Cylindrical Plasmaoptical Magnetron

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Abstract – The use of efficient technologies of magnetron sputtering in producing of the new materials and coatings is worldwide practice. DC and AC planar and cylinder magnetrons of different modifications are used for obtaining the functional and decorative layers. Of those, the cylindrical magnetron sputtering systems are more economic in material usage sense and more suitable for coating wires, fibers and so on. Such sources can work with minimal losses of cathode material. Usually such devices can be efficiently used for treatment of metal targets. In some cases of treatment of non-conductive targets there is a problem of anodes placement, the anode shadow on the object. The usage of plasmaoptical principles in the cylindrical magnetron design allows to build device with the virtual anode for pressure region 10^{-4}–10^{-2} Torr. Thus, we can produce simple and productive source without these disadvantages. Other advantage of such design is approximately 100 % utilization of the cathode surface.

In the present work the first results of such magnetron operating are presented. We can also use this magnetron for precoating treatment. For Cu cathode, the deposition rate of about 500 nm/min on metal substrate under floating potential was obtained with good adhesion.

1. Introduction

DC and AC planar and cylinder magnetron sputtering system (MSS) of different modifications are worldwide used in modern technological processes and scientific applications [1–4]. Of those, the cylindrical MSS are more economic in material usage sense and more suitable for coating wires, fibers, small pieces and so on. Due to their design, such sources can work with minimal losses of cathode material. Main imperfections of such system are known practically since their first appearance: low efficiency of discharge working volume utilization and small coefficient of cathode usage.

Basic scientific efforts are directed mainly to elimination of the second imperfection. At the same time actually the sight is lost of fact that this imperfection is rather a consequence of the first one. Expanding of the discharge existence volume into the working region above cathode-target surface allows efficient increase of the ion flow density on the target and, often, etching zone area on it simultaneously. Creation of conditions for uniform ion generation in a whole magnetron volume above the cathode automatically assures uniform consumption of the cathode material and high rate of its etching.

Proposed aim can be achieve by the use of plasma-optical principle [5] in building of magnetron electromagnetic system.

2. Experimental setup

The experiments were carried out at the setup schematically shown in Fig. 1. Cylindrical magnetron was placed in the vacuum chamber. There were two opportunities to place samples (4) in the internal magnetron volume: one cylindrical sample directly at the axis or several samples in nosepiece (5). Magnetron had magnetic system (1) assembled of permanent magnets and cooled cathode (2). Cathode was cooled due to thermal contact with reservoir with cold water being pumped through it. Cylindrical cathode made of copper with 109 mm internal diameter, 150 mm outer one and 153 mm height was used. Anode system (3) consisted of two moveable units and allowed to set different anodes on various depths from outside section of magnetic system at the magnetron axis. It was possible to obtain continuous anode (when both anode units are connected) or split ones (when there was a gap between the anode units in cathode region localization). Anode electrodes were made of nonmagnetic steel and didn't form magnetron magnetic field. Usually anode unit had 6 stems placed parallel to working cathode surface and uniformly along a circle. Distance between the anode and the cathode could be adjusted. Besides, single anode post could be placed exactly at the magnetron axis. Working gas (argon) was supplied directly into the chamber and produced working pressure from 10^{-5} up to 10^{-2} Torr.

Magnetron magnetic system formed axially symmetric magnetic field similar to that of current coil, Fig. 2. In the picture magnetic system limits are shown by solid parallel line. Rectangles show cathode localization. A field region with the cathode placement was limited by means of counter magnets. That fact led to formation of magnetic trap for electrons above the cathode surface and provided magnetic insulation from the anodes. Magnetic field magnitude at the axis of system was about 0,064 T, and one nearby the cathode surface comprised – 0,075 T. The magnetron operation principle was similar to that of A.I. Morozov plasma lens and was based on the so-called plasma-optical principle. Based on this fact, we called such magnetron as plasmaoptical magnetron or magnetron with spatial charge.

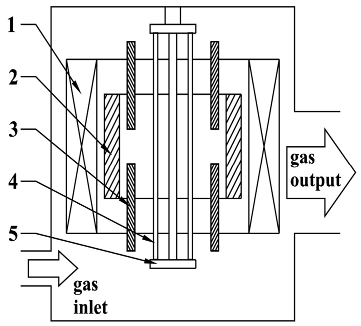

Fig. 1. Principle scheme of the experiments with magnetron. 1 – magnetic system; 2 – cathode; 3 – anode; 4 – samples; 5 – samples holder

