

The influence of tantalum content in relation to substrate temperature on magnetic and structural properties of Co–Cr–Ta thin films

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Abstract

In this study, we investigated the influence of Ta content (in $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ compositions) on magnetic and structural properties of Co–Cr–Ta perpendicular media samples grown on Si substrates at different substrate temperatures during RF-sputter deposition. In general, coercivity of $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ samples is higher than that of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ samples, whereas the perpendicular *c*-axis orientation of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ samples is better. Ta content was suggested to be in between 2 and 5 at% to give optimum magnetic and structural properties. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

In sputtered Co–Cr–Ta magnetic thin films used as media for high-density recording disks, the roles of Cr and Ta are reportedly different. In the olden days, only Cr was added to Co to increase H_c . Cr, whose content is about 10–20 at%, is observed to segregate at the grain boundaries and inside the grains [1]. The compositional separation is the main reason for the reduction of inter-granular interaction, which causes the coercivity to increase. Later, a third element was added. Ta is commonly used today. By adding Ta into CoCr, a significant in-

crease of coercivity was reported [2]. Small addition of Ta is more effective in raising H_c than further addition of Cr to Co alloy films [2]. To date, there have been a few papers interpreting the role of Ta [2–4]. In this study, we investigate the difference in properties between $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ perpendicular thin film media (hereafter called CoCrTa_2 and CoCrTa_5 , respectively) grown on Si substrates realized at different substrate temperatures, T_s . Based on these results, some interpretations for the role of Ta in relation to substrate temperature will be proposed.

2. Experiment

Co–Cr–Ta thin films were deposited onto Si substrates using Leybold Z400 RF-sputtering system. Two series of samples corresponding to two target compositions of 2 and 5 at% of Ta were produced at different T_s from room temperature to 250°C. All other sputter conditions

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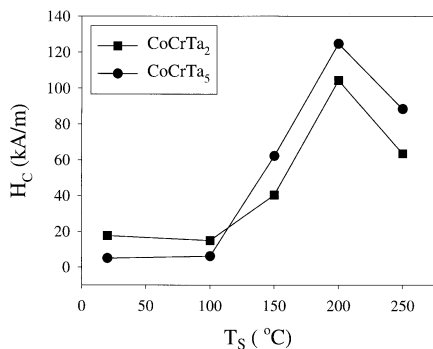


Fig. 1. Perpendicular coercivity of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ thin films at different T_S .

were kept constant. The thickness of all the films was about 100 nm. Properties of the films were investigated by vibrating sample magnetometer (VSM) and X-ray diffractometer (XRD).

3. Results and discussions

It should be mentioned that Co alloy thin films grown on bare substrate such as Si, glass, etc. naturally have HCP c -axis perpendicular to the film plane [5,6]. As a result, the film exhibits perpendicular anisotropy. Varying T_S , we found that perpendicular coercivity, H_C , of both compositions reaches a maximum at about 200°C (Fig. 1). This is somewhat consistent with the work of Fartash et al. [7]. The explanation for this behavior could be as follows: increasing T_S causes higher mobility of adatoms, which stimulates surface diffusion. Due to the compositional separation (CS) of Cr [8], with the help of Ta, the exchange coupling decreases, which is expressed apparently by an increase in perpendicular coercivity. When T_S exceeds a certain value, about 200°C in our case, the perpendicular c -axis orientation becomes worse, leading to a decrease in H_C . It will be shown later in this paper that the worsening of perpendicular c -axis orientation is confirmed by the expansion of the initial layer and the decrease of the (0 0 0 2) XRD intensity at high T_S .

In spite of the same behaviors of H_C versus T_S of CoCrTa_2 and CoCrTa_5 samples, there is a difference between their coercivities at each value of T_S . Fig. 1 reveals that H_C of CoCrTa_5 is mainly higher than that of CoCrTa_2 at T_S above 100°C. This is undoubtedly caused by the difference in compositions in which Ta is thought to play the main role. Higher content of Ta in CoCrTa_5 samples may cause higher degree of CS, which therefore finally leads to higher coercivity, especially at elevated T_S [8].

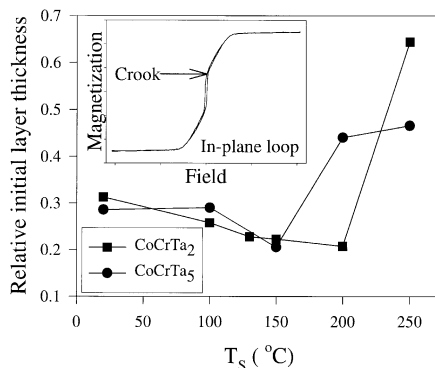


Fig. 2. Relative initial layer thickness of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ thin films at different T_S . The inset shows a typical in-plane Co–Cr–Ta hysteresis loop. The crook reveals the presence of an initial layer.

