Magnetic Recording Media II — Rajiv Ranjan, Chairman

Co–Cr films prepared by sputtering using electron cyclotron resonance microwave plasma

S. Yamamoto, K. Sato, H. Kurisu, and M. Matsuura
Faculty of Engineering, Yamamaguchi University, Tokiwadai, Ube 755, Japan

The sputtering deposition using an electron cyclotron resonance (ECR) microwave plasma was tried to use in the fabrication of the Co–Cr perpendicular magnetic recording media. As the Ar sputtering gas pressure increased from 4×10^{-2} to 8×10^{-2} Pa, 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 Co–Cr films with high perpendicular orientation and good crystallinity are achieved at high Ar gas pressure. The Co–Cr films deposited at a target to substrate distance of 230 mm had a good preferred crystal orientation ($\Delta\theta_{50}$ less than 4°), high perpendicular magnetic anisotropy (H_k higher than 4 kOe), and high perpendicular coercivity over 1400 Oe even though the Co–Cr thickness is as small as about 50 nm, and no underlayers were introduced. Thus, the ECR sputtering has high potential in the deposition of the Co–Cr films for ultrahigh density recording media. © *1996 American Institute of Physics.* [S0021-8979(96)14608-3]

I. INTRODUCTION

An extremely high density recording exceeding 500 kFRPI has already been achieved in perpendicular magnetic recording using a Co–Cr perpendicular media.[1–3] It has been proven that such a high recording resolution of Co–Cr films is originated from the compositional separation into Co- and Cr-rich regions in the size range of a few nanometers.[4–6] In order to improve the recording resolution further, it is necessary to develop the film deposition technology by which the compositional separation is controlled more precisely.

Recently, an electron cyclotron resonance (ECR) microwave plasma has been developed, and used in the thin-film deposition processing. Compared with the conventional diode sputtering, the ECR sputtering features: (1) generation of dense plasma even at Ar gas pressure as low as 10^{-2} Pa, (2) generation of highly ionized plasma, and its controllable irradiation to the substrate.[7,8]

Up to now, there have been only a few attempts concerning the application of the ECR sputtering to the Co–Cr film deposition.[9] Hirono and co-workers[10] have succeeded in reducing the grain size of Co–Cr films with a compositionally separated microstructure, while maintaining high grade magnetic properties by using the ECR sputtering method.

In this study, we have tried the deposition of the Co–Cr films for high density perpendicular magnetic recording media by using the ECR sputtering, focusing on the effects of Ar gas pressure, and substrate location on the crystallographic and magnetic properties.

II. EXPERIMENT

The ECR plasma sputtering deposition apparatus used in this experiment is shown in Fig. 1. The discharge chamber was designed as a TE_{113} resonance cavity. The main coils are arranged around the periphery of the discharge chamber. The magnetic field of 875 G satisfying the ECR condition is generated in this chamber by these coils. The 2.45 GHz microwave was introduced into the chamber perpendicularly to the chamber sidewall through the waveguide. This waveguide/discharge chamber geometry enables the continuous deposition of the conductive films. Under the ECR condition, high density plasma is generated at Ar gas pressure as low as 10^{-2} Pa. In this discharge chamber/substrate configuration shown in this figure, the plasma stream occurs from the discharge chamber toward the substrate along the magnetic lines of force. A cylindrical target to which the negative voltage, V_a, of -100 V was applied, was placed at the end of the discharge chamber. The composition of the target was $Co_{80}Cr_{20}$ wt %. The input microwave power was 300 W. The Co–Cr films with a thickness from 0.025 to 0.35 μm were deposited on the 30 μm thick polyimide substrate at the substrate temperature T_{sub}, of 100° in centigrade. The Ar gas pressure was varied in the range from 3×10^{-2} to 9×10^{-2}

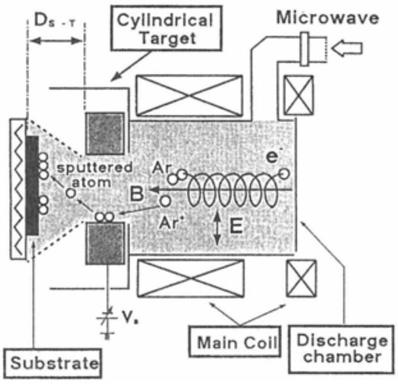

FIG. 1. Cross-sectional view of ECR plasma sputtering deposition apparatus.