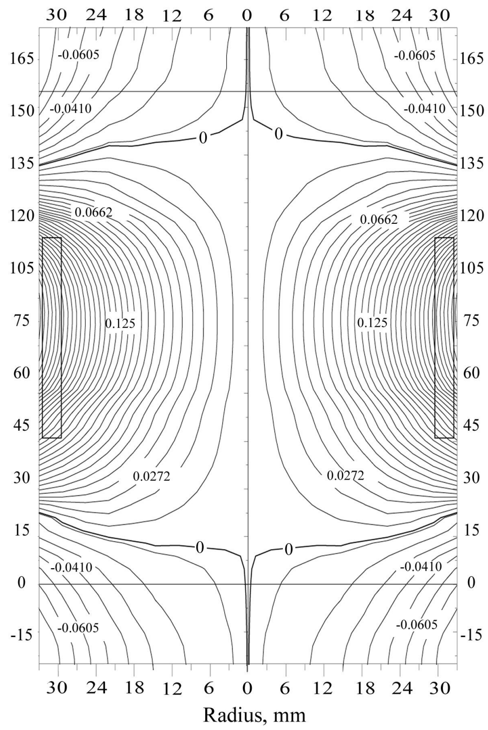

Fig. 2. Magnetron magnetic field lines (mWb)

3. Experimental results

As a rule it is considered that in planar magnetron distance between anode and cathode does not play main role and the discharge glow nature does not depend on pressure. In our experiments plasmaoptical magnetron operated in two regimes initiated two types of discharges. One of them is characterized by weak luminescence in the magnetron volume and low discharge current. High enough breakdown voltage and pressure about 10^{-3} Torr define a limit of existence of this regime. Voltage drop at the discharge is not observed, and current-voltage diagram is similar to linear one. Cathode sputtering is small. High discharge current and high drop voltage in comparison with breakdown one characterize another regime. Transition between weak-current and high-current regime occurs by a jump-like change at certain critical current in weak-current regime; as a rule it is about 30 mA and doesn't depend on pressure. Discharge voltage in high-current regime is about 400V and doesn't depend on pressure as well. Initial breakdown to high-current regime occurs at voltage magnitude that is essentially higher than the following ones. The reason for this fact consists in the cathode pollution during the chamber opening, first of all due to oxidative processes. Weak-current discharge cleans cathode from oxides. It leads to essential pressure hysteresis phenomenon. For example, initial breakdown occurs at pressure of order of $2{,}5^{-3}\cdot10^{-3}$ Torr (discharge voltage is about 1000 V), and in subsequent one can easily decrease it down to $1{,}3–1{,}5\cdot10^{-3}$ Torr. High-current discharge is characterized by intensive luminescence with a color being typical for sputtered cathode material and current magnitude in order 3 A under our conditions.

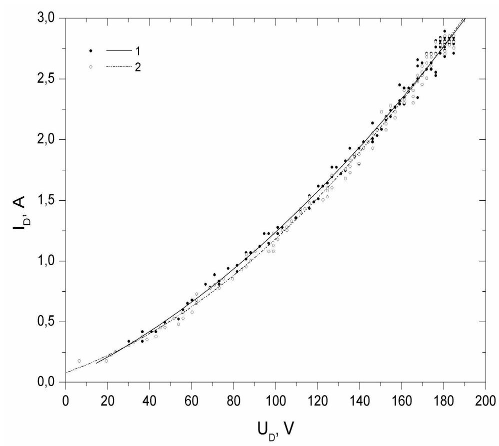

Fig. 3. VA characteristics of magnetron in high-current mode. The magnetic field is 0,07 T, anode to cathode distance is 12 mm; 1 – $5{,}6\cdot10^{-3}$ Torr; 2 – $9\cdot10^{-3}$ Torr

Discharge glow is possible at different distances between the anode and the cathode, but optimization of this parameter allows essential decrease of the pressure limit for high-current regime. At that, correlation between the discharge current and voltage remains practically unchanged. One can see from Fig. 2 that in the central part of the cathode region magnetic field lines extend enough in parallel to the cathode surface. Split anodes lead to formation of virtual ones along these lines. This fact results in the whole cathode surface treatment and the absence of samples surface shadow by the anodes. Experiments show that the magnetron continues its operation until the distance between anode electrodes up to 55 mm. Current-voltage diagram of high-current regime operation with virtual anode length of 35 mm is shown in Fig. 3. After the sputtering experiments, cathode surface inspection shows the whole cathode surface etching with more intensive zone in the central plane of about 60 % width relatively to total cathode height.

