Study of Physical Characteristics of Magnetron Diode Based on Liquid Phase Copper Target

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Abstract – In the paper the physical parameters of magnetron diode with liquid phase target have been studied. The discharge volt-ampere characteristics as well as the temperature dependence of copper target on discharge current are presented in diagrams. The optimal output of magnetron with the liquid phase copper target to the self-sputtering mode has been selected. It was calculated that the sputtering from the liquid phase make the energy inputs for 1-µm coating generation five times lower in comparison to the sputtering from solid phase. The possibility of magnetron operation with the liquid phase target has been shown at a low working pressure in vacuum chamber of about 0.01 Pa. This provides the purity of the applied coatings.

1. Introduction

One of the promising methods of coating generation is magnetron sputtering of metals from liquid phase. It allows combining the advantages of thermal evaporation and magnetron sputtering. The magnetrons with liquid phase target possess very high productivity but are very hard to make. Moreover, they are not studied well enough, and this represents an obstacle for their practical application.

The purpose of this work is to study volt-ampere characteristics of magnetron diode with liquid phase copper target.

2. Configuration of magnetron diode

For the experiments, the magnetron the configuration of which is presented in Fig. 1 was used [1].

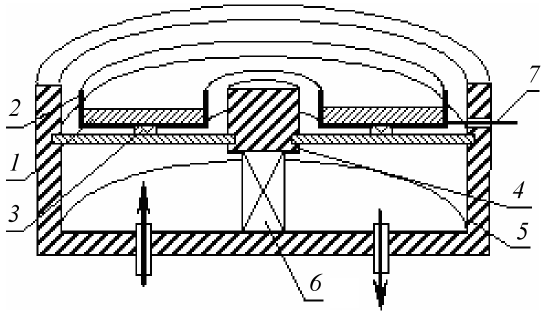

Fig. 1. The configuration of the magnetron with liquid phase target [1]: *1* – copper target; *2* – graphite capsule; *3* – ceramic inserts; *4* – central magnetic conductor; *5* – magnetron body; *6* – constant magnets; *7* – thermal couple

The copper target is placed in graphite capsule which is thermally isolated by ceramic inserts from magnetron body and is surrounded by polar tips of central and external magnetic conductors. The magnet system consists of magnetic conductor and a set of constant magnets cooled by the running water. The capsule temperature is controlled by tungsten-rhenium thermal couple.

Magnetic field at the target surface was created by the constant magnets; the inductance was about $\sim 0.1 \div 0.2$ T. The discharge voltage of the presented magnetron varied within the range of $340 \div 610$ V with the current density of $40 \div 190$ mA/cm^2.

At the beginning, the magnetron operates in a regular mode. The target stays solid. But as the magnetron discharge plasma influences the target gradually heats up and melts. After that, its surface erosion type changes completely because a significant part of atoms loses the target due to evaporation instead of sputtering as in the case of solid target. At that, their quantity can be so big that there is a possibility to switch off the working gas supply, and the magnetron would operate at the metal vapors.

It should be noted that a part of metal ions in the gas-discharge plasma gradually increases also due to their lower ionization potential in comparison to that of argon.

Thus, magnetron shifts to the self-sputtering mode where atoms of target material act as working gas.

The experiment was done according to the following scheme. The working chamber was pumped out to the pressure of 0.01 Pa, argon was introduced and the discharge was ignited at the pressure of 0.1 Pa.

After that, all the required characteristics have been measured.

3. Results of the experiment and discussion

During the experiment two operation modes of magnetron diode have been used:

1) output of magnetron to the operation mode of metal sputtering from liquid phase with the stabilization of supply source by power which was 2300 W;

2) output of magnetron to the operation mode of metal sputtering from liquid phase with the stabilization of supply source by current. The obtained dependences are presented in Figs. 2–5.

When stabilizing the supply source by power the measurements of discharge voltage and current depending on time have been performed.

Practically right after the discharge ignition the current decrease for about 1 A can be observed. This can be explained by the presence of oxide film at the target surface. After it is etched, the sputtering of pure metal begins. This is characterized by the discharge current stabilization. Then the current goes up what is connected to the transfer of target material from solid to liquid phase. The point *B* in Fig. 2 characterizes the phase transfer of copper target. Observing this process, it is possible to say that the target surface placed directly under the plasma localization zone melts first.