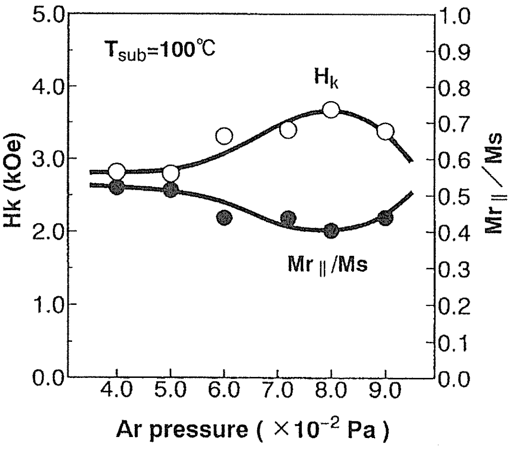

FIG. 2. Ar gas pressure dependence of perpendicular magnetic anisotopy field H_k, and in-plane squareness $M_{r_{\|}}/M_s$.

Pa. The substrate-to-target distance D_{s-t} was varied from 170 to 230 mm. The plasma with the electron temperature from 5 to 12 eV, and the electron density from 0.6×10^9 to 1.6×10^9 cm^{-3}, was achieved in the above described experimental condition. The deposition rate in our experiments varies from 1.5 to 7.2 nm/min according to Ar gas pressure and target to substrate distance.

The crystallographic and magnetic properties were measured using an x-ray diffractometer and a vibrating sample magnetometer, respectively.

III. RESULTS AND DISCUSSION

At first, the Ar sputtering gas pressure dependence of crystallographic and magnetic properties was investigated for a substrate-to-target distance D_{s-t} of 170 mm. As the Ar gas pressure increased from 4×10^{-2} to 8×10^{-2} Pa, the Co(002) x-ray peak intensity drastically increased, and the half-value width of the rocking curve $\Delta\theta_{50}$, became a half, showing that the crystallinity and perpendicular orientation of Co c axis has been improved. The Ar gas pressure dependence of perpendicular magnetic anisotropy field H_k, and in-plane squareness, $M_{r_{\|}}/M_s$, are shown in Fig. 2. The maximum H_k and the minimum $M_{r_{\|}}/M_s$ were obtained at an Ar gas pressure of 8×10^{-2} Pa. The maximum of perpendicular coercivity $H_{c_\perp}$, and the minimum of in-plane coercivity $H_{c_{\|}}$, were also achieved at Ar gas pressure of 8×10^{-2} Pa. These results show that the highly perpendicularly oriented Co–Cr films with high perpendicular orientation and magnetic properties desired for high density perpendicular recording have been prepared at relatively high Ar gas pressure of 8×10^{-2} Pa using ECR sputtering.

To clarify this phenomenon, the probe diagnosis for the ECR plasma was performed. From the $V-I$ characteristics, it was found that both the floating potential of the substrate V_f, and the plasma potential V_s, decrease with increasing Ar gas pressure. Some of the Ar ions in the plasma are accelerated by the voltage difference between V_s and V_f, i.e., V_s-V_f, and move along the magnetic lines of force, and finally bombard the substrate. It is surmised that the excessive amount of Ar ion bombardment to the substrate at low Ar gas pressure disturbs the crystal orientation, and consequently, the H_k and $H_{c_\perp}$ are low.