Existence of two-regime magnetron operation allows use of the same device both for preparation of

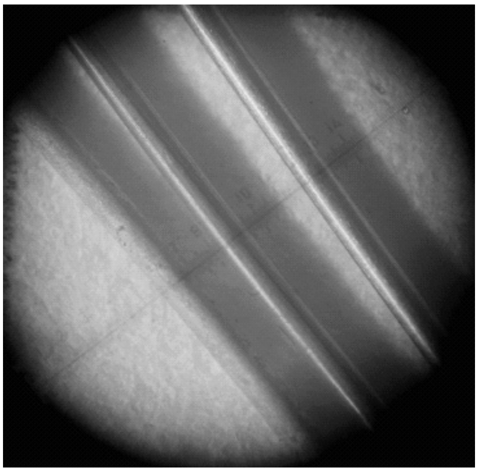

Fig. 4. Stainless steel wires covered with copper and without covering. The first and the second wires are covered by copper and the last one is without coverage

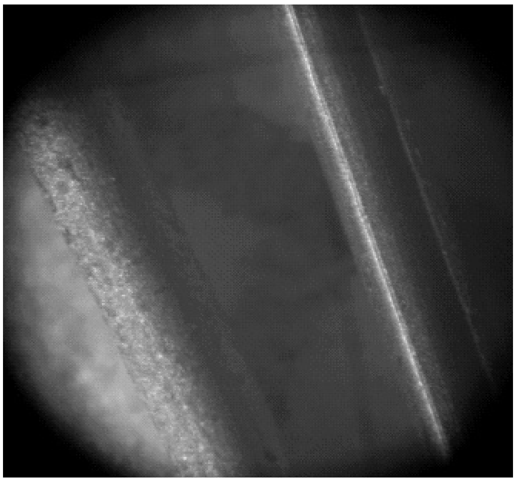

Fig. 5. The first and the second samples separately

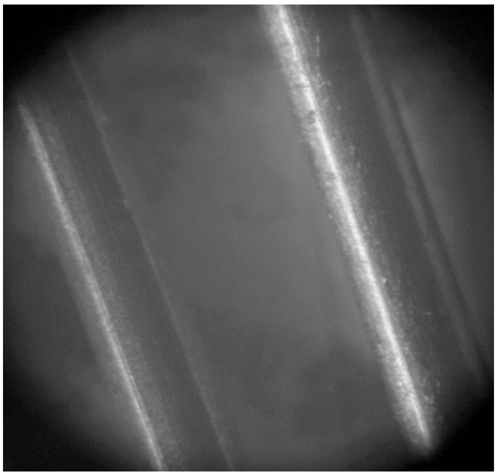

Fig. 6. The second and the last samples

samples for the sputtering and for the sputtering itself. Weak-current discharge exists in whole volume. It results in cleaning of cathode and sample surfaces. It allows sample treatment in regime close to transition from weak-current to high-current ones at first, and after that enables switch to the sputtering by the chamber condition change. Experiments show that the use of such type of treatment increases adhesion of coating indeed. Stainless steel wires coated by copper in such type mode are shown in Fig. 4, 5 and 6. Deposition onto the first sample was performed for the longest time. One can see that structure of the thin deposited layer is similar to that of the substrate. It acquires its individual relief later on.

Deposition rate was about 500 nm/min. Profile of the deposition is shown in Fig. 7. Its asymmetry perhaps results from non-ideal symmetry of magnetic system which can be seen in Fig. 2.

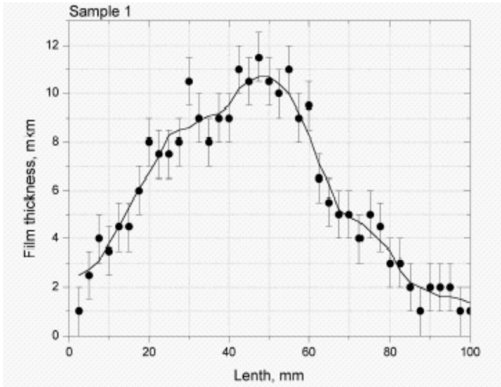

Fig. 7. Distribution of film thickness on length of the sample

4. Conclusions

Discharge in cylindrical magnetron with strong magnetic field in the whole volume has two stages of glowing. Transition between the discharge stages happens in spurts, on reaching of critical current value. High-current stage is characterized by abrupt voltage reduction with current growth in spurts and weak dependence of working voltage on pressure.

Anode to cathode distance and the anode localization contribute to magnetron operation. Efficient high-current discharge glow is possible in the pressure range from $2 \cdot 10^{-3}$ Torr. Magnetron operation with virtual anodes is possible under this condition as well. Preliminary sample preparation before sputtering is possible immediately in this magnetron. High-current mode allows achieving sputtering rate of about 500 nm/min.

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