MAGNETIC AND CRYSTALLOGRAPHIC PROPERTIES OF Co-Cr/Ti-ALLOY THIN FILM DISKS

Yoshibumi MATSUDA, Yoshihiro SHIROISHI, Teruho SHIMOTSU, and Kazumasa TAKAGI

Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo 185, Japan

The c-axis orientation dispersion $\Delta \theta_{50}$ of Co-Cr films does not go lower than 10° on conventional rigid recording disk substrates such as those made of Ni-P/Al or strengthened glass under ordinary sputtering conditions. In addition, the Ti underlayer, which is used to improve the c-axis orientation of Co-Cr deposited by evaporation, has almost no effect on the c-axis orientation of the Co-Cr films on these substrates. This is due to the poor c-axis orientation of the h.c.p. Ti underlayer. Therefore, to improve the c-axis orientation of the underlayer, a second element M (such as Cr, Ta, Nb, Co, Pt, and Pd) is added to Ti. Ti-M alloy underlayers with 10at%Cr, 18at%Ta, 18at%Nb, and 1at%Pt additives significantly improve the c-axis orientation of Co-Cr films, giving a $\Delta \theta_{50}$ of about 5° . For example, X-ray analysis and cross-sectional TEM observation of Co-Cr/Ti-Cr and Co-Cr/Ti films reveal that Co-Cr with a Ti-10at%Cr underlayer show a better c-axis orientation than that of Co-Cr with a Ti-alloy underlayer. Co-Cr/Ti-alloy recording disks with a high c-axis orientation show excellent perpendicular magnetic properties and read/write characteristics.

INTRODUCTION

Co-Cr thin films with a c-axis orientation which have been proposed by S. Iwasaki et al. are expected to be well-suited for extremely high density perpendicular magnetic recording [1], [2]. An intensive study on flexible magnetic disks and VTR tapes utilizing Co-Cr films revealed very high recording characteristics, with high c-axis orientation and perpendicular magnetic properties [3].

In the case of rigid disks, Ni-P/Al or strengthened glass, both requiring a hard and very smooth surface that allows low head flying, must be used as the substrate [4]. Preliminary experiments showed that Co-Cr films directly prepared on such substrates had a low c-axis orientation under normal sputtering conditions. In this paper, improvement in the c-axis orientation of Co-Cr films using a Ti-M (M: Cr, Ta, Nb, Pt, and Pd) alloy underlayer is described along with the read/write characteristics of the films[5].

EXPERIMENTS

C/Co-Cr, C/Co-Cr/Ti, and C/Co-Cr/Ti-M (M: Cr, Ta, Nb, Pt, Pd, and Co) alloy films were prepared using a conventional RF sputtering system. The film structure and preparation conditions examined are shown in Fig.1. The typical substrate temperature, T_s , was 100°C , the Ar pressure, P_{Ar} , was 0.67Pa, and the applied power density, P_a , was 48 kW/m^2 . The

overcoat layer	C	] 40nm
magnetic layer	Co-22at%Cr	] 250nm
underlayer	Ti, Ti-alloys	] 480nm
substrate	Ni-P/Al, s-glass, cover glass, polyimide	

substrate temperature, T_s	20-150 $^\circ\text{C}$
Ar pressure, P_{Ar}	0.67-2.0 Pa
applied power density, P_a	16-48 kW/m^2

Fig.1 Film structure and preparation conditions.

substrates used were an amorphous Ni-P plated Al-alloy(Ni-P/Al), strengthened glass(s-glass), cover glass, and polyimide. Co-Cr films were deposited using a Co-22at%Cr alloy or composite targets. Ti-M alloy underlayers were prepared by utilizing the composite targets.

