Co-Cr PERPENDICULAR ANISOTROPY FILM PREPARED BY ION PLATING

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Abstract--- An rf ion plating was examined as the fabrication method for a Co-Cr film to improve its crystallographic and magnetic properties. As a result, it was found that the c-axis orientation and the perpendicular anisotropy of a Co-Cr film was remarkably improved by increasing rf power. Moreover, the density of cracks in the Co-Cr film was noticeably reduced by rf plasma excitation during deposition. No change was found in the saturation magnetization and morphological structure of the Co-Cr film. On the other hand, substrate bias did not influence on the magnetic properties and the c-axis orientation of the Co-Cr film. These results suggest that the above effects found in the rf ion plated films are attributed not to the energies of ions, but to the number of ions in the vapor.

INTRODUCTION

A Co-Cr thin film is one of the most favorable materials for perpendicular magnetic recording media [1]. Although much work on this material has been done by many researchers [2] - [4], there are few reports on the effect of ions on the physical properties of the Co-Cr film [5] - [8].

In this paper, we will report on Co-Cr films prepared by rf ion plating method, in particular, on their magnetic properties, crystallographic structures and morphologies. Moreover, the effects of substrate bias and rf plasma excitation during deposition on the above properties will be discussed.

EXPERIMENTAL PROCEDURE

The ion plating system used in this experiment is shown schematically in Fig.1. A Co-Cr thin film was deposited on a polymer substrate by vacuum evaporation with an electron beam gun. The polymer substrate was attached to a stainless steel substrate holder whose temperature was maintained at room temperature

(25°C). The rf electrode was placed between the evaporation source and the substrate holder. Plasma discharge was induced in Co-Cr vapor from the source through the rf electrode

Fig.1 The ion plating apparatus used in this experiment.

excited by an rf oscillator (frequency :13.56 MHz). The distance between the evaporation source and the substrate holder was 20 cm. Substrate bias was applied during deposition by a regulated DC power supply connected to substrate holder. The details of deposition conditions are shown in Table 1.

The magnetic properties of the Co-Cr films were measured using a vibrating sample magnetometer (VSM) and torque magnetometer. Their crystallographic and a morphological structures were investigated by X-ray diffraction analysis and field-emission type scanning electron microscope (SEM). The cracks in the Co-Cr films were observed using a optical microscope.

Table 1 The detail of deposition condition

Substrate Temperature	Room Temperature
Pressure During Deposition	$<3 \times 10^{-6}$ Torr
Deposition Rate	5~10nm/sec
RF Power	0~130W
Bias Voltage	0~-300V

EXPERIMENTAL RESULTS

Magnetic properties

Figures 2 (a), (b) and (c) show the typical M-H hysteresis curves of the Co-Cr films prepared by rf ion plating at room temperature (25°C). The film thicknesses and Cr contents of all samples were set 3000 Å and 20 wt%, respectively. Figure 2 (a) is for the case of rf power $P_{rf} = 0$ V and bias voltage $V_b = 0$ V, (b) for $P_{rf} = 90$ W and $V_b = 0$ V and (c) for $P_{rf} = 90$ W and $V_b = -300$ V. It is recognized that the shoulder part in the perpendicular hysteresis curve becomes sharper by rf plasma excitation during deposition. This result suggests that the perpendicular anisotropy of the Co-Cr film was improved by rf plasma excitation. On the other hand, substrate bias did not give any influence to the magnetic properties of the Co-Cr films. Figure 3 shows the

dependence of the perpendicular anisotropy field (H_k) on rf power applied during deposition. In this case, the bias voltage applied to the substrate was set at 0 V or -300 V. As can be seen in this figure, the perpendicular anisotropy is considerably improved as rf power

Fig.2 The typical M-H hysteresis curves of the Co-Cr films prepared by rf ion plating.

Fig.3 The dependence of the perpendicular anisotropy field H_k on rf power applied during deposition.

increases, whereas substrate bias does not give any influence to the perpendicular anisotropy. It should be also noticed that the Co-Cr film prepared by rf ion plating method has a large perpendicular anisotropy field (4 kOe) even when it is deposited on a non-heated substrate.

As mentioned above, the perpendicular anisotropy of a Co-Cr film can be greatly improved by rf plasma excitation to Co-Cr vapor. Substrate bias, however, does not give any influence to the magnetic properties of a Co-Cr film.

Crystallographic and morphological structures

The crystallographic and morphological structures of Co-Cr films were studied to investigate the cause for the improvement of their perpendicular anisotropies by rf plasma excitation. Figures 4 (a) and (b) show the dependence of half-value width $\Delta\theta_{50}$ of the Co-Cr (00·2) plane rocking curve on rf power P_{rf} and bias voltage V_b , respectively. As rf power increases, the value $\Delta\theta_{50}$, the degree of c-axis orientation, greatly improves. According to Figs.3 and 4, rf plasma excitation in Co-Cr vapor improves the c-axis orientation

of the Co-Cr film, and consequently improves its perpendicular anisotropy. However, substrate bias does not give rise to any changes in the c-axis orientation as is the case for the magnetic properties.

