Preparation of Co-Cr Films Using Inductively-Coupled-Plasma Assisted Magnetron Sputtering

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Abstract - **A novel sputtering apparatus using a magnetron sputtering cathode and inductively-coupled-plasma (ICP) generation system was built for Co-Cr film deposition. With this new sputtering apparatus, flexible control of plasma characteristics and ion bombardment is possible. The plasma etching was modified by applying a bias voltage to the substrate in the range of -50 to +100 V. When the plasma bombardment was very small, the deposited Co-Cr films showed low perpendicular coercivity and low perpendicular magnetic anisotropy. From these results and from similar results obtained using electron-cyclotron-resonance (ECR) microwave plasma sputtering, it can be shown that Co-Cr films with high perpendicular coercivities and large perpendicular magnetic anisotropies are obtained when a moderate ion bombardment is supplied during film deposition.**

I. INTRODUCTION

High perpendicular coercivity, large perpendicular magnetic anisotropy and low media noise characteristics are required for recording media to achieve multi-gigabit per square inch. By enhancing compositional separation between Co- and Cr-rich regions in nano-meter size Co-Cr films, these requirements may be satisfied.

Recently we have been challenged to achieve Co-Cr perpendicular media with the magnetic microstructure described above by introducing new sputtering deposition methods, *i.e.* sputtering deposition using electron-cyclotron-resonance (ECR) microwave plasma [1-3]. From our earlier experimental results, it was shown that enhanced compositional separation was formed in nano-meter size Co-Cr media when the energy and quantity of ions which bombard the substrate were small. This desirable condition was realized in the cusp magnetic field in ECR sputtering [3].

By the way, with the diode type sputtering already widely used today, the functions of plasma generation, sputtering and film deposition are not separate. Hence, flexible control of plasma characteristics and ion bombardment during film deposition is difficult.

In this study, we have built a novel sputtering apparatus in which the magnetron sputtering mechanism and inductively-coupled-plasma (ICP) generation were combined. In short, we call this new sputtering system ICP assisted sputtering [4]. Using this sputtering apparatus, we have deposited Co-Cr perpendicular magnetic films to investigate the conditions needed to obtain Co-Cr perpendicular magnetic recording media with magnetic properties suitable for high density recording, focusing on the effects of ion bombardment.

II. EXPERIMENTAL PROCEDURE

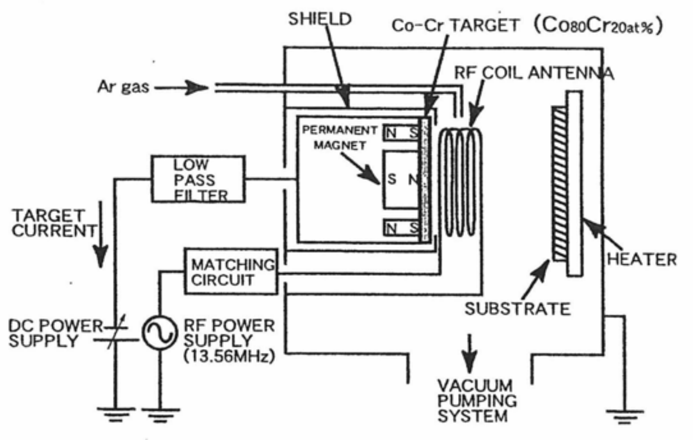

Fig.1 Schematic illustration of ICP assisted magnetron sputtering apparatus.

Figure 1 shows a schematic illustration of an ICP assisted sputtering apparatus. A coil antenna whose diameter was 40 mm and the number of turns was four was installed above a magnetron sputtering cathode. Radio frequency (13.56 MHz) electric power was supplied to the antenna through a matching circuit to generate plasma. The mechanism of plasma generation is as follows: When the 13.56 MHz electric current, **J**, flows into the coil antenna, a time varying magnetic field, **B**, is generated in axial direction of the coil antenna according to the equation, $\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$. The magnetic field induces an electric field, **E**, according to the equation, $\nabla \times \mathbf{E} = -(d\,\mathbf{B}/d\,t)$. Electrons are accelerated by this induced electric field, **E**, which then collide with Ar gas molecules and ionize them. This plasma generation mechanism called Inductively-coupled-plasma (ICP) enables us to get high efficiency plasma generation with rf powers as low as a few watts. The plasma density and film deposition rate can be increased by increasing the rf power supplied to the ICP coil antenna.