Concerning the morphology of Co-alloy thin films, one can say that films grown on Si or amorphous substrates normally have two sublayers [5,6]: (1) an initial layer, closest to the substrate, where the hexagonal c -axis are randomly distributed in the plane of the film and (2) the top layer where the c -axis are well oriented perpendicular to the film plane. The relative thickness of the initial layer, t_{relative} , can be estimated approximately from the magnetization value of the crook of the in-plane hysteresis loop (see the inset of Fig. 2), given by: $t_{\text{relative}} = t_{\text{ini}}/t_{\text{total}} = M_{\text{ini}}/M_S$, where t_{ini} and t_{total} are thicknesses of the initial layer and the total film, respectively; M_{ini} and M_S are magnetization of the crook and of the saturation state, respectively. We have derived experimentally the above formula by measuring in-plane loops of samples of different thicknesses. The smaller the initial layer thickness, the better the perpendicular c -axis orientation of the sample is. Fig. 2 shows that t_{relative} of the two compositions decreases slightly when T_S increases from room temperature to about 150–200°C and then drastically increases at higher T_S . Minima of these curves indicate that the best perpendicular c -axis orientation is formed at T_S of about 150–200°C.

AFM surface images were taken from four most interesting samples: CoCrTa_2 and CoCrTa_5 at RT and 200°C (Fig. 3). Round caps of crystal grains are seen clearly, based on which their sizes could be estimated. We have analyzed scan lines of the images to estimate the average grain sizes of the samples. Grain sizes of CoCrTa_2 samples are slightly larger than those of CoCrTa_5 in both RT and 200°C cases. This is consistent with the results of some other authors, for instance [9]. In our case, when T_S increases from RT to 200°C, grain sizes of both compositions increase about double.

Crystalline orientation of the samples were examined by XRD. The XRD spectra show that only (0 0 0 2) peaks

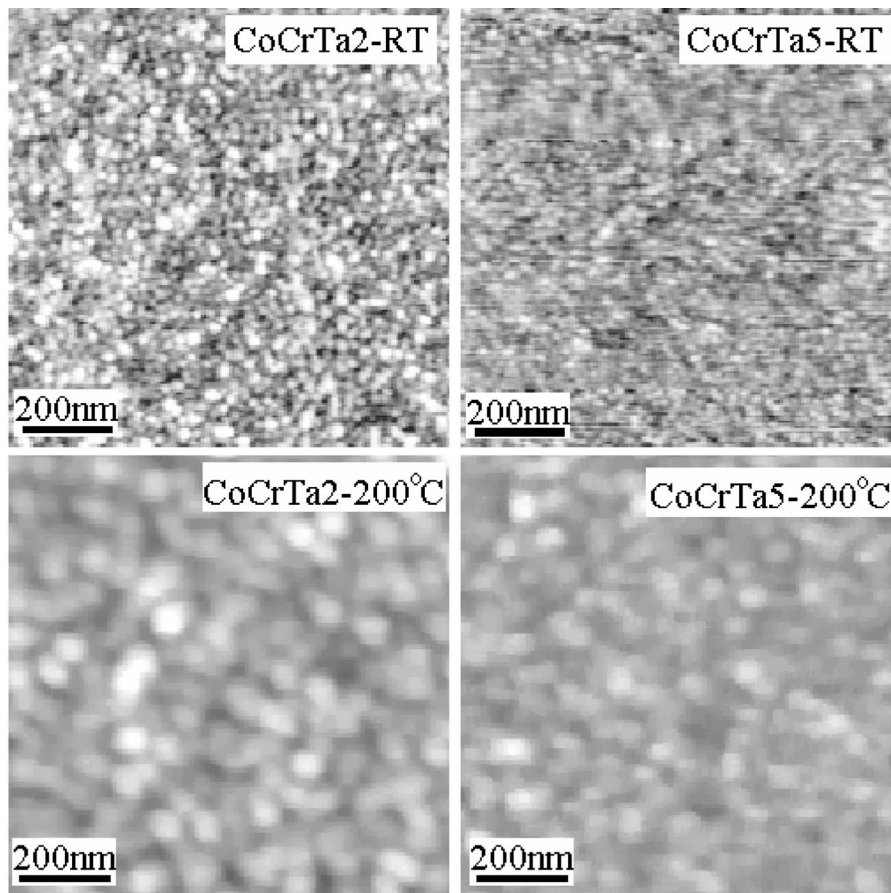


Fig. 3. AFM images show that the average grain size of samples CoCrTa₂ increases from 43 to 90 nm and of samples CoCrTa₅ increases from 35 to 75 nm when T_s is increased from RT to 200°C.

appear at all samples. This means that c -axis of the samples are mainly perpendicular to the film plane. Comparing the heights of these peaks one can see that the perpendicular c -axis orientation of samples of the two compositions seems to be the best at T_s of about 100–150°C (Fig. 4). At T_s higher than about 150–200°C, (0 0 0 2) peak intensity of both compositions drops drastically. The behaviors of c -axis orientation versus T_s of the samples can be understood if we consider the role of the mobility of adatoms. Higher T_s and therefore higher mobility of adatoms enables them to reach the equilibrium state more easily at which the growing crystal has the lowest potential energy. The crystal is therefore in a better order, or in other words, it has a better crystalline orientation. This argument accounts for the increase of (0 0 0 2) intensity which is the most favorable growth direction (Fig. 4) and the decrease of initial layer thickness with increasing T_s up to about 150°C (Fig. 2). When T_s is further increased, the rate of defect formation increases, which hinders the growing crystals from being well crystallized [10,11].