The magnetic and crystallographic properties of the films were measured by VSM and the X-ray diffraction method (Cu-K α , 40kV, 30mA). The c-axis dispersion, $\Delta\theta_{50}$, was determined by the rocking curve method using the h.c.p. (002) peak. The microstructure of the films was observed by cross-sectional TEM and electron diffraction [6]. Read/write characteristic measurements were carried out on the C/Co-Cr/Ti and C/Co-Cr/Ti-Cr films on 5.25" ϕ Ni-P/Al disks at a head-to-Co-Cr-surface spacing, hg, of 0.15-0.25 μ m at a disk-head relative velocity of 5.5-11.6m/s. This was done using a metal-in-gap head with a gap length, gl, of 0.46 μ m, a track width of 17.2 μ m, and 20+20 turns.

RESULTS AND DISCUSSION

A. C-axis orientation of Co-Cr films on various substrates

The c-axis orientation of the Co-Cr films greatly depended on the substrate materials. Fig.2 shows the c-axis dispersion, $\Delta\theta_{50}$, of the Co-Cr films on Ni-P/Al, s-glass, cover glass, and polyimide substrates. $\Delta\theta_{50}$ resulted in large differences in these substrates. $\Delta\theta_{50}$ had a very small value of about 6° on the polyimide and cover glass substrates, indicating high c-axis orientations for the Co-Cr. On the other hand, the $\Delta\theta_{50}$ of the Co-Cr films was very large (about 10°) on the Ni-P/Al and s-glass substrates, which are usually used for rigid magnetic recording disks.

It is believed that Ni-P/Al and s-glass have a high surface energy. Thus, the Co and Cr atoms deposited on these substrates could not move freely and the c-axis orientation of

Fig.2 Substrate dependence of $\Delta\theta_{50}$ of Co-Cr films.

the Co-Cr films was disturbed during the initial growth.

B. The effect of Ti-alloy underlayers

A lot of research has been done on improving the c-axis orientation of Co-Cr films by supplying several underlayers [7], [8]. It is well known that, in the case of flexible substrates, h.c.p. Ti underlayers result in a high c-axis orientation for Co-Cr films [9]. Consequently, Ti and Ti-M alloy underlayers were examined to improve the c-axis orientation of Co-Cr film on a Ni-P/Al substrate and on a s-glass substrate.

First, Ti film was selected for the underlayer for the Co-Cr film. However, for rigid disk substrates, the Ti underlayers did not cause a high c-axis Co-Cr orientation films under any of the sputtering conditions examined. This was due to the low c-axis orientation of the Ti underlayers. Next, second elements, such as Cr, Ta, Nb, Co, Pt, and Pd, were added to the Ti films to improve the c-axis orientation of the underlayer.

Fig.3 shows the $\Delta\theta_{50}$ of Co-22at%Cr formed on Ti-M (M: Cr, Ta, Nb, Pt, Pd, and Co) underlayers. The c-axis dispersion, $\Delta\theta_{50}$, of the Co-Cr films decreased significantly

Fig. 3 $\Delta\theta_{50}$ dependence of Co-Cr films on the content of additive element M for Co-Cr/Ti-M films.

to about 5° when about 10at% of Cr, 18at% of Ta (or Nb), and about 1at% of Pt were added to the Ti, where the Co-Cr films showed the largest I_{002} . Ti-Pd alloy underlayers showed a similar effect on the c-axis orientation. However, the $\Delta\theta_{50}$ of the Co-Cr films did not become smaller than 8.5° . On the other hand, the Ti-Co alloy underlayers showed almost no improvement of the c-axis orientation.

Fig. 4 shows the dependence of the magnetic properties on the Cr content in the Ti-Cr underlayer for Co-Cr/Ti-Cr films. For Ti-10at%Cr, the in-plane squareness, $Mr_{||}/Ms$, was the lowest at about 0.1, the vertical squareness, $Mr_{\perp}/Ms$, was the highest at about 0.3, and the vertical coercivity, $H_{c\perp}$, was the highest at about 70kA/m, where the $\Delta\theta_{50}$ of the Co-Cr films was the lowest at about 5° ($\sim 0.1\text{rad}$) as shown in Fig. 3. Thus, the Co-Cr/Ti-10at%Cr had excellent crystallographic and perpendicular magnetic properties. To investigate the reasons for the high c-axis orientation of the Co-Cr film structure, X-ray diffraction patterns, cross-sectional TEM,

Fig. 4 Magnetic properties dependence on Cr content in Ti-Cr underlayer for Co-Cr/Ti-Cr films.

and electron diffraction patterns were analyzed.

