Perpendicular Co–Cr Magnetic Recording Media Prepared by Sputtering Using ECR Microwave Plasma

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Abstract -- **Perpendicular Co–Cr media were deposited on polyimide substrates by sputtering using an electron–cyclotron–resonance microwave plasma in an Ar sputtering gas pressure ranging from 3×10^{-2} to 8×10^{-2} Pa at a target to substrate distance from 170 to 230 mm. The accelerating voltage of the ions which bombard the media surface during deposition drastically affects the crystallographic and magnetic properties of Co–Cr films. Co–Cr media (50 nm in thickness) with good preferred crystal orientation ($\Delta\theta_{50}$ less than 5 degrees), high perpendicular magnetic anisotropy (H_k higher than 4 kOe), high perpendicular coercivity ($H_{c\perp}$ over 1400 Oe) and no initial layer were successfully deposited when the ion accelerating voltage was reduced less than about 20 V.**

I. INTRODUCTION

In order to achieve ultra–high density recording, perpendicular magnetic recording medium is required to possess a large perpendicular magnetic anisotropy, a high perpendicular coercivity ($H_{c\perp}$), compositionally well separated microstructure, and small grain size. However, an initial layer which shows poor crystal orientation, low magnetic anisotropy field (H_k), low $H_{c\perp}$ and poor compositional separation exists in Co–Cr films deposited by conventional or magnetron diode sputtering methods.

Sputtering deposition using an electron–cyclotron–resonance (ECR) microwave plasma has advantages over the diode sputtering, *i.e.* generation of a highly ionized dense plasma even at low Ar gas pressure, and controllable ion bombardment of the substrate [1–3]. The former enables high energy with a long mean free path in adatoms. The latter is effective in enhancing the atom migration on the film surface. The crystallographic and magnetic properties and compositional microstructure of Co–Cr films can be easily controlled using ECR sputtering [4, 5].

In this study, perpendicular Co–Cr magnetic recording media which satisfy the above described requirements for high density recording was fabricated using ECR sputtering and controlling ion bombardment of the media.

II. EXPERIMENTS

Co–Cr films were deposited by ECR sputtering on polyimide substrates. The schematic illustration of cross sectional view of the ECR sputtering apparatus is shown in Figure 1. The 875 Gauss magnetic field and 2.45 GHz microwave satisfy the ECR condition and a dense plasma is generated in the discharge chamber. The base pressure of this apparatus was less than 5×10^{-5} Pa. A negative voltage of –100 V was applied to a cylindrical $Co_{80}Cr_{20}$ wt% target whose inner diameter and length were 100 mm and 40 mm, respectively. The input microwave power was 300 W and the substrate temperature was kept at 100 °C during film deposition.

Since electrons have much greater mobility than ions, they stream out along the dispersing magnetic flux lines from the discharge chamber to the substrate holder with much faster cyclotron motion than ions. The ions in the plasma are accelerated toward the substrate holder by the electric field caused by the electrons diffusion from the plasma [2]. It was expected that ion bombardment of the substrate would affect the atom migration and the properties of deposited Co–Cr films. The Ar sputtering gas pressure, P_{Ar}, and the target–to–substrate distance, D_{t-s}, are the parameters which can change the plasma condition and the intensity of the ion bombardment.

In this experiment, P_{Ar} was varied from 3×10^{-2} to 9×10^{-2} Pa and D_{T-S} was varied from 170 to 230 mm. The deposition rate in our experiment was varied from 1.5 to 7.2 nm/min according to P_{Ar} and D_{T-S}. The uniformity of the deposited film thickness was less than ±10% over the substrate with a diameter of 65 mm. The deposited Co–CR films had compressive stress.

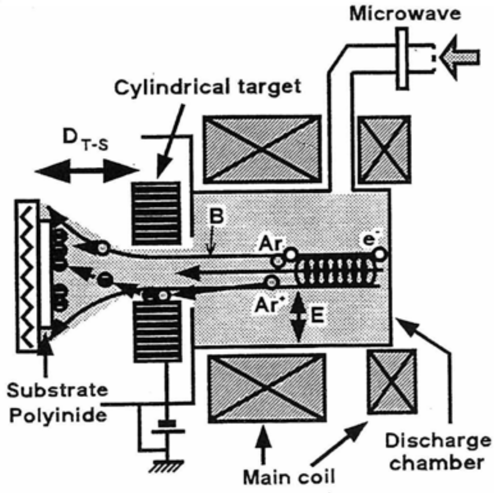

Fig. 1. Cross sectional view of ECR plasma sputtering deposition apparatus.

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The crystallographic and magnetic properties were measured by an X-ray diffractometer and a vibrating sample magnetometer, respectively. To clarify compositional separation, Spin-echo ^{59}Co nuclear-magnetic-resonance (NMR) was performed at 4.2 K. A scanning electron microscope (SEM) was used to observe the surface morphology. A single-probe diagnosis was performed to investigate the plasma parameters. From the V-I characteristics, the plasma potential, V_s, and a floating potential of the substrate, V_f, were estimated because the ions are accelerated according to the voltage difference between V_s and V_f, *i.e.* V_s-V_f.

