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Magnetic and structural properties of CoCrTa films and multilayers with Cr

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Magnetic and structural properties of CoCrTa films and multilayers with Cr

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We report our studies of epitaxial growth of CoCrTa films on Cr underlayers and the properties of CoCrTa/Cr multilayers. The coercivity, H_c, strongly depends on Ta composition, sputtering conditions, and the thicknesses of the magnetic layer and Cr underlayer. An H_c value of 1300 Oe was obtained for a Ta composition of 2 at. %, a Cr underlayer thickness of 4000 Å, and a magnetic layer thickness of 400 Å. The x-ray data show that the high H_c occurs when crystallites of the Cr underlayer and CoCrTa layer are aligned with the Cr (200) and CoCrTa (110) planes in the film plane. Thus, the *c* axis of the CoCrTa lies essentially in the plane of the film. When the thickness of the magnetic layer increases above 1000 Å the *c* axis begins to tip out of the film plane. The basal plane lattice parameter varies roughly linearly with Ta content up to 13 at. %. For the CoCrTa/Cr multilayered films, H_c values up to 1200 Oe were obtained although the *c*-axis orientation of the magnetic layer becomes somewhat dispersed. Models for the dependence of magnetization reversal on microstructure are discussed.

I. INTRODUCTION

CoCr films have been widely studied for both perpendicular and longitudinal magnetic-recording media.[1] As longitudinal recording media, the major disadvantage of CoCr is its relatively low coercivity. Many efforts have been made to improve it through a thick Cr underlayer or additive third element (Ta, W, Nb).[2,3] With a thick enough Cr underlayer (> 3000 Å) and the addition of a few atomic percent Ta, high H_c, high signal-to-noise ratio, good frequency response, and good corrosion resistance have been obtained.[3,4] Tamai *et al.*[5] found that *c* orientation is improved and grain size increases by Ta addition. Various magnetization reversal models have been proposed for CoCr films, and this depends on details of the anisotropy, texture, thickness, etc.[6,7] We report here some results on the effects of Ta addition, present data on the angular dependence of H_c for CoCr and CoCrTa films, give thickness dependence results on CoCrTa/Cr multilayers, and discuss the results in terms of existing models.

II. SAMPLE PREPARATION AND MEASUREMENT

Films were prepared in a multiple-gun dc sputtering system. Both the CoCrTa layer and Cr underlayer were sputtered in the same pumpdown of the chamber. Samples were deposited on both copper and glass substrates which were mounted on a temperature-controlled electric furnace; the former were used for magnetization measurements and the latter for diffraction and fluorescence measurements. Substrate temperatures, T_s, were measured by a thermocouple clamped to the substrate. T_s values between 20 and 500 °C were investigated and it was found that H_c was maximized for 370 °C. This is consistent with the annealing studies of CoCr films.[8] Ta pieces were put on the top of a CoCr alloy target whose composition was 86 at. % Co and 14 at. % Cr. The base pressure was below 5×10^{-7} Torr and the argon pressure during sputtering was 30 mTorr. The thickness of the Cr underlayer was kept at 4000 Å while that of CoCrTa was 400 Å, except as otherwise mentioned. Individual layer thicknesses of CoCrTa/Cr multilayered films were controlled by programming the time that the substrate was stationary above the corresponding target. Alloy compositions were measured using a Kevex x-ray fluorescence spectrometer. It is estimated that the uncertainties in the Co and Cr compositions are about 2% and in the Ta composition, 5%. The structure was checked by x-ray diffraction. Vibrating sample magnetometry was used to measure the magnetic properties at room temperature, with a maximum field of 18 kOe.

III. RESULTS AND DISCUSSION

A. Structure

Typical x-ray diffraction data are shown in Fig. 1 for films with different thicknesses. There is only a strong CoCrTa(110) peak for the film of 400 Å besides the Cr(110) and (200) peaks. The basal plane CoCrTa(002) peak is very near the Cr(110) peak. High resolution x-ray data show a single Gaussian distribution of Cr(110) and no CoCrTa(002). This means the film is oriented with *c* axis parallel to the film plane which is preferred in longitudinal recording. For films thicker than 1000 Å and multilayered films, a weak CoCrTa(101) peak began to appear, which means the *c* axis started to tip out of the film plane, but there was still a strong *c* orientation in plane. It is interesting to note that the basal plane lattice parameter, *a*, increases roughly linearly with Ta composition up to 13 at. % (Fig. 2). Figure 2 also gives the calculated curve using a linear substitution formula and the covalent radius of Ta (1.34 Å). This may suggest that the Ta atoms go into CoCr substitutionally. The total change is about 0.5%.

