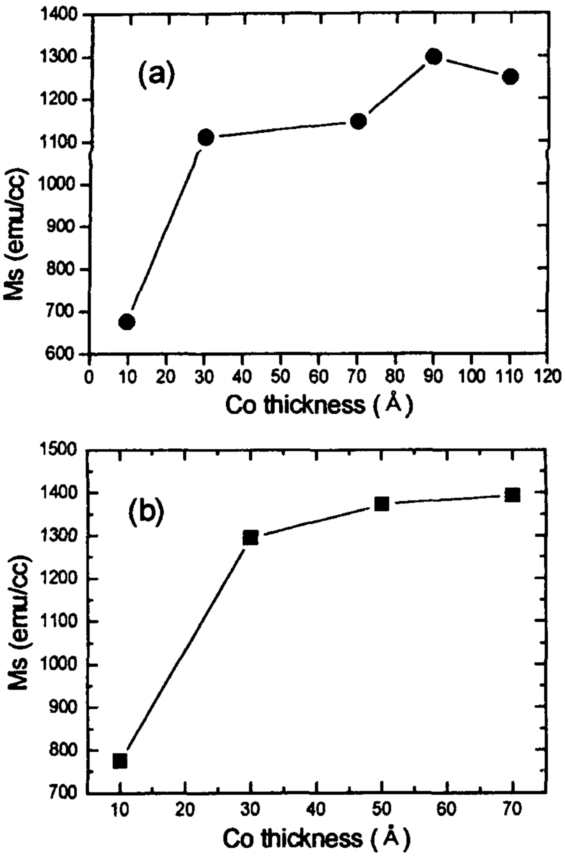


Fig. 7. Co layer thickness dependence of the saturation magnetization for (a) Cr 10 Å films (b) Mo 10 Å films with various thickness ratio.

coercivity $Hc_{\parallel}$ indicating a soft magnetic property. Saturation magnetization which obtained from in-plane hysteresis loop is plotted as a function of Co layer thickness as shown in Fig. 7. Saturation magnetizations of two multilayer films increased with Co thickness. Co layer thickness dependence of saturation magnetization is similar to the earlier reported results [4]. Co/Mo multilayer films show higher saturation magnetization than Co/Cr multilayer films in all range of Co thickness. It indicate that the degree of is larger than that of Co/Cr films. This may be interpreted with the larger increase of d-value in Mo than Cr because of larger lattice parameter of Mo (Fig. 4).

Fig. 8 shows the Co layer thickness dependence of perpendicular coercivity for Co/Cr and Co/Mo multilayer films. $H_C(\perp)$ increases as the Co film becomes thicker, and reaches maximum values at 90 Å Co thickness. The maximum value is about 550 Oe indicating not enough value for perpendicular recording.

This result indicates that the increase in Co thickness leads to preferred growth of (0002) plane parallel to the film plane resulting in enhancement of crystal anisotropy of Co layer. If there should be no additional effects, perpendicular coercivity should increase with increasing Co layer thickness. However, it is not clear what kinds of anisotropy effects are additionally involved in this finding.

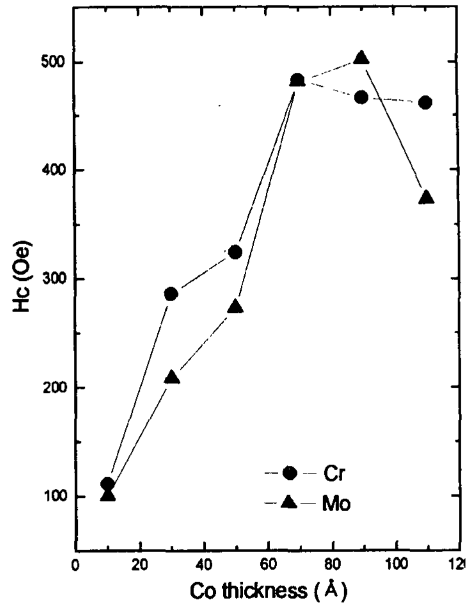


Fig. 8. Perpendicular coercivity change for Co/Cr and Co/Mo films as a function of the Co layer thickness.

## 4. Conclusions

E-beam evaporated Co/Cr and Co/Mo multilayer films identified as artificial layered structure by using small-angle X-ray diffraction analysis. For the films with thinner Co thickness, there is an evidence for interdiffusion between Co and Cr or Mo. Mo may induce the increase of interplanar distance of Co (0002) plane because of it's larger atomic size comparing with Cr.

It was found that Mo layer is more effective for growth of Co (0002) plane parallel to the film plane than Cr layer.

## Acknowledgement

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## References

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