Co-Cr RECORDING FILMS WITH PERPENDICULAR MAGNETIC ANISOTROPY

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ABSTRACT

For a new perpendicular magnetic recording system, a Co-Cr recording film with perpendicular anisotropy has been developed by an RF sputtering. The Co-Cr films are found to show some suitable properties for high density recording such as perpendicular anisotropy, a rectangular M-H loop, and fine grain structure. An extremely high recording density of 100,000 bits/inch was realized by using the Co-Cr film. The crystal and microscopic structure of the films are also discussed, and the perpendicular anisotropy of the Co-Cr films is mainly originated from the uniaxial magneto-crystalline anisotropy.

INTRODUCTION

We have recently proposed a new perpendicular magnetic recording system, and confirmed that a flat response curve of the output voltage can be realized in the high density region.[1] This system must consist of a recording head which produces a pure perpendicular magnetic field, and a medium which has an easy axis of magnetization perpendicular to the medium plane.

For the perpendicular recording medium, it has been pointed out[1] that a high saturation magnetization and a high coercive force as well as perpendicular anisotropy are necessary to obtain high output voltage and high recording resolution. Furthermore, the mechanical and the chemical stability of the medium and the productivity are also desired.

Taking into account these properties, the authors have prepared the Co-Cr perpendicular anisotropy film.[2]

Cobalt has a large magneto-crystalline uniaxial anisotropy energy, hence it can be used to develop the perpendicular anisotropy film. The films must have the anisotropy field H_k surpassing the maximum demagnetizing field $4\pi Ms$. Therefore, it is necessary to add other metals to reduce Ms, keeping the c-axis oriented perpendicularly to the film surface. We have chosen chromium as an additional metal, because Co-Cr alloy has a relatively stable hcp phase at a lower content of Cr, and at the same time, the saturation magnetization is expected to decrease when a small amount of Cr is added.

To prepare the film of Co-Cr alloy, RF sputtering was used, since it is suitable to prepare the films of a high melting point Co-Cr alloy, and superior to the other methods for the adhesion of the deposited magnetic layer to the substrate, and also for reproducibility. In addition, it is also convenient that Cr has the same sputtering yield as Co in the RF sputtering process.

It was found that the RF sputtered Co-Cr film has a large perpendicular magnetic anisotropy, a high coercive force, and also other favorable properties for the high density magnetic recording.

In this paper, the magnetic properties of the Co-Cr films, and the origin of the perpendicular anisotropy of the films are discussed.

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UNIAXIAL PERPENDICULAR ANISOTROPY OF THE Co-Cr FILMS

Co and Cr were co-deposited by an RF sputtering on the Polyimide film, from the cobalt target on which a number of electrolytic Cr pellets were placed at regular intervals in a grid pattern. The composition of the film was controlled by changing the surface area of the Cr pellets. An alloy target of Co-Cr was also successfully used for RF sputtering.

The RF sputtering was done in an Argon gas atmosphere after baking the vacuum chamber and the substrate holder at about 300°C. The back ground pressure reaches below 2×10^{-7} Torr.

The thickness of the film was controlled by the sputtering time. The deposition rate is mainly influenced by the RF power density and the Argon pressure. In this study, we have chosen such a sputtering condition as deposition rate of 0.33 μm/1hr., the Argon pressure is 0.01 Torr and the RF power density is 0.44 watt/cm^2.

The most influential factor on the magnetic properties was found to be Cr content of the film. The saturation magnetization Ms of the film decreases almost linearly with an increase of the Cr content, as shown in Fig.1. The change in Ms with the Cr content agrees with that of bulk Co-Cr[3], which is depicted by a dotted line in Fig.1.

Fig.2 shows the M-H loops of the films of different Cr contents, measured parallel (//) and perpendicular (⊥) to the film surface. The measurements were taken of disk samples (5mmϕ) of a 0.8 μm-thick film. In the figure, no compensation for demagnetization is made for the perpendicular M-H loops. Therefore, it is supposed that an intrinsic M-H loop (⊥), when compensated for the demagnetization, has a rectangular shape with an almost infinite slope. On the contrary, the M-H loop (//) is isotropic in the film plane and has a very small hysteresis loss.