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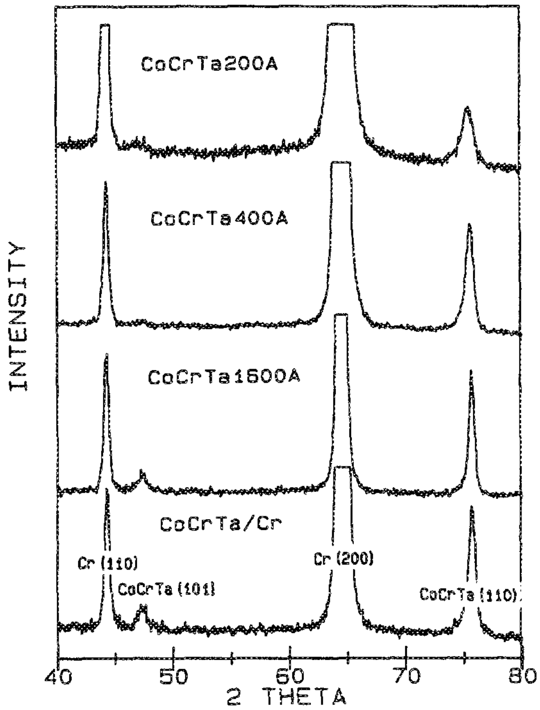

FIG. 1. X-ray diffraction patterns of CoCrTa films with thicknesses of 200, 400, and 1600 Å, and a CoCrTa/Cr multilayered film with magnetic layer thickness of 400 Å.

B. Magnetic properties

The parallel coercivity H_c (in the plane of the film) is dependent on Ta concentration, film thickness, sputtering conditions, and the thickness of the Cr underlayer.[3] Figure 2 shows the relationship between H_c and the Ta concentration. There is a peak of H_c around 2 at. % Ta where H_c is 200 Oe bigger than that of CoCr film. High Ta concentration makes H_c smaller and magnetization lower, so most of the samples were made with 2 at. % Ta. It is known that CoCr films exhibit particulate behavior. H_c depends on crystalline anisotropy, the coupling strength among the particles, and the particle size and shape which affect the magnetization

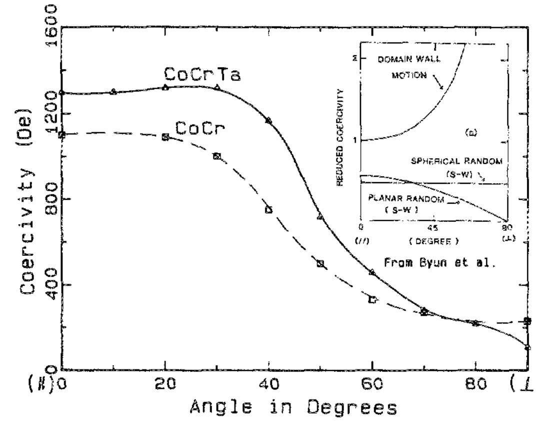

FIG. 3. H_c as a function of the angle between the applied field and the film plane for CoCrTa and CoCr films. The inset shows calculated curves with planar random SW model and the domain-wall motion model from Ref. 7.

rotation.[6] It is difficult to explain this complex Ta dependence of H_c by the formula

$$H_c = C(2K/M_s) - N_{\text{eff}} M_s,$$

where C is a constant, K is the uniaxial anisotropy, M_s is the magnetization, and N_{eff} is an effective demagnetization factor. Several magnetization-reversal mechanisms for CoCr films have been suggested, including domain-wall motion, Stoner–Wohlfarth (SW) coherent rotation, and incoherent rotation.[6,7] We have measured the angular dependence of H_c for a number of samples. Some data are shown in Fig. 3. In the case of a longitudinal magnetic recording film having an in-plane easy axis, the inset portion of Fig. 3 gives the theoretical variations of H_c as a function of the angle of the applied field with respect to the film plane, for domain-wall motion and planar random SW behavior.[7] These calculations do not include a demagnetization field which is likely to be present in our films. Both CoCr and CoCrTa curves are qualitatively similar to the SW planar random result. For films with different thicknesses, the angular dependencies of H_c are shown in Fig. 4. The two thinner films, one of 200 Å