Fig. 5 shows the dependences of the (002) diffraction peak, I_{002} , and c-axis dispersion, $\Delta\theta_{50}$, of the Ti-Cr underlayers on the Cr content. The dependence of the Ti-Cr underlayer $\Delta\theta_{50}$ on the Cr content was similar to that for the Co-Cr on Ti-Cr films shown in Fig. 3. X-ray diffraction pattern showed a selective growth of (002) grains for Ti-M alloys. The reason of this high c-axis orientation may be explained of segregation of additive element M for Ti [10] as observed in Co-Cr [11], [12]. Consequently, it is assumed that the high c-axis orientation of the Ti-10at%Cr underlayer caused the very high c-axis orientation of the Co-Cr film because it grew on the underlayer epitaxially.

In fact, the microstructures of a well-oriented Co-Cr film on a well-oriented Ti-Cr underlayer and a poorly-oriented Co-Cr film on a poorly-oriented Ti underlayer were observed by means of cross-sectional TEM and electron diffraction and are shown in Fig. 6. The TEM image of the Ti underlayer shows

Fig.5 X-ray peak intensity, I_{002} , and c-axis dispersion, $\Delta\theta_{50}$, dependence on Cr content in Ti-Cr underlayer for Co-Cr/Ti-Cr films.

randomly grown columnar structure with large in-plane grain sizes of about 60nm. The Co-Cr film grown on the Ti underlayer has non-uniformly grown columnar structure. On the other hand, in the case of the Ti-10at%Cr underlayer, fine uniform columnars grew vertically on the substrate. The Co-Cr film grown on the Ti-10at%Cr underlayer had also fine uniform columnars.

The electron diffractions of these cross-sections show good agreement with the cross-sectional TEM results, as follows. On the Co-Cr/Ti film, the diffraction pattern of the Ti underlayer showed fine Debye-Scherrer type diffraction spots. This means that large Ti grains are oriented randomly. The diffraction pattern of the Co-Cr film on the Ti underlayer had a pattern similar to that of the Ti film. It is believed that, depending on the direct effect of the Ti underlayer, the large Co-Cr grains epitaxially grown on poorly-oriented Ti with large grains are oriented randomly. On the Co-Cr/Ti-10at%Cr

(a) Poorly-oriented Co-Cr/Ti film

(b) Well-oriented Co-Cr/Ti-10at%Cr film

Fig.6 Cross-sectional TEM micrographs and electron diffraction patterns of poorly-oriented Co-Cr/Ti film and well-oriented Co-Cr/Ti-10at%Cr film.

film, the diffraction spots of the Ti-Cr underlayer were very broad and c-axis oriented. This shows that the Ti-Cr film consists of well-oriented fine grains in the c-axis direction. The diffraction pattern of the Co-Cr film on the Ti-Cr underlayer showed also clear diffraction spots with a high c-axis orientation. It is believed that the large Co-Cr grains with the high c-axis orientation grew epitaxially on the Ti-Cr underlayer with the high c-axis orientation.

C. Recording characteristics

The read/write characteristics of the well c-axis oriented Co-Cr/Ti-Cr films and the Co-Cr/Ti films with the poor c-axis orientation were measured with a sendust metal-in-gap head.

Fig.7 shows the recording density

response curves for the Co-Cr films that were well- and poorly-oriented by the Ti-10at%Cr underlayer and the Ti underlayer, respectively. The measurements were taken at hg : $0.15\mu m$. The low recording density output of the well-oriented Co-Cr/Ti-Cr film was twice as large as that of the poorly-oriented Co-Cr/Ti film. The output was $45nV_{pp}/\mu m \cdot (m/s) \cdot turns$. The half-output recording density, D_{50} , of the Co-Cr/Ti-Cr film ($42.5kFCI$) was much larger than that of the Co-Cr/Ti film ($39.0kFCI$).

