Study of Features of Magnetron Discharge Stimulating by Intensive Ion Beam

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Abstract – The integrated ion-assisted magnetron deposition system was developed to extend the control possibilities of deposited thin-film layer parameters. This device allows to deposit coatings at rates typical for the magnetron sputtering process with a capability of flexibly controlling the structure and correspondingly the physicochemical properties of the formed layers by means the ion bombardment.

The results of experimental research of the magnetron deposition system discharge characteristics are reviewed as well as ion flow density distribution with divergent geometry of an ion beam, and magnetic field impact. The electromagnetic compatibility features of anodic and cathode discharge systems in a crossed electric and magnetic field in case of joint operation were discovered. The impact of the ion stimulation on initiation and stability of a magnetron discharge under various configurations of a plasma ion process was studied. Possibilities to considerably reduce the breakdown potential for a magnetron discharge down to 200–250 V, and its generating under operating pressures of an order of (4–6) · 10^{-2} Pa were established. Capability to neutralize positive space charge of a low energy ion beam was pointed out.

1. Introduction

The abnormal glow discharge in the crossed electric and magnetic field finds wide application in magnetron sputtering systems (MSS) of a planar type to form thin-film structures [1, 2]. At the same time intensive bombardment of a growing film with high-energy electrons results in defects in the structure of a depositing coating and deterioration of its parameters, as well as builds up a significant thermal load for a substrate that is not always acceptable. When depositing dielectric coatings a discharge is formed on a surface of a growing film, thus promoting its breakdown [3]. One of the ways to eliminate these drawbacks is to work on the condensation surface with directed beams of positively charged particles. Thus the bombardment of a growing film surface with low energy ions from an independent source allows controlling the nucleation properties, morphology, chemical composition, microstructure and internal stresses in the film [4, 5].

A possibility to combine the advantages of plasma and beam methods in a single technological process enables to considerably expand the number of technological approaches to grow thin films and to improve general technical specifications of the equipment, by means of a variety of operation conditions not feasible neither in case of conventional magnetron sputtering nor in case of ion-beam deposition. However, a difference in operating pressures of magnetron sputtering system and autonomous ion-beam sources seems to be a significant obstacle. The results of research presented in papers [1, 6–8] prove the possibility to reduce the operating pressure in the MSS by means of optimization of the size and shape of the magnetic field and additional stimulation of the discharge with an ion beam. Therefore it is considered promising to develop a system featuring joint functioning of MSS and autonomous ion source to perform the procedure of assisted film deposition, that will enable to fully disclose the advantages of the both methods.

2. Experiment

The integrated ion–plasma system (IIPS) has been developed on the background of a double-beam ion source and a planar magnetron. Its schematics is shown in Fig. 1. Constructively the IIPS consists of two independent systems: a magnetron sputtering system of a balanced type and a double-beam ring ion source with conical beams, placed between the magnetron and a substrate in such a way, that the inward ring slit of the source is directed at the cathode target, and the external slit – to the substrate. To investigate the peculiarities of interaction between the magnetron discharges and external ring slit of the source, as well as to vary by damming of ion-plasma flows at the substrate, there has been an option envisaged for lengthwise movement of the cathode unit along the axis of system.

The magnetron sputtering systems is a cathode unit with a system of permanent magnets. Two separate blocks of ganged magnets form both the internal and external magnetic poles and the arc configuration of the field over the cathode surface. To diminish magnetic losses on the reverse side of the MSS the magnet blocks are mounted on a disc of magnetic steel. The cathode target diameter is 80 mm. The system of magnets has direct running-water cooling, and the cathode, for convenient replacement of targets and prevention of the water into the vacuum changer, is cooled indirectly through copper membrane. The work gas was supplied through gas distribution system in the ion-beam system.