A Co80Cr20at.% alloy target with a diameter of 50 mm was used. Direct current was supplied to the target cathode via low-pass filter to suppress interference from the rf power supplied to ICP antenna. The plasma generated by ICP plays the roll of an igniter. Therefore, this sputtering apparatus can generate plasma and deposit thin films at low dc cathode voltage of less than -350V at which conventional sputtering apparatus cannot maintain plasma generation.

The base pressure of the apparatus is 10^{-8} Torr. The Si substrate was located 100 mm away from the target so as not to be exposed to the dense plasma above the magnetron target. Co-Cr film deposition was performed at a Ar gas pressure of

4 mTorr. The dc voltage applied to the target was –500 V, and the substrate temperature was 200 ℃. The rf power supplied to the ICP antenna was set to 10 W. The thickness of the deposited Co-Cr films was 200 nm.

Magnetic properties of the Co-Cr films were measured with a vibrating sample magnetometer (VSM). The plasma parameters such as ion current density (I_i) and plasma potential (V_p) were estimated from the current vs. voltage curve measured by the single-probe plasma diagnosis method.

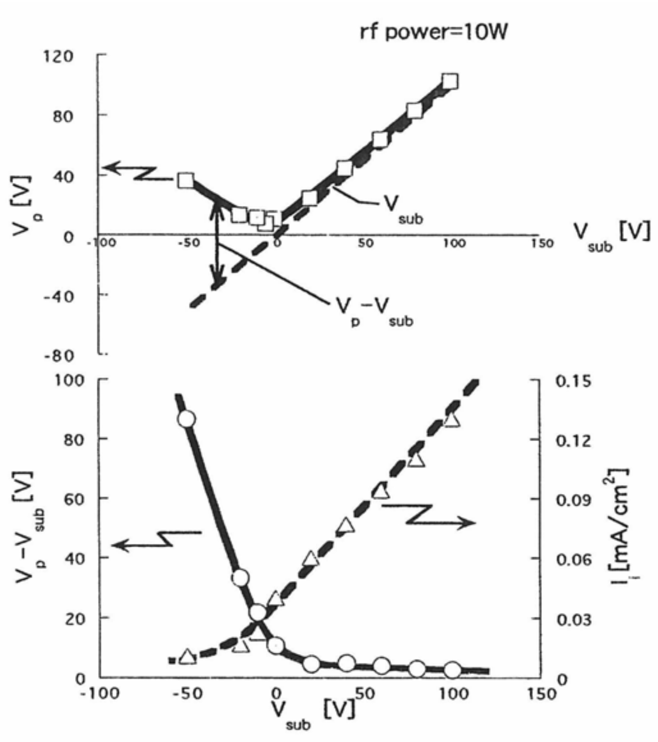

Fig.2 Substrate bias voltage (V_{sub}) dependence of plasma potential, V_P, (top figure), and ion acceleration voltage, V_p-V_{sub}, and ion current density, I_i, (bottom figure).

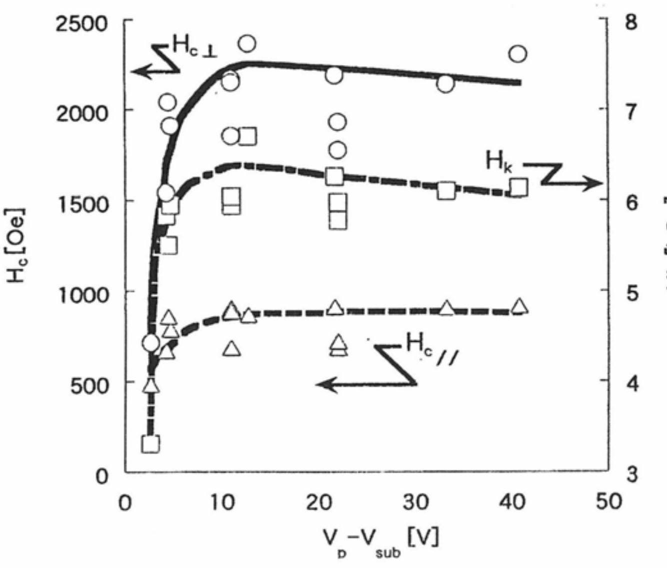

Fig.3 Ion acceleration voltage (V_p-V_{sub}) dependence of Hc and Hk.

