Parameters of magnetron sputtering gas discharge plasma with a small anode

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Abstract. The plasma parameters of magnetron sputtering with a small cylindrical anode were investigated by electrical methods. Measurements of the current-voltage characteristics of the gas discharge were carried out. It is shown that changes in the operating modes of the magnetron are possible using an additional electrode of small size, to which a positive voltage is supplied from an independent source.

1. Introduction
One of the widely used and effective methods of physical vapor deposition for growing thin films is magnetron sputtering. This method is based on sputtering a solid target with energetic ions from a glow discharge with a strengthened magnetic field. One of the distinguishing features of a magnetron discharge is an applied magnetic field with a strength of about 0.1 T, which serves to keep secondary electrons close to the cathode. In the near-cathode region, the electric and magnetic fields are perpendicular to each other. The result is a closed electron drift in a small region of the cathode layer, which leads to a relatively high plasma density. Sputtering of ions on the target surface plays the role of a supplier of raw materials: sputtered atoms and molecules with kinetic energy of up to 10 eV fly to the substrate, where the film grows [1–2]. The method of magnetron sputtering is widely used to obtain films of various materials, including films of complex multicomponent oxides [3], films on substrates of complex shape [4].

DC magnetron sputtering has several disadvantages. First, during sputtering, a material may be formed that does not have good electrical contact with the surface, which can be a source of arc. Secondly, a part of the product can be deposited on the target, reducing the deposition rate. To improve the systems of magnetron sputtering, various approaches are used: changing the depth of erosion; cathode thickness; pressure, composition and method of inlet buffer times; the magnitude of the magnetic field; the distance between the anode and the cathode, as well as their design [5].

In this work, a system for magnetron sputtering with a small-sized anode is used [6]. A discharge with a small anode has a number of features: radial change in current density, different directions of the drift and diffusion currents, etc. This can lead to the separation of such a discharge [7–8], a sharp increase in the concentration of electrons and ions [9]. In chemically active plasma [10], dust particles can be formed, which are held near the anode or in strata [11–13].
2. Experimental Setup

The experiments were carried out on the plant to study the processes occurring in a gas discharge with a small anode. A steel cylindrical grounded vacuum chamber with a diameter of 50 cm and a length of 60 cm was equipped with windows for viewing the gas discharge, moved electric probe and a dust detection system in the plasma using a laser knife. In the center of the chamber there is a movable graphite electrode (1) having the shape of a cylinder 10 mm long and 7 mm in diameter, shown in figure 1.

The voltage on the vacuum magnetron (2) was supplied from a high-voltage source with a power of up to 600 W and a maximum current of up to 3 A. Power was supplied to the central small electrode from an independent high-voltage source with an output positive voltage of up to 4 kV, with a power of 600 W. Opposite the magnetron there was a 4x4 cm copper substrate (3).

Figure 1. The experimental setup: 1 – graphite electrode, 2 – vacuum magnetron, 3 – copper substrate.

The experiments were carried out as follows. After degassing the chamber walls in an argon discharge and cleaning the substrate, the chamber was pumped out to 0.1 Pa. The working gas was added to it, so that in the flow regime the pressure in the chamber was 1 Pa. The plasma-forming gas was supplied either from a cylinder pre-filled with gas or from a glass flask containing ethanol.

The measurements were carried out in the flow mode: the vacuum pumping operated continuously, the working gas was fed into the chamber through the valve, and stabilization of the pressure in the chamber at a given level was achieved by changing the transfer rate and adding the working gas.

3. Result and Discussion

After annealing in hydrogen, the working gas was fed into the chamber. Then the discharge was ignited by applying a positive voltage to the small anode relative to the chamber walls. Then a negative voltage was applied to the magnetron, which led to sputtering of the graphite surface of the magnetron. By varying the voltage at the anode, it was possible to change the voltage at the magnetron.
3.1. Plasma parameters in argon discharge

A photograph of the discharge glow in argon is shown in figure 2. The substrate (1) on which the coating was applied was placed between the magnetron (2) and the small anode (3). A plasma shell, characteristic of a discharge with a small anode, appeared around the anode.

![Figure 2. Photo of the discharge of magnetron sputtering in an argon atmosphere: 1 – copper substrate, 2 – vacuum magnetron, 3 – graphite electrode.](image)

By increasing the voltage at the anode, it was possible to reduce the voltage at the magnetron, without reducing the electric current to it. The voltage-current characteristic of the gas discharge is shown in Figure 3. Experiments show the positive dependence of the sum of the voltage on the magnetron and the small anode (1) on the sum of their total current. It was shown that the voltage on the magnetron (2) can be reduced by increasing the voltage on the anode (3). The total current to the magnetron did not practically change and was about 15-17 mA.

![Figure 3. Voltage-current characteristic of the gas discharge: sum of the voltage on the magnetron and the small anode (1), voltage on the magnetron (2) and voltage on the anode (3) on the sum of total current.](image)
Thus, it is possible to change the parameters of magnetron sputtering without changing the geometry and characteristics of the magnetron. As it is shown, the increase in current on the magnetron, and, consequently, in the amount of material sprayed is possible without increasing the voltage on the magnetron.

3.2. Plasma parameters in ethyl alcohol discharge

In contrast to a discharge in an atomic gas, in ethyl alcohol around a small-sized anode a spherical stratification occurs, as shown in Figure 4 (left). After the voltage is applied to the magnetron, the stratification disappears (right). It is shown that increasing the voltage at the anode can reduce the voltage at the magnetron. If dust particles appear in the discharge, they concentrate near the anode, without affecting the deposition of the material on the substrate.

![Figure 4. Photo of the discharge with a small anode without applying voltage to the magnetron (on the left) and turning on the magnetron (on the right).](image)

3.3. The structure of the sprayed films

Photos of the coatings obtained on a copper substrate are shown in Figure 5: in argon plasma (on the left) and ethyl alcohol (on the right). The structure of the deposited films is carbon, with a pronounced roughness in one direction. According to energy dispersive X-ray spectroscopy (EDX), the films consist of carbon with a small amount of oxygen (about 5%). In the ethanol discharge the amount of carbon increases by about 20%. Micron-sized particles are also observed on the surface, probably obtained as a result of arcing on the magnetron.
Figure 5. SEM images of material synthesized in argon plasma (on the left) and in methanol (on the right).

Conclusion
This paper presents the results of experimental studies of the characteristics of magnetron sputtering of a graphite material in argon and ethyl alcohol. As a result of research, it was shown that the sputtering parameters can be improved by varying the current and voltage on the small electrode, practically without affecting the characteristics of the magnetron. To improve the quality of sprayed films, it is necessary to use power sources that prevent arcing.

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