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 $\Delta \theta_{60}$ 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 $\Delta \theta_{60}$ 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, $P_A$, was 0.67Pa, and the applied power density, $P_a$, was 48kW/m². 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 |

$T_s$ = 20-150°C

$P_A$ = 0.67-2.0 Pa

$P_a$ = 16-48 kW/m²

Fig.1 Film structure and preparation conditions.
substrates used were 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\alpha, 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" Ni-P/Al disks at a head-to-Co-Cr surface spacing, $h_{g}$, of 0.15-0.25 $\mu$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, $g_{l}$, of 0.46 $\mu$m, a track width of 17.2 $\mu$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 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.
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 1°. Ti-Pd alloy underlayers showed a similar effect on the c-axis orientation. However, the Δθ_{5θ} 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⊥/Ms, was the highest at about 0.3, and the vertical coercivity, Hc⊥, was the highest at about 70kA/m, where the Δθ_{5θ} of the Co-Cr films was the lowest at about 5° (~0.1rad) 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, and electron diffraction patterns were analyzed.

Fig. 5 shows the dependences of the (002) diffraction peak, I_{002}, and c-axis dispersion, Δθ_{5θ}, of the Ti-Cr underlayers on the Cr content. The dependence of the Ti-Cr underlayer Δθ_{5θ} 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...
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 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: 0.15μm. 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 μm/m/s·turns. The half-output recording density, D₀, 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: 0.25μm. 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 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. Δθ₀= about 5°, Mr/Ms= 0.1, and Hc= 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 μm) 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.

ACKNOWLEDGEMENTS

The authors would like to thank Drs. T. Suganuma and M. Futamoto of Central Research Laboratory of Hitachi for their encouragement and also to Mr. F. Kugiya for his helpful discussion. They are also indebted to Mr. Y. Kojima for evaluating the constitutions of the samples and to Mr. S. Hishiyama for helping the preparation of the samples.

REFERENCES