In order to change the ion bombardment to the substrate widely, a dc bias voltage was supplied to the substrate in the range of -50 V to +100 V, and the ion acceleration voltage was changed.

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the results of our plasma diagnosis. When the substrate bias voltage (V_{sub}) was changed from -50 V to +100V, the plasma potential (V_p) decreases to a minimum around V_{sub} of 0 V, and increases for positive substrate bias voltages, because the plasma potential is always higher than the voltage of the chamber walls and a substrate. The ions in the plasma are accelerated by the potential difference (V_p-V_{sub}) and bombard the substrate. Hence we call V_p-V_{sub} the ion acceleration voltage. It was found that the ion acceleration voltage ranged from 85 V to 3V, while ion current density (I_i) monotonically increased from 0.005 mA/cm^2 to 0.13 mA/cm^2, when the substrate bias voltage (V_{sub}) was changed from -50 V to +100 V.

Fig.3 shows experimental results of the acceleration voltage dependence of perpendicular coercivity ($H_{c\perp}$), in-plane coercivity ($H_{c//}$) and the perpendicular magnetic anisotropy field (H_k) of the deposited Co-Cr films. At an acceleration voltage of 3 V, the Co-Cr film showed a very low $H_{c\perp}$ of 700 Oe and a H_k of 3.3 kOe. With increasing acceleration voltage, both $H_{c\perp}$ and H_k increased reaching a maximum value of 2200 Oe and 6 kOe, respectively. At acceleration voltages greater than 10 V, $H_{c\perp}$ and H_k continued to gradually decrease.

It has been known that the ions which bombard the substrate need a kinetic energy of several eV to several tens of eV to overcome the atomic binding energy and cause the displacement of atoms at a film surface [7]. Our above mentioned experimental results show that the energy of Ar ions accelerated by an acceleration voltage over 10 V was large enough to enhance the migration of atoms at the film surface and compositional separation between Co-rich and Cr-rich phases, resulting in increased M_s.

We have already performed a similar experiment as this, using an ECR sputtering apparatus [6], in which the ion acceleration voltage was varied in the range of 10 V to 32 V by changing substrate bias voltage. This experimental results showed that the $H_{c\perp}$ and H_k of the Co-Cr films also increased with decreasing ion acceleration voltage. Therefore to achieve high $H_{c\perp}$ and large H_k with ECR sputtering, lower ion acceleration voltage (less than 10 V) was preferable [6].

On the other hand, with the ICP assisted sputtering, moderate ion acceleration voltages (~ 10 V) are preferable. To solve the apparent conflict between these experimental results, a better parameter than V_p-V_{sub} must be found to present ion bombardment phenomena. As the ion current density of the ECR sputtering is about one order larger than that of the ICP assisted sputtering, we thought that the compositional segregation phenomena were affected not only by ion acceleration voltage but also ion flux.

Let us consider the situation in which the Co-Cr films grows as it is exposed to ion bombardment. Ion assist may be estimated by considering the kinetic energy of ion, ion flux per unit time and area, and the time needed for deposition. The ion's kinetic energy is proportional to V_p-V_{sub}. The ion flux is proportional to ion current, I_i,