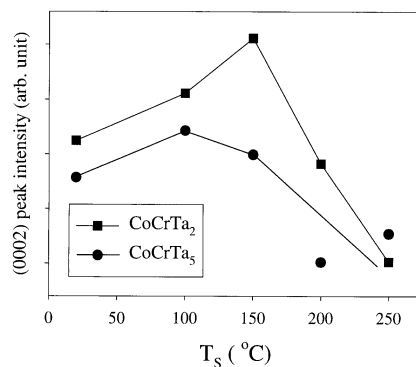


Fig. 4. (0 0 0 2) XRD peak intensity of Co₈₆Cr₁₂Ta₂ and Co₈₂Cr₁₃Ta₅ thin films at different T_s .

Therefore, at excessively high T_s , the c -axis orientation becomes worse, resulting in the drop of (0 0 0 2) peak intensity of both samples at T_s higher than about 150–200°C (Fig. 4). The above argument also explains the

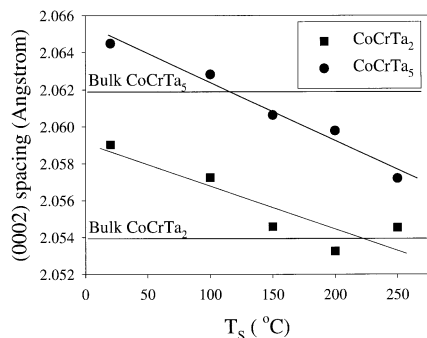


Fig. 5. (0 0 0 2) spacing of $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$ thin films and that of corresponding target materials versus T_s .

expansion of the initial layer when T_s is higher than 200°C (Fig. 2)

In addition, Fig. 4 reveals that CoCrTa_2 samples have better c -axis orientation than CoCrTa_5 . The addition of alien elements to a crystal always influences its orientation. In our case, this is the addition of Cr and Ta to the HCP Co crystal. In thin films made of Co-alloy material consisting of sufficiently small percentage of Cr and Ta, HCP structure is still preserved. The better c -axis orientation of CoCrTa_2 samples compared to that of CoCrTa_5 samples (Fig. 4) could be attributed to the smaller amount of Ta and Cr in $\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ samples than that in $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$.

Besides the worsening of crystalline orientation, the addition of Ta and Cr may expand the lattice constants due to the strain caused by lattice inclusion. Lattice constant calculations of the bulk samples (derived from the peak position of the XRD spectra of the target materials) show that (0 0 0 2) spacing of the material having 18 at% of Cr and Ta (in CoCrTa_5) is larger than that of material having 14 at% of Cr and Ta (in CoCrTa_2). These spacing values of bulk are marked as the lines “Bulk” in Fig. 5. The (0 0 0 2) spacing of thin films of both compositions was found to decrease with increasing T_s . Similar to the bulk case, spacing values of CoCrTa_5 films are larger than those of CoCrTa_2 films at all temperatures. It is obvious that the peak (0 0 0 2) comes from the HCP structure of the Co-rich regions in the film. When T_s is increased, as discussed above, CS between Co and Cr is enhanced. As a result, the Co-rich regions become richer and contain less Cr and Ta atoms, causing the average (0 0 0 2) spacing measured on the whole sample to contract. This can account for the decrease of the

(0 0 0 2) spacing with increasing T_s (Fig. 5). Another possible reason for this decrease is that when growing at high T_s , the lattice is more relaxed while being formed, therefore the lattice strain and thus the lattice spacing is reduced.

4. Conclusion

Magnetic and structural properties of perpendicular media samples made of two different compositions ($\text{Co}_{86}\text{Cr}_{12}\text{Ta}_2$ and $\text{Co}_{82}\text{Cr}_{13}\text{Ta}_5$) deposited on Si substrates and at different substrate temperatures from room temperature to 250°C have been studied and interpreted. It was found that perpendicular H_C of the two compositions reaches maximum at T_s of about 200°C. Generally, H_C of CoCrTa_5 is higher than that of CoCrTa_2 . Contrary to the behavior of H_C , c -axis orientation of CoCrTa_2 samples was found to be better than that of CoCrTa_5 samples. c -axis orientation was observed to be the best at T_s of about 100–150°C. When T_s increases, lattice constant c of the samples contracts. Moreover, lattice constant c of the CoCrTa_5 samples is always larger than that of CoCrTa_2 samples. To get an optimum material, suitable for making magnetic recording media, we suggest that Ta content should be in between 2–5 at% to compromise the two contrary trends as mentioned above and T_s should be about 150–200°C.

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