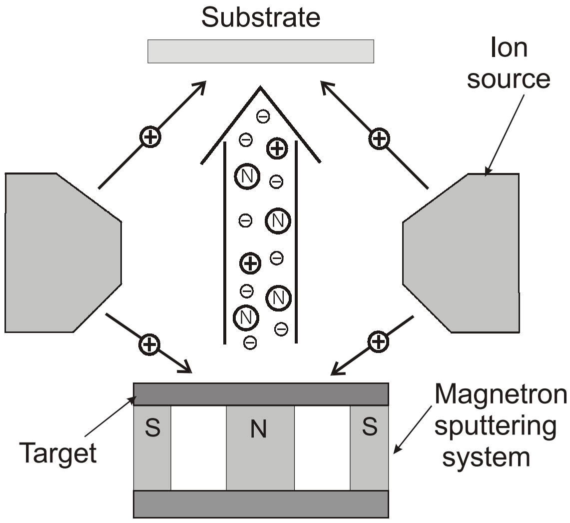

Fig. 1. Schematics of integrated ion-plasma system

The flange ion source was developed on the basis of an accelerator with closed electron drift in the crossed electric and magnetic field. The internal sputtering stage of the source is configured as an accelerator with an anodic layer. The ion beam is cone-shaped and is sloped under 30 degrees to the target surface. The average ion energy is varied within the limits from 400 to 1500 eV under beam current of 200 mA. The external, assisting stage of the ion source may function either as an accelerator with an anodic layer, or as end Hall current accelerator. This is determined by the size and the magnetic flow vector in the accelerating channel, that in their turn are defined by geometric parameters of magnetic circuits and accelerating electrode in the discharge zone. In the configuration of the end Hall current accelerator the ion flow featuring average energies of the order as high as 40–150 eV under discharge current over 1 A is generated.

The magnetic system of the ion source represents a torus-like magnet circuit made of magnetic steel with a solenoid inside. The ion beams are extracted through two ring slits. The solenoid coil is situated beyond the vacuum chamber space.

The gas is supplied to the discharge zones of the ion source through a double-section gas dispenser, consisting of a system of distributing channels, where gas is uniformly distributed about the ring discharge camera perimeter.

The anode system cooling is executed through water coils, to prevent electric breakdown of the cooling water by high voltage.

3. Result and Discussion

As a result of experimental research, the preferable shape of the external stage beam was established to intensify the discharges, the magnetron volt-ampere characteristics were determined under various IIPS configurations, the size of the magnetic field in the electromagnet was optimized.

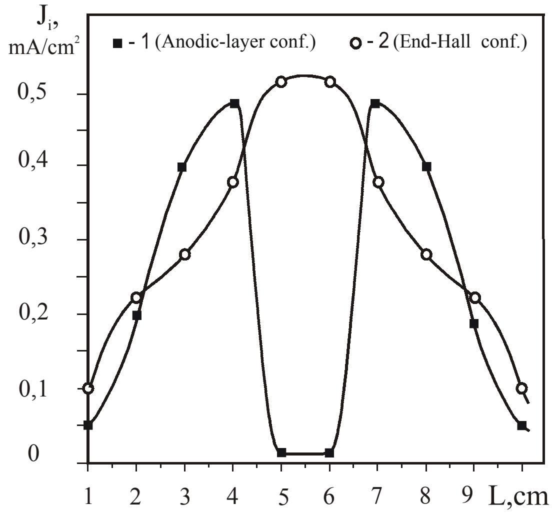

Fig. 2. Ion beam current density distribution under various configurations of the ion source external stage

The curves, represented in Fig. 2 describe variations in the ion current density of the ion source external stage as a function of geometric configuration of the discharge zone. Curve 1 corresponds to the accelerator with anodic-layer configuration, curve 2 – to the end-Hall current accelerator configuration. Researching of the dependencies was done under pressure $6 \cdot 10^{-2}$ Pa in the vacuum chamber at a distance of 90 mm from the ion-source end. As it is obvious from the diagrams, in the first case O-like shape of the ion beam was observed. The dip in the center may be accounted for electrostatic repulsion of high-energy ions (of 1 кeV order) in the center, with further divergence in the direction of the periphery. In the second case the maximum formation was observed in the paraxial area that is associated with radial convergence of the peripheral part of the ion beam and with an increase in the low-energy ion density (200–300 eV) in the vicinity of their trajectories interception in the center. For assisting the second discharge zone geometric configuration corresponds to magnetron sputtering since the ion current density distribution coincide with that of the MSS [2].