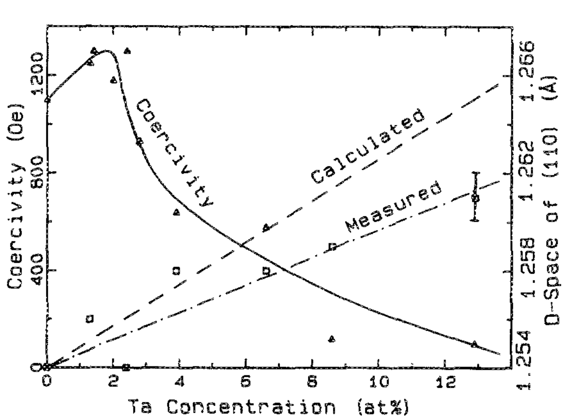

FIG. 2. Ta compositional dependence of H_c and lattice parameter, a, of the basal plane CoCrTa (110). The error bar shown is representative of that for all the lattice parameter data.

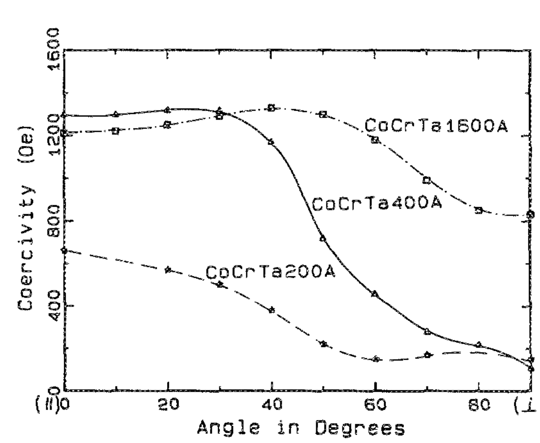

FIG. 4. H_c as a function of the angle between the applied field and the film plane for CoCrTa films with different thicknesses of 200, 400, and 1600 Å.

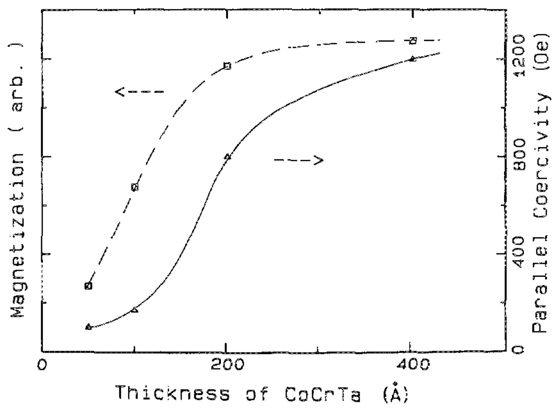

FIG. 5. CoCrTa layer thickness dependence of H_c and magnetization for CoCrTa/Cr multilayers.

thick and the other of 400 Å, behave similar as described by the planar random SW model rather than domain-wall motion. The film of 1600 Å thickness shows an obvious peak and H_c in the perpendicular direction is quite large. One possibility for H_c in the perpendicular direction being different from zero is that the *c* orientations become dispersed for thick films, which is supported by the x-ray diffraction data. Figure 5 gives the data for CoCrTa/Cr multilayered films with constant Cr thickness of 50 Å and constant Cr underlayer thickness of 4000 Å. The total magnetic layer thickness is about 1200 Å. H_c and the magnetization decrease very rapidly as the CoCrTa layer becomes less than about 200 Å. This behavior may be caused by both the smaller grain size and the strong interface atomic diffusion.

IV. SUMMARY

In Ta-doped CoCr films, a maximum H_c value of 1300 Oe was obtained under the conditions of 2 at. % Ta, 400-Å-thick CoCrTa, and 4000-Å-thick Cr underlayer at 370 °C. High H_c occurs when the Cr(200) and CoCrTa(110) are aligned in the film plane. When the thickness of the magnetic layer increases above 1000 Å, the *c* axis begins to tip out of the film plane and H_c decreases slowly. For the thinner films the angular dependence of H_c is similar to that described by the SW planar random model, while for thicker films the data may be the result of the combined effects of planar random SW rotation and domain wall motion. High H_c is obtained for a CoCrTa/Cr multilayered film when the magnetic layer is thick enough. It will be of interest to study the variation of coupling between CoCrTa layer by changing the Cr-layer thickness.

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