# Magnetic-structural development in Co-Cr films for perpendicular recording media

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Transmission electron microscopy (TEM) was employed to examine the relation between microstructure and the corresponding magnetic domain structure in Co-Cr films. Emphasis has been placed on the influence of crystallographic orientation on the magnetic domain morphology. Examination of thin samples (7.5–35 nm) reveals that randomly oriented small grains form in-plane domain structures with cross-tie walls, magnetic ripple structure, and Bloch lines. As the film thickness increases (40–50 nm), the grains become well oriented along their *c* axes and the corresponding domain structures are comprised of the stripe-type characteristic of perpendicular domains. The magnetic domain structures will be discussed in terms of crystallographic orientation and microstructural defects.

## INTRODUCTION

We have reported previously microstructural details of Co-Cr thin films for perpendicular recording media.[1,2] There, we described a proposed nucleation and growth mechanism of the films which leads to microstructural defects such as microvoids and twinning. These defects are of importance for magnetic recording since they may pin the magnetic domain walls and/or act as nucleation sites for the domains during the magnetization process. However, no attempts have been made to correlate these defects with the magnetic domain structures of the Co-Cr films. Previous studies[3-6] have reported that magnetic domain structures were comprised of the stripe-type domains together with white/black dots in well oriented films with the *c* axis perpendicular to the film plane. The stripe- (or maze-) type contrast has been suggested to be due to an in-plane magnetization component where the film consists of columnar grains.[3] Similarly, the dotted contrast has been suggested to originate from the in-plane magnetization curling surrounding a perpendicular domain where one column contains an assembly of equiaxed grains.[4-6] However, why an in-plane component exists has never been fully explained. Therefore, our objectives are to correlate the crystallographic orientation of the films of various thicknesses with their corresponding magnetic domain structures and to examine the effect of microstructural defects on the magnetic domain structures.

## EXPERIMENT

The films were deposited on carbon-coated copper grids from an alloy target of Co-22 at. %Cr in a dc magnetron sputtering system. The thicknesses of the films were in the range of 7.5–50 nm; therefore, they could be observed by transmission electron microscopy (TEM) without thinning. The deposition conditions were kept approximately constant; the deposition rate was about 14 nm/min at room temperature. The microstructure and crystallographic orientation of the films were investigated using a Philips EM420T analytical electron microscope operating at 120 kV. The magnetic domain structures were observed by the Fresnel mode imaging in Lorentz electron microscopy (LEM).

## RESULTS AND DISCUSSION

Figures 1–3 are typical bright-field TEM micrographs, their representative convergent beam electron diffraction (CBED) patterns and Lorentz electron micrographs, respectively. The microstructure shown in Fig. 1(a) (7.5 nm thick) appears to be that of an amorphous phase along with small crystals. The diffuse ring in the CBED pattern [Fig. 2(a)] from this area confirms this.[2]

As the film thickness increases (15 nm), we see the beginnings of the development of randomly oriented crystalline grains [Figs. 1(b) and 2(b)]. With increasing film thickness (40 nm), the film displays a *c* axis orientation [Figs. 1(c) and 2(c)]. In the 50-nm thickness film, one can see Moiré fringes within grains formed from overlapping grains [arrowed, Fig. 1(d)]. The grains show a stronger orientation of the [0001] zone axis [Fig. 2(d)].

Figure 3 reveals the magnetic domain structures of Co-Cr films of four different thicknesses. In Fig. 3(a) (7.5 nm), the micrograph exhibits a 180° in-plane magnetic domain structure with magnetic ripple configurations. This is expected since the grains which coexist with the amorphous phase are randomly oriented. In addition, one can see cross-

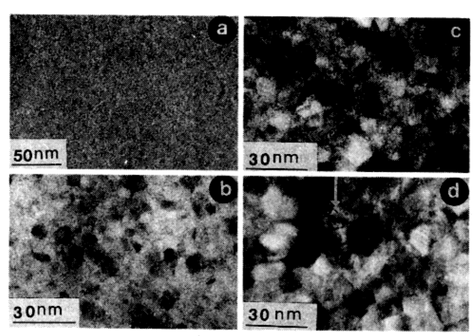


FIG. 1. TEM images of Co-Cr films on carbon-coated Cu grids: (a) 7.5 nm thick, (b) 15 nm thick, (c) 40 nm thick, and (d) 50 nm thick.

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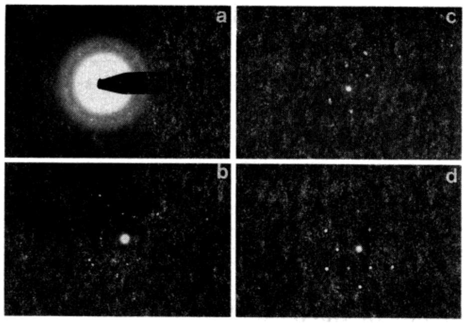


FIG. 2. CBED patterns of Co-Cr films or carbon-coated Cu grids: (a) 7.5 nm thick, (b) 15 nm thick, (c) 40 nm thick, and (d) 50 nm thick.