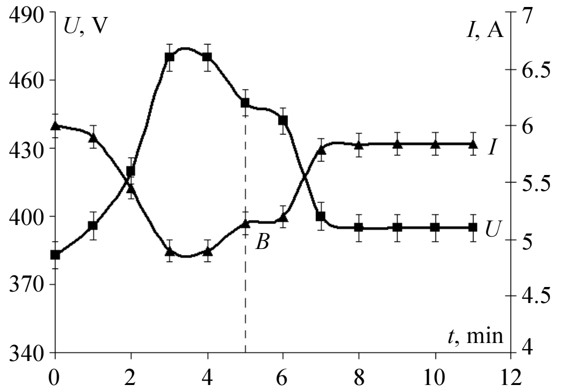

Fig. 2. The dependence of discharge voltage and current on time

After the entire target transfers to the liquid state it does not stay in the quiescent state but revolution with the angular speed of 1.25 s^{-1} begins. This is explained by the interaction of electric and magnetic fields in liquid metal. Due to this the force which makes the liquid metal move to the direction which is stated by the known Fleming's rule appears. Such behavior of liquid metal positively influences the process of sputtering because the removal of residual contaminations from the target surface to the capsule walls takes place.

When the supply source is stabilized by current the dependences of capsule temperature, voltage and film growth speed on the discharge current have been studied. Figs. 3–5 show the obtained results.

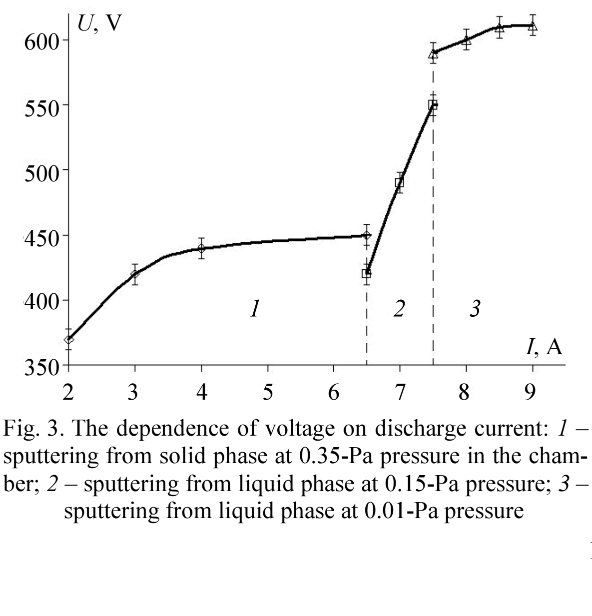

Fig. 3. The dependence of voltage on discharge current: *1* – sputtering from solid phase at 0.35-Pa pressure in the chamber; *2* – sputtering from liquid phase at 0.15-Pa pressure; *3* – sputtering from liquid phase at 0.01-Pa pressure

The curve presented in Fig. 3 can be conditionally divided into three parts which characterize the process of magnetron sputtering: 1) sputtering from solid phase at 0.35-Pa pressure in the chamber 2) sputtering from liquid phase at 0.15-Pa pressure; 3) sputtering from liquid phase with the absence of working gas at 0.01-Pa pressure. Under the initial conditions the target materials completely transfers to liquid state within 4–5 min, the interphase transfer is shown in the diagram as a voltage jump at the discharge current of 6.5 A and pressure in vacuum chamber of 0.15 Pa. The second voltage jump at the discharge current of 7.5 A is connected to the switching off the working gas. This leads to the decrease of working pressure in the chamber down to 0.01 Pa. After that, the operation of magnetron with the liquid phase target stabilizes.

When the supply source is stabilizes by power the process of target melting is accompanied by the increase of discharge current due to the additional ionization of sputtered material vapors and increase of thermal emission current from melt [2]. In the case when current is stabilized the discharge voltage changes step-wise.

