FABRICATION OF HIGH-MELTING POINT METAL COATING①

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ABSTRACT A new multiple hollow cathode sputtering target which has a simple configuration and a high sputtering rate was developed. Parameters of discharge and coating were studied. The results indicate that the current density and sputtering rate depend on the working pressure, target voltage and configuration. When $H \cdot D^{-1}$ is 2~ 3, the target has an efficient sputtering rate. The optimum negative bias voltage is 200~ 300 V for Mo coating.

Key words multiple hollow cathode sputtering target coating high-melting point metal

1 INTRODUCTION

Many surface coating techniques, such as cathodic arc vapor deposition(CAVD), ion beam assisted deposition(IBAD) and r. f. sputtering (RFS), have been considerable developed in recent years[1- 3]. The sputtering of the high-melting point metal is relative difficult, so the deposition rate becomes lower than others[4].

The hollow cathode discharge not only provides a high electron and ion current density, but also intensifies cathode sputtering and produces metallic vapor around the cathode. Hollow cathode usually is used as an electron gun to provide an electron beam to sputter the target[5- 7], not directly as a sputtering target. According to the property of a high sputtering rate by the hollow cathode discharge, a new multiple hollow cathode sputtering target composed of many hollow cathode units was developed. The characteristics of the multiple hollow cathode sputtering target discharge and sputtering rate were investigated. This method for forming target is suitable for many metals or their alloys as target, in particular, for the high-melting point metals (W, Mo, Nb and Ta, etc) or their alloys.

2 EXPERIMENTAL FACILITY

The experiment facility is shown in Fig. 1. The system is mainly equipped with a vacuum

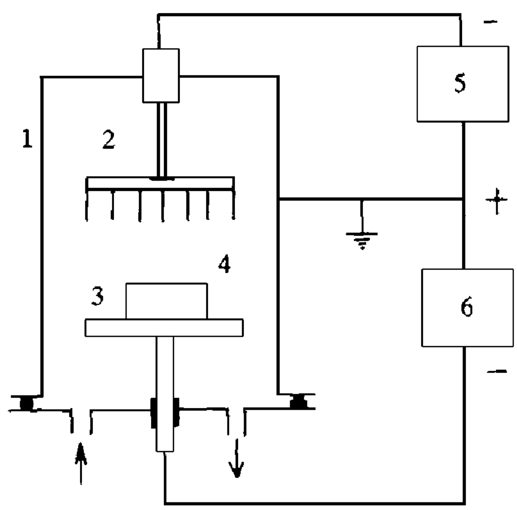

Fig. 1 A skematic diagram of equipment

1 —chamber(anode); 2 —multiple hollow cathode target; 3 —cathode; 4 —specimen; 5 —DC power; 6 —bias DC power

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chamber, a sample holder, two DC power supplies and the multiple hollow cathode sputtering target. The positive electrode of one DC power is linked with the chamber, the negative electrode with the multiple hollow cathode and the sample with a reverse bias, usually the negative bias voltage is 300~ 500 V. The principle of this method is similar to that of Double Glow Discharge[8, 9]. When the vacuum chamber was filled with medium gases to working pressure and the system was linked to DC power, a hollow cathode would be ignited and discharged. Atoms and ions were sputtered from the hollow cathode, and these particles would be transmitted to the nearby sample surface. As a result of the action of ionization and electric field acceleration (with the reverse bias), these particles would be absorbed and deposited on the sample surface.

The multiple hollow cathode sputtering target is composed of hollow cathode units and a base. These units on the base are made of metals or their alloys that were deposited to the sample. The base could be made of target materials or others. Many types are suitable for this target, e.g. plate, comb and honey comb-like shape. In this experiment, the plates were parallel to each other. The properties of discharge and sputtering depend on the cathode height (H) and cavity width (D), as shown in Fig. 2.

Pure Mo was used as the material of the multiple hollow cathode. The cathode height (H) is 10~ 50 mm, and the cavity width (D) is 5~ 50 mm. The medium gas is argon. The current density (J) is defined as $J = I/A$, where I is current; A is area of the hollows; $A = N \cdot L \cdot D$, N is the number of units. The Δm is the whole target weight loss.