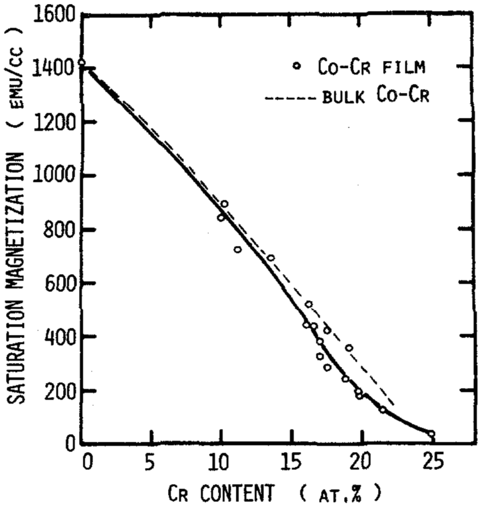

Fig.1 Ms vs. Cr content for Co-Cr film.

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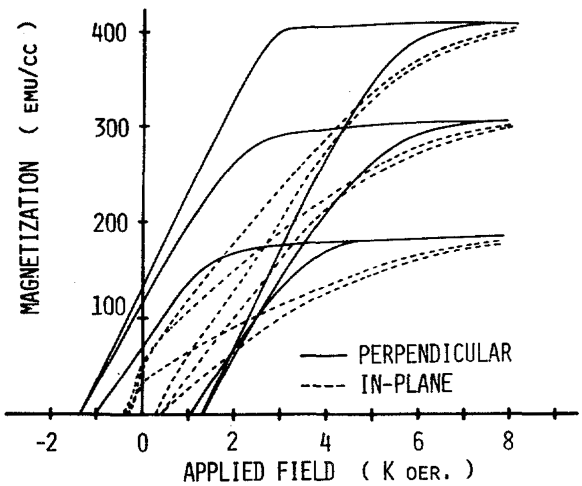

Fig.2 M-H loops of Co-Cr films.

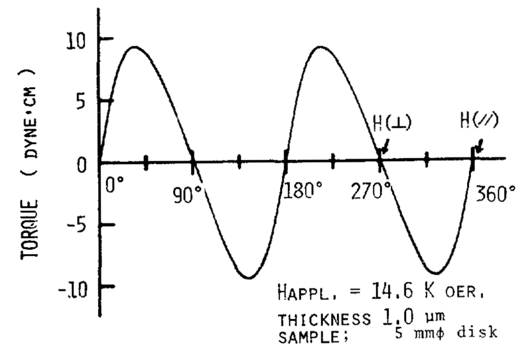

Fig.3 Torque curve of Co-Cr film.

From the result, it is safe to conclude that the Co-Cr film has an easy axis of magnetization in the normal of the film plane and a hard axis lying in the film plane.

In order to confirm the anisotropy, we have measured the torque curve of the Co-Cr film of Ms = 300 emu/cc in the normal plane of the disk sample. The measured torque curve, as shown in Fig.3, is a slightly distorted sine wave with a period of 180°. The polarity of the curve, together with its period, suggests that the film has the uniaxial anisotropy whose easy axis lies along the film normal.

Since the torque curve shows uniaxial anisotropy, the anisotropy energy Ku can be evaluated, by using an extrapolation method[4], from the relation between the torque and the applied magnetic field strength. In the method, Ku is expressed as follows, with the shape anisotropy energy $2\pi Ms^2$ for the circular disk sample,

$$Ku = K_{\perp} - 2\pi Ms^2 \quad (1)$$

where, $K_{\perp}$ is the intrinsic perpendicular anisotropy energy.

Fig.4 shows the Ku dependence on Ms for the films of 1.0 μm in thickness, where the results in the low (curve (A)) and the high (curve (B)) rate sputtering conditions are shown.

In the case of (A), we can describe as follows: With decreasing Ms of the film by an increase of Cr content, Ku increases steeply from negative values and crosses over the zero Ku around Ms = 700 emu/cc, then reaches to the maximum value of Ku = 4.9×10^5 erg/cc at Ms = 300 emu/cc. The positive values of Ku in

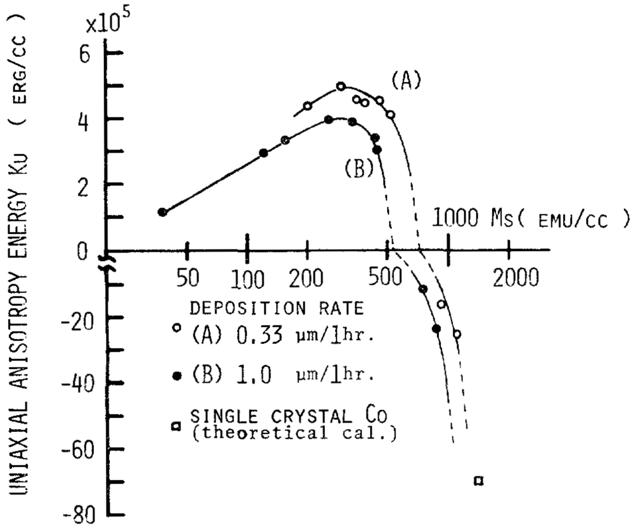

Fig.4 Ku vs. Ms in Co-Cr film for deposition rate (A) and (B).