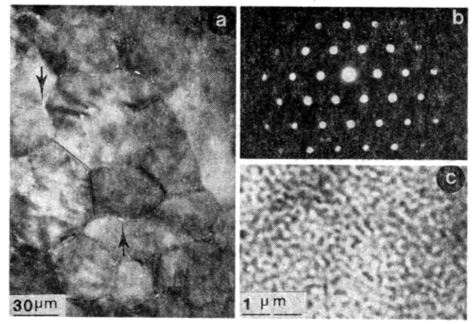


FIG. 4. A TEM image of Co-Cr films on glass substrate (a), together with a representative CBED pattern $z = [0001]$ (b), and a Lorentz image (c).

tie walls and Bloch lines of black/white dots along Néel walls. However, the contrast is not strong, due to the small Lorentz force generated by the thinner films. In this investigation the cross-tie walls are present in films that are much thinner than the theoretically predicted thickness (25 nm) for cobalt.[7]

At a film thickness of 15 nm, the magnetic domain structures do not show any 180° in-plane domain walls but do show a featherlike configuration together with small perpendicular components of magnetization exhibited by the black and white dots [arrowed, Fig. 3(b)]. The corresponding CBED patterns occasionally reveal [0001] zone axes but other zone axes, $[2\bar{1}\bar{1}0]$, $[1\bar{2}1\bar{3}]$, or $[01\bar{1}2]$ were more frequently observed. This suggests that the featherlike magnetic domain structures are due to randomly oriented in-plane crystals while the perpendicular domain configuration is caused by crystals with the [0001] zone axes.

In the 40-nm thickness film, the featherlike configuration completely disappeared leaving behind weak contrast of stripe-type domains [Fig. 3(c)]. The CBED patterns show a high frequency of *c* axes perpendicular to the film plane. Further increase in film thickness (50 nm) results in better contrast of stripe and dot magnetic domains. The increase in the contrast is due to the increase in perpendicular magnetization components.

Figure 4(a) is a bright-field micrograph, Fig. 4(b) a representative CBED pattern, and Fig. 4(c) the Lorentz micrograph taken from a region near to the top of a Co-Cr film

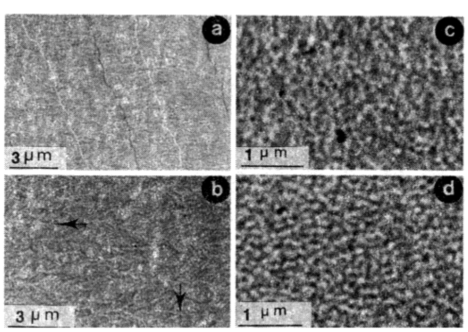


FIG. 3. Lorentz images of Co-Cr films on carbon-coated Cu grids: (a) 7.5 nm thick, (b) 15 nm thick, (c) 40 nm thick, and (d) 50 nm thick.

which had been deposited onto a glass substrate. In this instance, the film shows a large number of microvoids at grain boundaries and edges [arrowed, Fig. 4(a)]. These are larger than the ones observed in Co-Cr films deposited on carbon[2] because the former are thicker than the latter. The grains are well oriented along the *c* axis [Fig. 4(b)]. The Lorentz micrograph reveals a stripe-type magnetic domain structure as well as white and black dots [Fig. 3(d)].

The formation mechanism for microvoids has been described by present authors.[2] However, none of the published papers have attempted to explain the effect of microvoids on the magnetic domain configuration in Co-Cr films. We reported previously that the misorientation about *c* axis between adjacent grains is always less than 5°.[1] This misorientation could produce in-plane components to obtain observable contrast for stripe- (maze-) type domains as suggested by Ouchi and Iwasaki.[3] This is not enough to explain the origin of the black and white contrast of dotted domains. It is well known, however,[8] that imperfections such as inclusions and microvoids can create closure domains at the edge of the defects and at the domain walls in bulk alloys. The size of the defects in materials is related to the ability to form closure domains[9]: for example, the critical size for iron is 100 nm. For very small holes, similar closure domains in permalloy films have been suggested.[10] For Co-Cr films, the microvoids are present along column boundaries[2] and the length and volume fraction are not negligible. Therefore, it is likely that the free poles at the microvoids result in closure domains producing in-plane magnetization components along the *c* axis of the films.

The presence of microvoids indicates that each column may be magnetically isolated and independent. The formation of nonmagnetic oxides of Cr and Co along the column boundaries could also produce magnetically isolated grains, thus reducing the exchange interaction.[11] Maeda[12] suggested that the lower value of the magnetization saturation ($M_s$) in the Co-Ni thin films compared to bulk Co-Ni is due to the formation of nonmagnetic Co oxides along microvoids and grain boundaries. In Co-Cr thin films, Cr oxide would form, thereby increasing the value of $M_s$ in the thin films relative to the bulk value. This difference in Co-Cr films has also been suggested to be due to the segregation of Cr at grain boundaries.[4]

## CONCLUSIONS

(1) The magnetic domain morphologies are closely related to the crystallographic orientation of Co-Cr films: (a) For thin specimens, the films are randomly oriented and the corresponding magnetic domain configurations show 180° domain walls together with cross-tie walls and Bloch lines. (b) At medium thicknesses, the grains in the films are randomly oriented with a small fraction of their *c* axes perpendicular to the film plane. The magnetic domains reveal featherlike configurations as well as some white and black dots. (c) For thicker films, the magnetic structure is comprised of stripe types and white/black dots associated with the preferred orientation of *c* axis perpendicular to the film plane.

(2) It is suggested that microvoids may play an important role in the formation of in-plane magnetization components for the contrast of white/black dot type domains. These microvoids would also greatly affect other magnetic properties of the film (e.g., $M_s$).

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