In the next step, optimization of the substrate-to-target distance D_{s-t} was performed at an Ar gas pressure of 8×10^{-2} Pa. The D_{s-t} was varied from 170 to 230 mm. The Co–Cr films with half-value width of the rocking curve $\Delta\theta_{50}$, less than 4° were obtained around D_{s-t} of 170 and 230 mm. However, the in-plane M–H hysteresis loops of the films are different in each other as shown in Fig. 3. The in-plane M–H loop for the film deposited at D_{s-t} of 170 mm

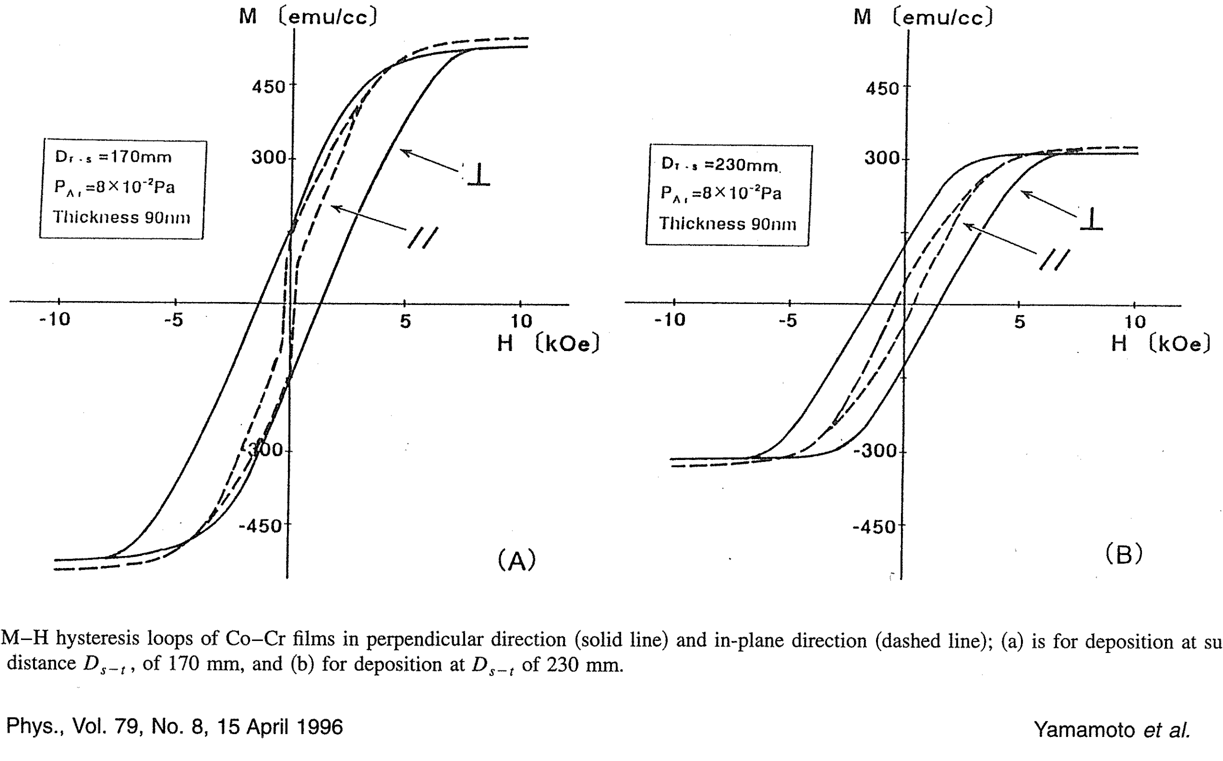

FIG. 3. M–H hysteresis loops of Co–Cr films in perpendicular direction (solid line) and in-plane direction (dashed line); (a) is for deposition at substrate-to-target distance D_{s-t}, of 170 mm, and (b) for deposition at D_{s-t} of 230 mm.

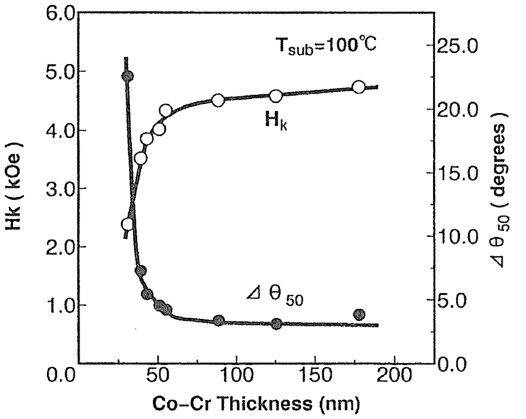

FIG. 4. Thickness dependence of $\Delta\theta_{50}$ and H_k of Co–Cr films deposited at optimal condition, i.e., D_{s-t} of 230 mm and Ar gas pressure of 8×10^{-2} Pa.