Figure 4 shows the dependence diagram of capsule temperature on discharge current. From the diagram it can be seen that there is a rapid growth of temperature up to 1500 °C when the current is 8 A, after that the temperature stabilizes at 1600 °C, this temperature corresponds to the operation of liquid phase magnetron in the absence of working gas.

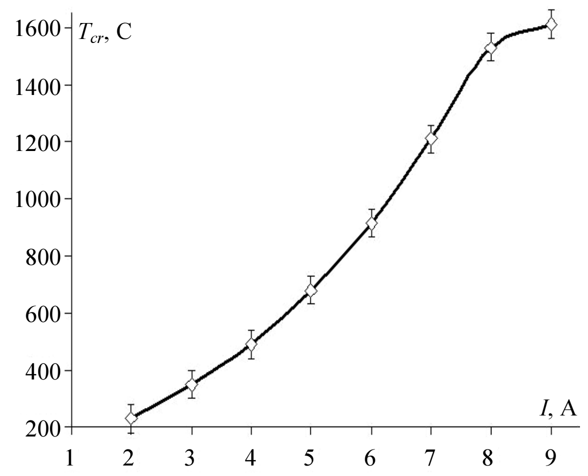

Fig. 4. The dependence of capsule temperature on discharge current

Figure 5 shows the dependence of film growth speed on discharge current. At the initial period of time when the target is in solid state, the speed of inductance grows insignificantly. But at the beginning of target melting a significant increase of film growth speed takes place. After the target transfers to the liquid phase a sharp increase of deposition speed follows. The increase of film growth speed is associated with a significant increase of evaporation component part in the process of liquid phase sputtering.

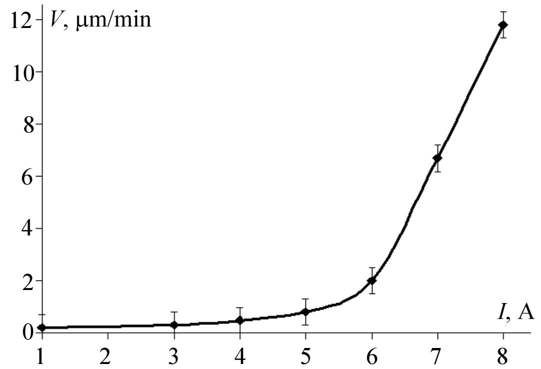

Fig. 5. The dependence of film growth speed on discharge current

From the obtained result, it is possible to calculate the energy value of the obtained coatings at various sputtering modes. Thus, when the sputtering from the solid phase is used for the deposition of coating with the speed of 1 μm/min the discharge power was 2200 W, while from liquid phase the coatings are deposited at the speed of 11 μm/min at the discharge power of 4800 W. Having correlated two modes of operation it is possible to say that the sputtering from liquid phase makes the energy input for 1-μm coating five times lower in comparison to the sputtering from solid phase.

4. Conclusion

Thus during the performance of this work the physical parameters of magnetron diode with liquid phase target have been studied. The volt-ampere characteristics of discharge as well as the temperature dependence of copper target on discharge current are presented in diagrams. The rotation of metal mesh while operating in the liquid phase was discovered. This is explained by the interaction of electric and magnetic fields in liquid metal.

The optimal output of magnetron with liquid phase copper target to the self-sputtering mode has been selected. The speed of copper coating deposition has been altered and is about 11 μm/min.

It has been calculated that the sputtering from liquid target makes the energy input for 1-μm coating generation five times lower in comparison to the sputtering from solid phase.

The possibility of magnetron operation with liquid phase target at low working pressure of 0.01 Pa in vacuum chamber is shown. This provides the purity of deposited coatings.

All the presented results indicate the future of this method for coating deposition.

References

[1] V.V. Zhukov, D.M. Kosmin, V.P. Krivobokov, and S.N. Yanin, *in Proc. 7th Intern. Conf. on Modification of Materials with Particle Beams and Plasma Flows*, Tomsk, 2004, pp. 277-280.

[2] B.S. Danilin and V.K. Syrchin, *Magnetron Sputtering Systems*, Moscow, Radio and Connection, 1982, 68 p.