Fig4 mean that $K_{\perp}$ surpasses $2\pi Ms^2$, then the thin film disk is magnetizable along the normal of the film surface. $K_{\perp}$, calculated by the equation(1), is positive in the whole Ms region. Typically, $K_{\perp} = 1.0 \times 10^6$ erg/cc was obtained for a Ms of 300 emu/cc. Pure Co film has the highest $K_{\perp}$, which decreases monotonically when the Cr content is incresed. The $2\pi Ms^2$, however, decreases more rapidly than $K_{\perp}$ with the increasing Cr content, hence the relation, $K_{\perp} > 2\pi Ms^2$, holds for films of Cr content greater than 13 at.%. Comparing the curves (A) and (B) in Fig.4, we found that the lower deposition rate yields films of higher perpendicular anisotropy.

CRYSTAL STRUCTURE OF THE Co-Cr FILMS

From the X-ray analysis, the Co-Cr film was found to have a hcp structure, and neither σ phase nor bcc phase of Cr. The lattice constant C is 4.055 Å for the film of 20 at.% Cr, which is slightly smaller than the lattice constant of bulk Co (4.069 Å). An X-ray diffraction pattern in Fig.5(a) shows only the (002) line, suggesting that the c-plane of hcp structure is oriented parallel to the film plane. Therefore, the c-axis of a hcp Co-Cr solid solution, or the easy axis of the uniaxial magneto-crystalline anisotropy, lies mainly along the normal of the film plane.

To investigate the c-axis dispersion of the crystallites, a rocking curve was

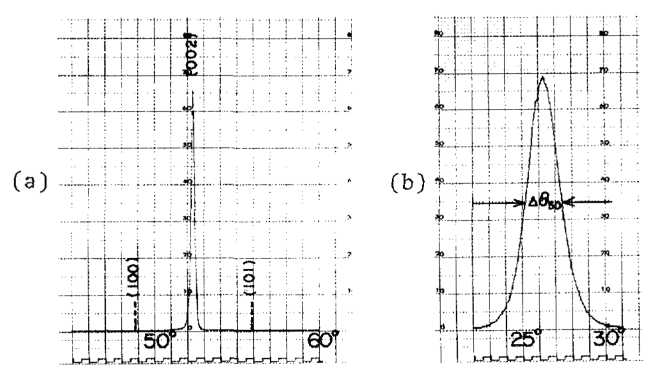

Fig.5 (a) X-ray diffraction pattern
(b) Rocking curve of (002) plane.

measured as shown in Fig.5(b). The rocking curve represents the angle distribution of the intensity of the X-ray diffracted from the (002) plane, and consequently, expresses the c-axis dispersion of the crystallites around the normal of the film. As shown in Fig.5(b), we defined the half angle width $\Delta\theta_{50}$ as the degree of orientation of the c-axis. The values of $\Delta\theta_{50}$ are 7.5° for the Co film, and 2.5° for the films of 13 at.% Cr. Therefore, the Co film, as well as the Co-Cr films, is found to have the c-axis of hcp structure which is oriented perpendicularly to the film plane. It can further be said that the c-axis dispersion of the Co-Cr film is narrower than that of the Co film. In the aforementioned high rate sputtering, the $\Delta\theta_{50}$'s are about two times as large as in the low rate sputtering, in the whole Ms range. The large values of $\Delta\theta_{50}$'s mean the broader angle dispersion of the c-axis. Combined with the result of Fig.4, the above result shows that the higher perpendicular anisotropy clearly corresponds to the narrower dispersion of the c-axis. Consequently, it is concluded that $K_\perp$ is primarily caused by the c-axis orientation of the hcp structure, and the dispersion of the c-axis must be narrowed to obtain the higher $K_\perp$.