In Fig. 3 volt-ampere curves for the MSS with autonomous operation into dependencies on pressure in the vacuum chamber can be seen. The working gas supply was provided through the gas dispenser in sputtering stage of the ion source.

It is evident from the diagrams, that in the discharge voltage range (U_d) from 400 up to 560 V the MSS stable operation is observed under varied discharge current (I_d) from 0.5 to 2.0 A. Under pressure of $1 \cdot 10^{-1}$ and higher in the chamber the discharge current exceeds 3 A, however operation conditions like that are confined to the cooling system capabilities. At the same time with a growth in the working pressure the minimal discharge current of the magnetron discharge also rises. When the pressure is decreased the magnetron discharge current drops to 1.0 A. Besides with a decrease in the pressure down to $7 \cdot 10^{-2}$ Pa the breakdown potential of the MSS discharge initiation remarkably increases and reaches 1000 V.

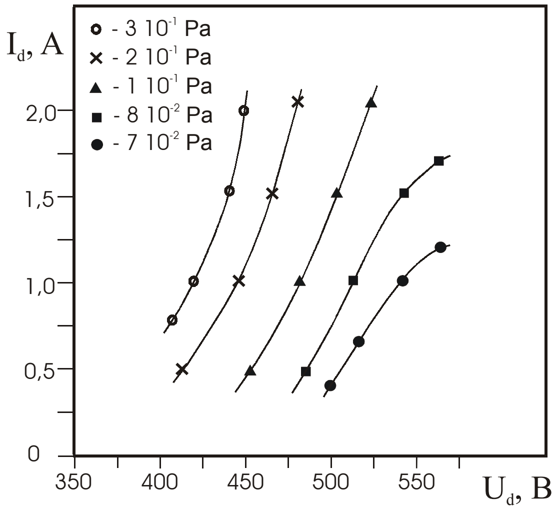

Fig. 3. MSS volt-ampere characteristic with autonomous operation into working pressure dependencies

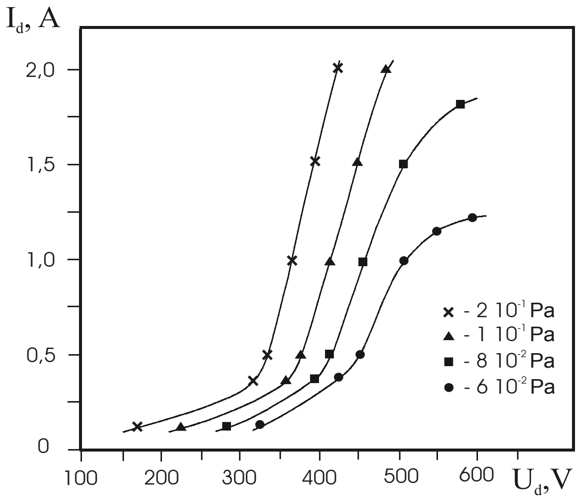

Fig. 4. MSS volt-ampere characteristics when working with ion source sputtering stage as a function of working pressure

Volt-ampere curves for the MSS in the configuration with the ion-beam sputtering stage are represented in Fig. 4. The source discharge current is set as 150 mA. In case of such a configuration considerable reduction in the magnetron breakdown potential down to 170–320 V, depending on pressure in the chamber. Stable ion-stimulated magnetron discharge with acceptable currents (up to 1.3 A) is observed under pressure of $6 \cdot 10^{-2}$ Pa.

The fall in the discharge voltage on the whole is worth mentioning in general, resultant from the ion flow introducing an additional electronic component, appearing when both the target material is sputtered and the working gas ionization degree is increased with sputtered atoms in the ion transit area observed.

Volt-ampere curves when operating two stages of the ion source are represented in Fig. 5. The sputtering stage discharge current was 150 mA, and that of the assisting stage – 300 mA. A further reduction of the initiation and discharge voltages under equal discharge currents may be mentioned. The general nature of dependencies does not change, but the volt-ampere saturation region, corresponding to pressure of $6 \cdot 10^{-2}$ Pa, takes place under discharge current of over 1.5 A. It has been established, that in case of ion stimulation the magnetron discharge may exist up to pressure of $2 \cdot 10^{-2}$ Pa. However the discharge current in these cases does not exceed 0.1 A.