Figures 5(a), (b) and (c) are the cross-

(a) Dependence on rf power

(b) Dependence on bias voltage

Fig.4 The dependence of the half-value width $\Delta\theta_{50}$ of the Co-Cr(00·2) plane rocking curve on rf power and bias voltage.

(a) $P_{rf} = 0 \text{ W}$
 $V_b = 0 \text{ V}$

(b) $P_{rf} = 90 \text{ W}$
 $V_b = 0 \text{ V}$

(c) $P_{rf} = 90 \text{ W}$
 $V_b = -300 \text{ V}$

0.1 μm

Fig.5 The cross sectional SEM micrographs of the Co-Cr films prepared by ion plating.

-sectional SEM micrographs of the Co-Cr films prepared by rf ion plating. Figure 5(a) is for the case of $P_{rf} = 0 \text{ W}$ and $V_b = 0 \text{ V}$, (b) for $P_{rf} = 90 \text{ W}$ and $V_b = 0 \text{ V}$ and (c) for $P_{rf} = 90 \text{ W}$ and $V_b = -300 \text{ V}$. As can be seen in these figures, these films deposited at low substrate temperature (RT) have smooth surfaces and unclear columnar structures. Figure 6 is the micrograph of the Co-Cr film prepared at a high substrate temperature (200 C) which has considerably high perpendicular coercivity (650 Oe). It can be seen that this film has a rough surface and a distinct columnar structure compared with those of the Co-Cr films deposited at RT. It is considered that the high perpendicular coercivity in this Co-Cr film prepared at 200 C is attributed to good magnetic separation between the columns due to distinct columnar structure.

As mentioned above, rf plasma excitation in Co-Cr vapour greatly improves the c-axis orientation and the perpendicular anisotropy of the Co-Cr film. However, it does not give any influence to its morphological structure and the perpendicular coercivity.

0.1 μm

Fig.6 The cross sectional SEM micrograph of the Co-Cr film prepared at high substrate temperature (200°C).

The density of cracks in Co-Cr films

Figures 7 (a), (b) and (c) are the optical micrographs of Co-Cr film surfaces. Figure 7 (a) is for the case of $P_{rf} = 0$ W and $V_b = 0$ V, (b) for $P_{rf} = 90$ W and $V_b = 0$ V and (c) for $P_{rf} = 90$ W and $V_b = -300$ V. According to these figures, it is recognized that rf plasma excitation remarkably reduces the number of cracks in the Co-Cr films. Substrate bias, however, does not cause any changes in the density of cracks. It was reported that the similar effect was found in Ar ion beam bombardment during the vacuum evaporation of Co-Cr alloy [7].

Although the influence of rf plasma excitation on the mechanical property of Co-Cr films is obviously observed, the mechanism for the above phenomenon is yet to be clarified.

DISCUSSION

Rf plasma excitation during deposition remarkably improves the c-axis orientation and the perpendicular anisotropy of a Co-Cr film. However, it does not give any influence to the perpendicular coercivity. We speculate the cause for the above effects as follows. The short-range diffusion of Co-Cr atoms is promoted by the existence of Co-Cr ions produced by the rf plasma excitation. As a result, the atoms tend to arrange toward the construction of stable crystal lattice (in this case hexagonal-closed-packed structure). Consequently, the rf plasma excitation during deposition improves the c-axis orientation and the perpendicular anisotropy. However, long-range diffusion influencing on the morphological structure of the Co-Cr film was not promoted by the existence of Co-Cr ions. In this case, therefore, the magnetic separation between the columns is not improved, and hence no increase in the coercivity is resulted in, in spite of the increase in the perpendicular anisotropy.

On the other hand, substrate bias does not give any influence to the magnetic properties, the crystallographic orientation, morphological

(a) $P_{rf} = 0$ W, $V_b = 0$ V

(b) $P_{rf} = 90$ W, $V_b = 0$ V

(c) $P_{rf} = 90$ W, $V_b = -300$ V 0.03mm

Fig.7 The optical micrographs of Co-Cr film surfaces.

structure and mechanical properties of the Co-Cr films. Although many similar results on the effect of substrate bias are obtained by other researchers, the cause for this is yet to be clarified [9] - [11].

In any event, more intensive studies on

the effects of rf plasma excitation and substrate bias will be needed.

CONCLUSION

Co-Cr films were prepared by rf ion plating method. The rf plasma excitation in Co-Cr vapor remarkably improved their c-axis orientation and perpendicular anisotropy. A good perpendicular anisotropy film with $\Delta\theta_{50} = 8^\circ$ and $H_K = 4$ kOe was obtained by the excitation of rf plasma even when it was prepared at RT. Moreover, the density of the cracks in a Co-Cr film was noticeably decreased by the excitation of rf plasma. However, substrate bias does not give any influence to the magnetic, crystallographic, morphological and mechanical properties of the Co-Cr film.

ACKNOWLEDGEMENT

The authors are grateful to Dr. T. Doi, Dr. Y. Otomo and Dr. K. Mizushima of Hitachi Maxell, Ltd. for their encouragement throughout this work. They also thank to Dr. K. Yoshida of Hitachi, Ltd. for his helpful advice.

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