III. RESULTS AND DISCUSSION

The influence of the target-to-substrate distance, D_{T-S}, was studied at an Ar gas pressure of 8×10^{-2} Pa. The D_{T-S} was varied from 170 to 230mm. Figure 2 shows M-H loops of 90 nm thick Co-Cr films deposited at a D_{T-S} of (a) 170 mm, and (b) 230mm. Significant differences are seen in these two loops, *i.e.*, an incredible change of the saturation magnetization (M_s) and the magnetization jump (M_{sj}) in the in-plane M-H loop occurs in the weak applied magnetic field region. The change of these two properties occurs gradually in accordance with D_{T-S}.

Measurement of the NMR frequency spectra for these Co-Cr films was performed. The NMR signal amplitude centered at around 214 MHz corresponds to a Co-riched component which is induced by compositional separation. It was found that the compositional separation for the Co-Cr film deposited at D_{T-S} of 170 mm is more distinctive compared with a film deposited at D_{T-S} of 230 mm. It is concluded that the large M_s for Co-Cr film deposited at D_{T-S} of 170 mm originates from the highly separated composition.

Figure 3 shows the angle dependence of the coercivity. The angle was measured from normal to the film to an applied magnetic field. In the figure, the open and solid symbols are for the Co-Cr films deposited at a D_{T-S} of 170 mm and 230mm, respectively. The broken line is the theoretical plots corresponding to wall motion [7]. While the Co-Cr film deposited at a D_{T-S} of 170 mm shows a wall motion like behavior, the Co-Cr film deposited at a D_{T-S} of 230 mm shows a magnetization rotation behavior. From the SEM observation, it was found that the grain size for the 90 nm thick Co-Cr film deposited at a D_{T-S} of 170 mm was 80–100 nm, which is about three times larger than that deposited at a D_{T-S} of 230 mm. It is surmised that the wall motion behavior occurs in excessively enlarged grains.

The results of plasma diagnosis show that the ion accelerating voltage, V_s-V_f, decreases from 23 V to 17 V with increasing target-to-substrate distance from 170 mm to 230 mm.

It was also found that not only D_{T-S} but also Ar gas pressure, P_{Ar}, are the factors which affect V_s-V_f. V_s-V_f decreases from 47 V to 22 V with increasing P_{Ar} from 3×10^{-2} to 9×10^{-2} Pa. Accordingly, the Co(002) X-ray diffraction peak intensity increased and the half-value-width of the rocking curve, $\Delta\theta_{50}$, decreased. This result implies that the Co-Cr films with high perpendicular orientation and good crystallinity are achieved at high Ar gas pressure. H_k and $H_{c\perp}$ also increased with increasing P_{Ar}, and showed maximum value at a relatively high P_{Ar} of 8×10^{-2} Pa.

As described above, it was found the crystal growth and magnetic properties are affected significantly by the ion accelerating voltage, V_s-V_f. To prove the effect of V_s-V_f, the parameter values of the 90 nm thick Co-Cr films are replotted against V_s-V_f as shown in figure 4,5,6.

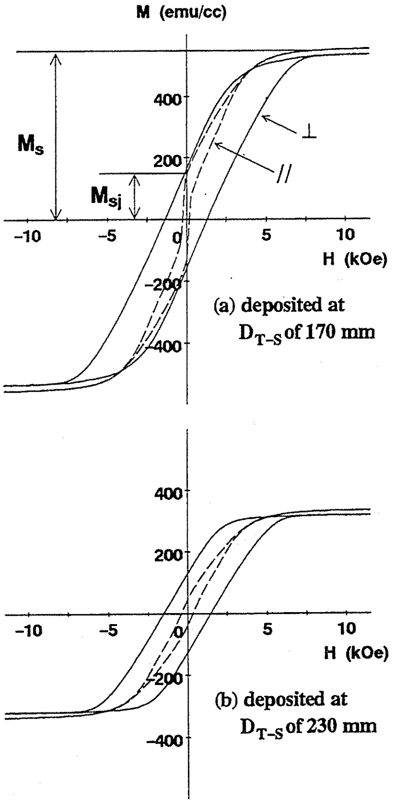

Fig. 2. M-H hysteresis loops of Co-Cr films in perpendicular direction (solid line) and in-plane direction (dashed line).

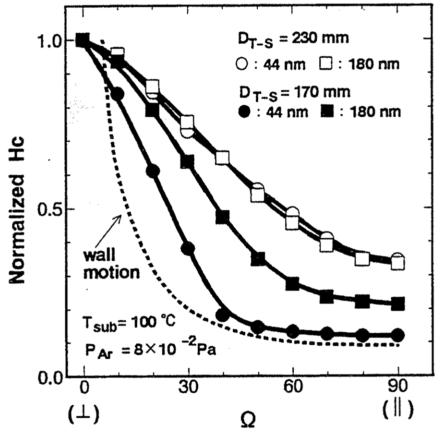

Fig. 3. Angular dependence of coercivity for Co-Cr films deposited at D_{T-S} of 170 mm (solid symbols) and 230 mm (open symbols). Circles and squares are for Co-Cr with thickness of 44 nm and 180 nm, respectively.