A transmission electron microscopy revealed that the Co-Cr film is composed of fine grains as shown in Fig.6. The crystallites are of uniform size and as small as 0.04 μm in diameter for the film of a thickness of 0.34 μm. The average grain size was calculated to be one-fourth and one-ninth of the film thickness for thickness 0.1 μm and 0.5 μm, respectively. Since the grains grow at a very slower rate than the thickness, it is supposed that the crystallites in the film grow into a rod like structure which elongates in the direction of the film thickness. The abovementioned micro-structure of the film is thought to contribute to the perpendicular anisotropy.

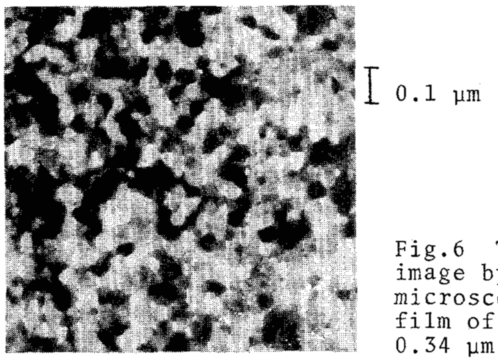

Fig.6 Transmission image by electron microscopy of Co-Cr film of thickness 0.34 μm.

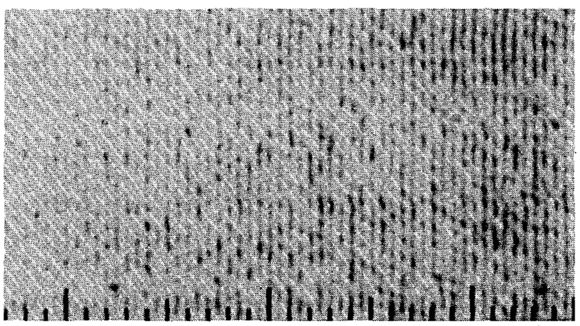

Fig.7 Bitter pattern of recorded signal on Co-Cr film of thickness 0.7 μm. One division of scale is 1.0 μm.

As described above, the Co-Cr sputtered film shows some suitable properties for the perpendicular recording medium, such as perpendicular anisotropy, fine grain structure, and rectangular M-H loop. We recorded a signal on a Co-Cr film of 0.7 μm thickness by a single pole head and realized an extremely high density recording. Fig.7, shows the recorded signal of 100,000 bits/inch developed by a Bitter technique. Since the direct observation is very difficult at the remarkably high density, the Bitter pattern was made by applying the perpendicular dc field to the film after recording[5], hence, the stripe's spacing is two times as large as the recorded bit's interval of 0.25 μm. By this fact, we confirmed that the signal of 100,000 bits/inch has been recorded on a relatively thick film.

CONCLUSIONS

The Co-Cr alloy films with perpendicular anisotropy have been successfully developed by an RF sputtering technique. To obtain the higher perpendicular anisotropy, the lower deposition rate was found to be preferable. It has also been confirmed that, as a high density recording medium, the Co-Cr film has some desirable properties such as a high recording resolution and a high output in the new perpendicular recording system. It was confirmed that Co-Cr sputtered films have sufficient reliability to record signals in high densities. The origin of the perpendicular anisotropy of the films was found to lie in the magneto-crystalline anisotropy and the shape effect of the rod like structure. The quantitative evaluation of the each origin of the anisotropy has not yet been done, and the reason why the addition of the Cr causes the high orientation of the c-axis is not yet known.

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REFERENCES

[1] S.Iwasaki and Y.Nakamura; "An analysis for the magnetization mode for high density magnetic recording," IEEE Trans. Magn., vol.MAG-13, no.5, pp.1272-1277, 1977.
[2] S.Iwasaki and H.Yamazaki; "Co-Cr sputtered films with perpendicular magnetic anisotropy," 7th Ann. Conf. on Magnetics, Japan, 4pA-7, 1975, (in Japanese).
[3] R.M.Bozorth; "Ferromagnetism," p.289, D. Van Nostrand Company, Inc., 1951.
[4] H.Miyajima, K.Sato and T.Matsuda; "New method for measuring the perpendicular anisotropy by using torquemeter," 7th Ann. Conf. on Magnetics, Japan, 5pB-13, 1975, (in Japanese).
[5] S.Iwasaki and K.Takemura; "An analysis for the circular mode of magnetization in short wavelength recording," IEEE Trans. Magn., vol.MAG-11, no.5, pp.1173-1175, 1975.