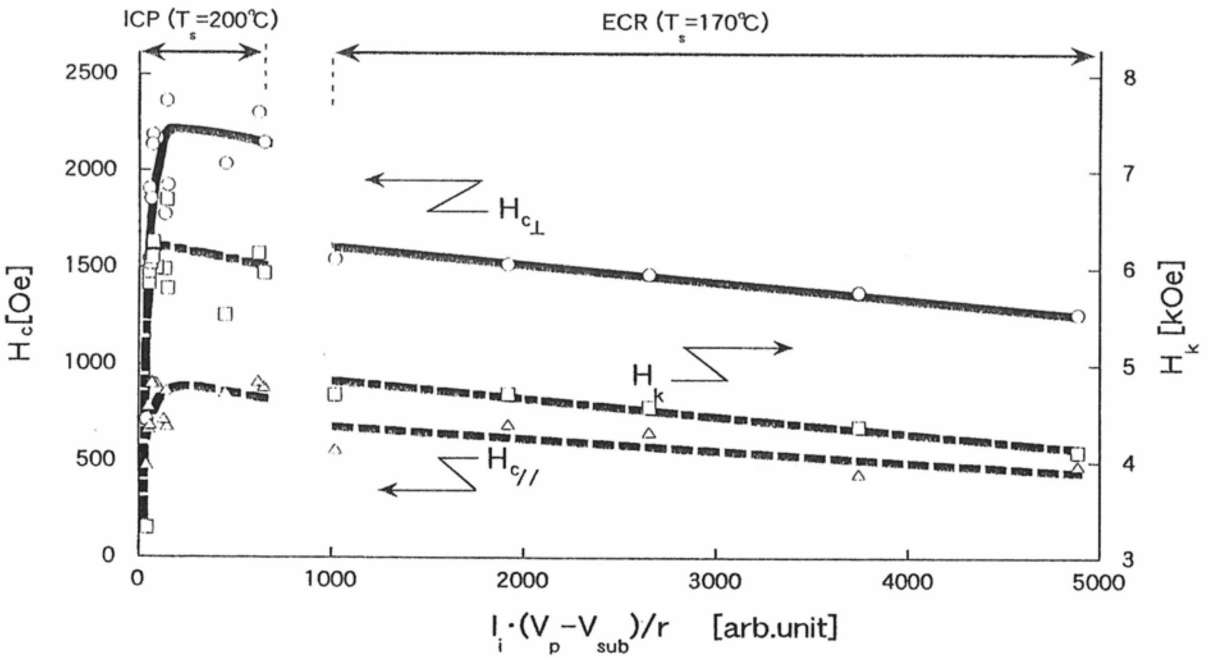

Fig.4 Ion assist $\{I_i\cdot(V_p-V_{sub})/r\}$ dependence of $H_{c\perp}$ (○), $H_{c//}$ (△) and H_k (□) of deposited Co-Cr films. These data are obtained with ICP assisted sputtering (left) and ECR sputtering (right). T_s is substrate temperature during film deposition.

measured by plasma diagnosis, and the deposition time is estimated by deposition rate, r. Therefore, we introduce the new parameter, $I_i\cdot(V_p-V_{sub})/r$, as a criteria showing ion assist, and we call this parameter ion assist.

Fig.4 shows the ion assist $\{I_i\cdot(V_p-V_{sub})/r\}$ dependence of $H_{c\perp}$ and H_k of deposited Co-Cr films. The experimental data obtained by the ICP assisted sputtering and the ECR sputtering [6] are plotted in this figure. The range of $I_i\cdot(V_p-V_{sub})/r$ in the ICP assisted sputtering experiment was 30-600. On the other hand, the $I_i\cdot(V_p-V_{sub})/r$ value for the ECR sputtering experiment (1000-5000) was about ten times larger than that in the ICP assisted sputtering experiment. From these figures, we may conclude that a moderate ion bombardment ($I_i\cdot(V_p-V_{sub})/r$ value of about 100) is most suitable to achieve Co-Cr films with high perpendicular coercivity and large perpendicular magnetic anisotropy, and that too little or excessive ion bombardment is not proper.

IV. CONCLUSIONS

A novel sputtering apparatus using a magnetron sputtering cathode and inductively-coupled-plasma (ICP) generation was built for Co-Cr film deposition. In this sputtering apparatus, flexible control of plasma characteristics and ion bombardment are possible. The plasma bombardment was changed by applying substrate bias voltage in the range of -50 to +100V. When the plasma assist was small, the deposited Co-Cr film showed low perpendicular coercivity and small perpendicular magnetic anisotropy. From this result and the results obtained using ECR sputtering, we conclude that the Co-Cr films with high perpendicular coercivity and large perpendicular magnetic anisotropy are obtained when moderate ion bombardment is supplied during film deposition.

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