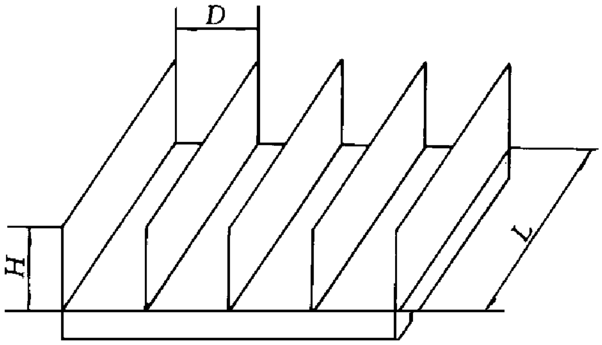

Fig. 2 Structure of multiple hollow cathode target

3 RESULTS AND DISCUSSION

3.1 Relationships between current density and voltage and pressure

In accord with the structure of the multiple hollow cathode, the current density increased with increasing the working voltage. But the effect of working pressure is more complicated. At first, the current density increased with increasing the pressure, then the current density reached a maximum, at last after the maximum the current density would decrease with increasing the pressure continuously. All of these phenomena resulted from the current density increasing with the pressure and the number of A^+ at lower pressure. But at higher pressure, when the pressure increased, it resulted in the separation of negative glow zone, the effect of the discharge of hollow cathode weakened and the ionization rate decreased, then the current density decreased (as shown in Fig. 3).

3.2 Relationships between current density and cavity width

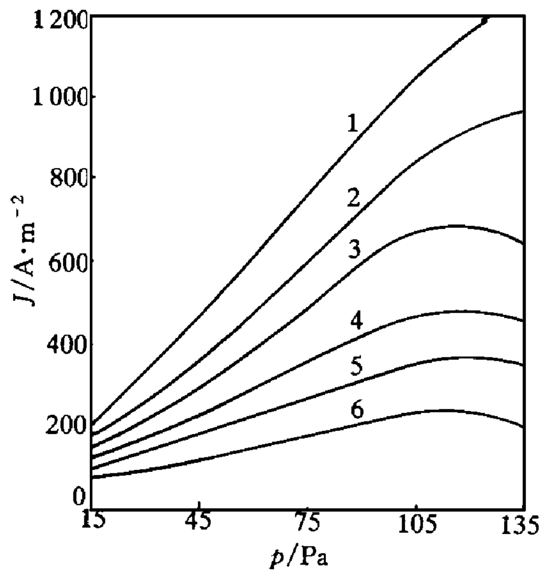

Fig. 3 Relationships between current density (J) and voltage (V) and pressure (p)
1 —1 000 V; 2 —900 V; 3 —800 V; 4 —700 V; 5 —600 V; 6 —500 V

The cavity width is a very important parameter for the hollow cathode, when other parameters are constants, the relationships between the cavity width and the current density were shown in Fig. 4. With increasing the cavity width, the current density will decrease. But when D is much smaller at low pressure, it is difficult to ignite the hollow cathode discharge, so that normal D is larger than 5 mm.

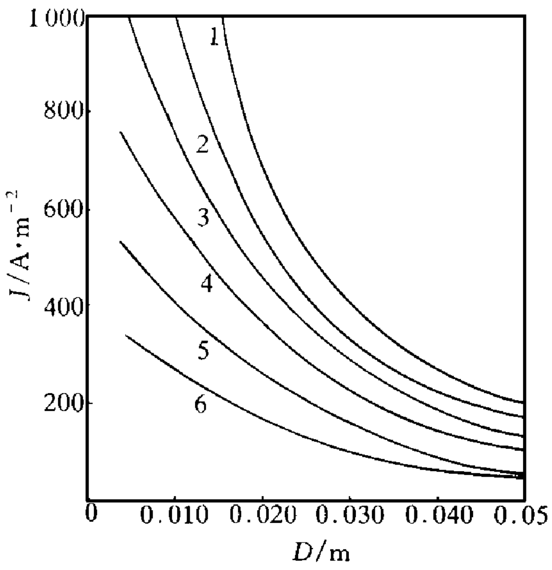

Fig. 4 Relationships between current density (J) and voltage (V) and hollow width (D)
1 —1 000 V; 2 —900 V; 3 —800 V; 4 —700 V; 5 —600 V; 6 —500 V

3. 3 Relationship between J and ratio of height to width $H \cdot D^{-1}$

Owing to the $H \cdot D^{-1}$ increasing, the area of discharge and the number of electrons vibration increased, which makes J increase with $H \cdot D^{-1}$. The results were shown in Fig. 5.