has jump at low magnetic field as shown by the broken line. This jump is caused by the existence of a low coercivity initial layer in which the Co c axis does not align in perpendicular direction.[11,12] In the conventional diode sputtering methods, it is difficult to eliminate this nonoriented initial layer unless the underlayer such as Ti and Cr are introduced. On the other hand, for the films deposited by the ECR sputtering at D_{s-t} of 230 mm, no jumps are observed as shown by the solid line because the Ar ion bombardment during deposition is so small that the crystallinity and crystal orientation are not disturbed.

The thickness dependence of the $\Delta\theta_{50}$ and H_k is shown in Fig. 4. These Co–Cr films are deposited at D_{s-t} of 230 mm and at an Ar gas pressure of 8×10^{-2} Pa. As the Co–Cr thickness increases from 27 to 50 nm, the $\Delta\theta_{50}$ drastically decreased and reached a near plateau value of around 3° at a thickness of 90 nm. H_k increased sharply in the thickness range 27 to 50 nm and showed a relatively small increase about 90 nm. Surprisingly, very small $\Delta\theta_{50}$ of 3.1° was obtained at a thickness of 90 nm.

The thickness dependence of the perpendicular coercivity, $H_{c_\perp}$, is shown in Fig. 5. The open circles are for the films deposited by the ECR sputtering condition tuned at D_{s-t} of 230 mm and at Ar gas pressure of 8×10^{-2} Pa. For comparison, the data for the Co–Cr films prepared by magnetron diode sputtering at the optimal sputtering condition, i.e., Ar gas pressure of 5×10^{-1} Pa, are plotted by solid circles. In both sputtering depositions, the same polyimide substrate was used, and the underlayers which play a role to control the Co crystal orientation were not introduced. Although the films prepared by conventional magnetron sputtering needs at least 100 nm thickness to achieve perpendicular coercivity higher than 1000 Oe, in the ECR sputtering, only 50 nm thickness is enough to realize 1400 Oe coercivity. This is considered by the authors as the specific advantage of the ECR sputtering over the diode sputtering for the Co–Cr films for perpendicular recording.

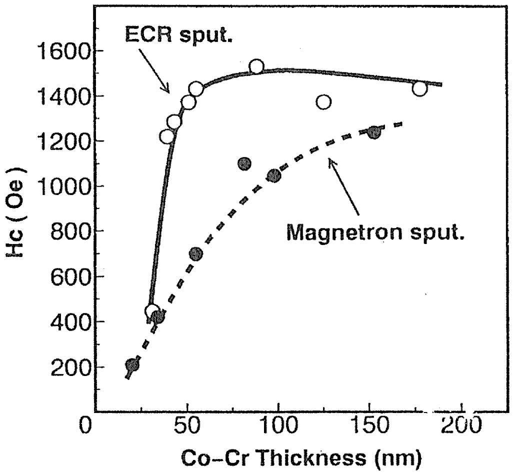

FIG. 5. Perpendicular coercivity $H_{c_\perp}$, as a function of Co–Cr film thickness. Open circles are for ECR sputtering deposition, and solid circles are for magnetron diode sputtering deposition.

IV. CONCLUSION

The ECR sputtering deposition technique was used in the fabrication of the Co–Cr perpendicular magnetic recording media. The Co–Cr films with superior crystallinity, perpendicular orientation, and magnetic properties desirable for high density recording were achieved at a high Ar gas pressure of 8×10^{-2} Pa. The Co–Cr films deposited at a target to a substrate distance of 230 mm showed good crystal orientation ($\Delta\theta_{50}$ less than 4°) high perpendicular magnetic anisotropy (H_k higher than 4 kOe), and high perpendicular coercivity over 1400 Oe even when the Co–Cr thickness was as small as about 50 nm. We conclude that the ECR sputtering has high potential in the deposition of the Co–Cr films for ultrahigh density recording media.

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