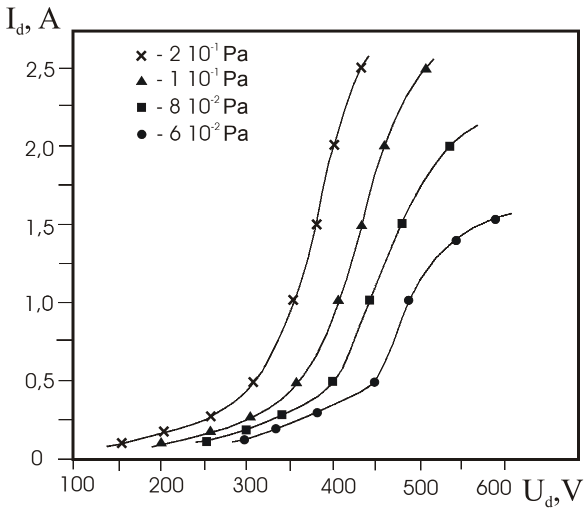

Fig. 5. MSS volt-ampere curves when operating two ion source stages depending on the working pressure

Joint functioning of the ion source and MSS enables to intensify the discharges and to ensure their high stability.

Figure 6 shows curves describing variations in the maximum MSS discharge current depending on the current applied to the ion source solenoid. The measurements were performed under pressure of $8 \cdot 10^{-2}$ Pa in the chamber. Curve 1 indicates, that when the magnetron is working with the internal source stage a more steady growth and fall in the MSS discharge current is observed, that is associated with the direct stimulation of the magnetron discharge with an ion beam. The fall in the current takes place either in case of a weak magnetic field, and hence under low density of the generated ion flow; or when the magnetic field is enhanced and the discharge region is “compressed” over the MSS cathode surface. When the MSS is operating the external stage in the end-Hall current accelerator configuration (ref. Fig. 2, curve 2) the magnetron current is remarkably increased, that may be an evidence of the optimal configuration of its magnetic field and interaction of cathode and anode discharges, however when the solenoid current is increased for more than 4 A an abrupt drop in the MSS current is observed, that is evidently related to the "compression" of the magnetron discharge region.

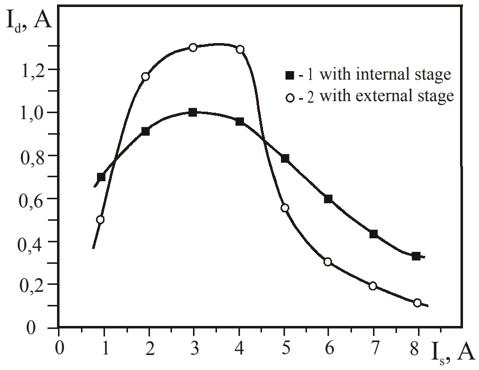

Fig. 6. MSS discharge current as a function of electromagnet current when operating with external and internal stages of ion source

In configurations with external stage as the end-Hall current source, a possibility to completely compensate the positive space charge with an electron flow from the MSS was discovered. In this operation condition the discharge current of over 1 A was gained in the ion source test stage, whereas in case of autonomous inclusion without external neutralizing cathode, this value did not exceed 150 мA.

4. Conclusions

The presented experimental curves fully reflect the advantages of constructive and functional joining of the MSS and ion-beam source. Based on that it is possible to point to a number of the IIPS merits:

– simultaneous functioning of the MSS and ion-beam source enabled to extend the MSS working pressure range;

– to intensify the target sputtering process;

– to increase the magnetron discharge current, especially under pressures lower than $8 \cdot 10^{-2}$ Pa;

– to eliminate the need for a breakdown potential and to diminish the magnetron discharge "burn" voltages.

The joint operation of the magnetron and low-energy ion source integrated in the IIPS (30–150 eV) allowed for implementation of the ion-assisted magnetron deposition without applying specialized tools to compensate positive space charge. Moreover, in future the immediate control of the ion-plasma flow potential seems to become available, and as a consequence, control of the potential on the surface of the condensed film.

Testing of IIPS proved its high stability, stability of operating parameters, simple and efficient control.

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