3. 4 Relationships between Δm, J and $H \cdot D^{-1}$

The target sputtering rate is important for the multiple hollow cathode target, so Δm is used as an evaluation parameter. Results indicate that when other parameters are constants, the weight loss of the target increases with J and $H \cdot D^{-1}$ increasing, But when $H \cdot D^{-1}$ increases, Δm increasing tendency became slow gradually, results were shown in Fig. 6.

3. 5 Fabrication mechanism of Mo coating layer

The metallic corpuscles sputtered from the multiple hollow cathode sputtering target, in the experiment, the target is made of pure Mo, then reached the nearby sample surface. With action of the reverse bias, these metal atoms would be ionized or would become directional motion atoms caused by ions collision, absorbed and deposited on the sample surface, then the coating layer would be formed. The microstructures of Mo coating layer were shown in Fig. 7. There is a diffusion layer (α- phase zone) between the

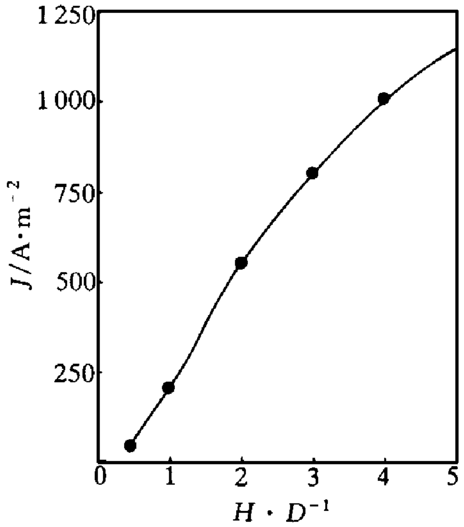

Fig. 5 Relationship between J and $H \cdot D^{-1}$

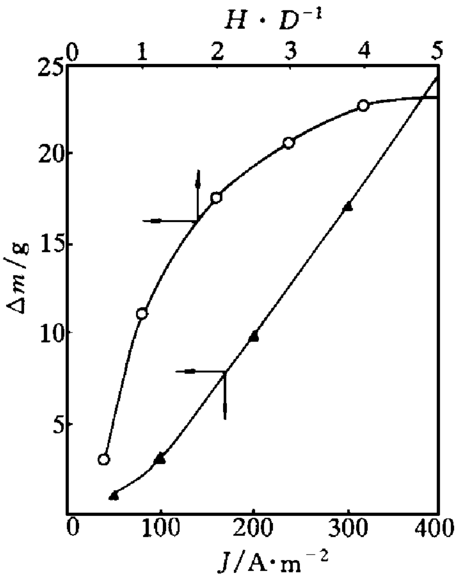

Fig. 6 Relationships between target weight loss Δm and J and $H \cdot D^{-1}$

substrate and coating layer. Usually, when the processing temperature is much higher than 800 ℃, and the metal sputtered from target is fewer than that of coating processing, it is easy to form diffusion layer, otherwise it would form the pure coating layer. As the substrate was high carbon steel, it was difficult to obtain diffusion layer[8]. The reverse bias of sample usually affected the film/substrate bonding strength and film structure. When the reverse bias was lower than 100 V, the film/substrate bonding strength would be weak and the coating layer would be loose. But when the reverse bias was much higher, due to sputtering action of the sample surface, the deposition rate would decrease, so that optimum negative bias voltage was about 200~300 V.

Fig. 7 Morphologies of coatings and substrates
(a) —AISI 1010, 800 ℃, 120 min; (b) —AISI 1080, 800 ℃, 120 min

5 CONCLUSIONS

(1) The multiple hollow cathode, which is made of high-melting point metals or their alloys, has much higher current density and strong cathode sputtering, and can be used directly as an efficient sputtering target.

(2) The current density (J) of the multiple hollow cathode target depends on the working pressure, target voltage and target structure. Usually, J will increase with increasing voltage, pressure and $H \cdot D^{-1}$, and decreasing D.

(3) The sputtering rate to J is direct ratio, and is related to $H \cdot D^{-1}$. When $H \cdot D^{-1}$ equals to 2~ 3, the target will have an efficient sputtering rate and low consumption of electric power.

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