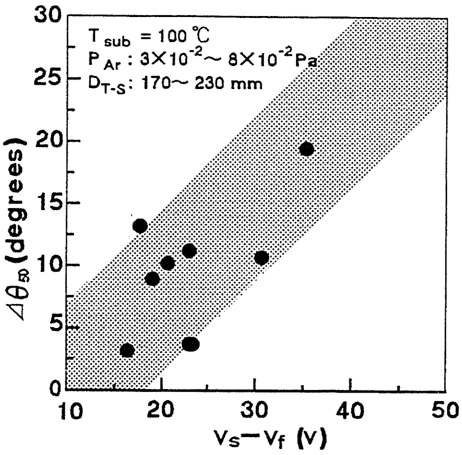

Fig. 4. Ion accelerating voltage, V_s–V_f, dependence of half-value-width of the rocking curve, $\Delta\theta_{50}$.

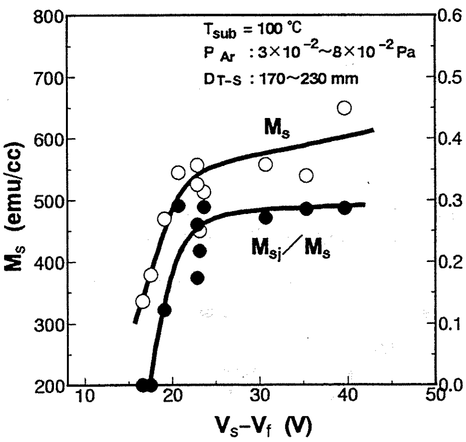

Fig. 5. V_s–V_f dependence of saturation magnetization, M_s, and magnetization jump, M_{sj}.

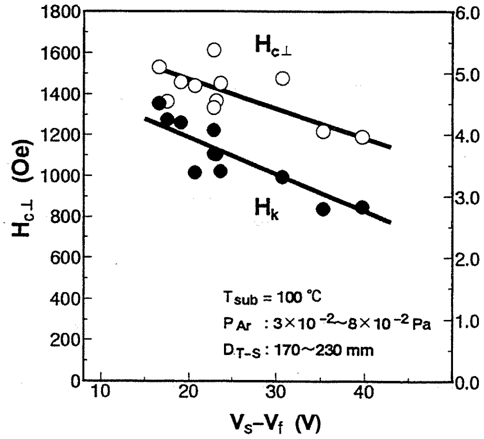

Fig. 6. V_s–V_f dependence of magnetic anisotropy field, H_k, and perpendicular coercivity, $H_{c\perp}$.

The change of V_s–V_f was achieved by changing P_{Ar} and D_{T-S}. Therefore the data in these figures has the influence of P_{Ar} as well as V_s–V_f.

In figure 4, the $\Delta\theta_{50}$ decreases with decreasing V_s–V_f, showing the improvement of Co c–axis perpendicular orientation. In figure 5, as the V_s–V_f decreased less than about 20 V, the saturation magnetization, M_s, and the ratio of magnetization jump and M_s, M_{sj}/M_s, decrease suggesting less compositional separation and the disappearance of initial layer which induced wall motion behavior. Figure 6 shows the increase of H_k and $H_{c\perp}$ with decreasing V_s–V_f.

From these results, it is concluded that excessive ion accelerating voltage over about 20 V is harmful from view point of crystal orientation, magnetic anisotropy and magnetization behavior. When V_s–V_f is less than 20 V, *e.g.* P_{Ar} of 8×10^{-2} Pa and D_{T-S} of 230 mm, Co–Cr films with good perpendicular crystal orientation (small $\Delta\theta_{50}$ less than 5 degrees), $H_{c\perp}$ higher than 1400 Oe, and H_k higher than 4 kOe, were obtained in spite of a very small thickness of 50 nm.

IV. CONCLUSION

In ECR sputtering, it was found that the accelerating voltage of ions which bombard the Co–Cr film surface during deposition drastically affects the crystallographic and magnetic properties of Co–Cr films. The 50 nm thick Co–Cr perpendicular media with a good preferred crystal orientation ($\Delta\theta_{50}$ less than 5 degrees), high perpendicular magnetic anisotropy (H_k higher than 4kOe), high perpendicular coercivity ($H_{c\perp}$ over 1400 Oe) and no initial layer were successfully deposited when the ion accelerating voltage is less than about 20 V.

Thus, it is concluded that ECR sputtering is a suitable method for depositing high–coercivity Co–Cr films for preparing ultra–high density recording.

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