Fig.8 shows isolated, reproduced output waveforms for the Co-Cr/Ti-Cr film and the Co-Cr/Ti film under the same read/write conditions at hg : $0.25\mu m$. The dipulse ratio of the Co-Cr/Ti-Cr film (0.54) was about twice as large as that of the Co-Cr/Ti film (0.25). These are due to the higher perpendicular orientation of the Co-Cr on the Ti-Cr than that on the Ti.

CONCLUSIONS

(1) It is difficult to achieve Co-Cr films with a high c-axis orientation on rigid

Fig.7 Reproduced output as a function of recording density.

(a) Co-Cr/Ti-10at%Cr film

(b) Co-Cr/Ti film

Fig.8 Isolated output waveforms.
(MIG Head: $gl=0.46\mu m$, $hg=0.25\mu m$)

recording disk substrates such as Ni-P/Al or strengthened (s-glass) under any sputtering conditions examined.

(2) The Ti underlayer has almost no effect on the high c-axis orientation of the Co-Cr films because the Ti underlayer has a poor c-axis orientation on the Ni-P/Al or s-glass substrates.

(3) Ti-alloy underlayers with a small amount of M (M= Cr, Ta, Nb, and Pt) additive elements have a better c-axis orientation than the Ti underlayer and improve the c-axis orientation and the magnetic properties of the Co-Cr films, i.e. $\Delta\theta_{50}$ = about 5° , $Mr_{||}/Ms$ = 0.1, and H_{c1} = 70kA/m.

(4) X-ray diffraction analysis, cross-section TEM, and electron diffraction analysis indicate that the Ti-Cr underlayer is well-oriented even on the Ni-P/Al or s-glass substrates, which causes the well-oriented Co-Cr film grain growth epitaxially.

(5) At the head-to-Co-Cr-surface spacing

(0.15-0.25 μ m) with the metal-in-gap head, the well-oriented Co-Cr/Ti-Cr film disk has much better read/write characteristics than the poorly-oriented Co-Cr/Ti film disk.

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REFERENCES

- [1] S. Iwasaki and K. Ouchi: IEEE Trans. Magn. MAG-14, 849 (1978).
- [2] M. Futamoto, Y. Honda, H. Kakibayashi, and K. Yoshida: IEEE Trans. Magn. MAG-21, 1426, (1985).
- [3] S. Yamamoto, Y. Nakamura, and S. Iwasaki: IEEE Trans. Magn. MAG-23, 2070 (1987).
- [4] T. Ohno, Y. Shiroishi, S. Hishiyama, H. Suzuki, and Y. Matsuda: IEEE Trans. Magn. MAG-23, 2809 (1987).
- [5] Y. Matsuda, Y. Shiroishi, T. Shimotsu, and K. Takagi: The 12th Annual Conference on Magnetism in Japan, (1988).
- [6] M. Futamoto, Y. Honda, T. Shimotsu, H. Kakibayashi, and K. Yoshida: Jpn. J. Appl. Phys. 25, 1128, (1986).
- [7] J. K. Howard: J. Vac. Sci. Technol. A4, 2975 (1986).
- [8] M. Yasumura, K. Ouchi, and S. Iwasaki: IEEE Trans. Magn. MAG-23, 2809 (1987).
- [9] R. Sugita: IEEE Trans. Magn. MAG-20, 687 (1984).
- [10] M. Hansen: "Constitution of Binary Alloys", McGraw-Hill, New York, (1958).
- [11] S. Iwasaki, K. Ouchi, and T. Hizawa, J. Mag. Soc. Jpn. 9, 57 (1985).
- [12] Y. Maeda and M. Asahi: J. Appl. Phys. 61, 1972 (1987).