DESIGN AND RESEARCH OF COMBINED MAGNETRON-ION-BEAM SPUTTERING SYSTEM

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The design and characteristics of a new combined magnetron-ion-beam sputtering system are presented. The system allows coating deposition both by means of magnetron discharge, and by sputtering of complex composite targets by high-energy ion beam. Computer simulation and optimization of magnetic field topology on the system, which is common for the magnetron discharge and the Hall-type ion source, have been carried out. The ignition curves, current-voltage characteristics of the system, in dependence on gas type and pressure, magnitude and topology of magnetic field have been researched both for autonomous operation of the planar magnetron discharge and ion source and for their combination. Spatial distributions of ion current are also presented.

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INTRODUCTION

Thin films of composite materials, which have a high melting point, hardness and corrosion resistance, are widely used as functional coatings in various fields of science, technology and industry. Usually such coatings are obtained by method of reactive magnetron sputtering of metals in the environment of chemically active gases as well as by ion-beam sputtering of composite targets involving ion bombardment [1-5]. Changing the magnetron sputtering processes parameters (gas pressure, substrate temperature, target-substrate distance, sample potential) it is possible to vary the flows of charged and neutral particles participating in the film formation. This makes possible synthesis of coatings of different structure and composition, with variety of physical and mechanical properties [4]. Studies have shown that at film deposition from atomic and molecular flows with ion bombardment the effect of *shock-activated ordering* of the structure of the growing film is observed [5].

Combined ion-plasma systems with electric E and magnetic H fields, satisfy the requirements of the technology of reactive ion-plasma synthesis and deposition of composite coatings [6-9]. It is the magnetic field in these devices that makes it possible to reduce the operational pressure, to localize the region of generation of active particles, and to form, in combination with electric fields, directed flows of activated particles: sputtered atoms, ions of different energy and radicals. Such systems consist of two or more independent plasma modules – gas-discharge magnetrons, sources of ions and chemically active particles [8]. Together with industrial applications, these systems are suitable for basic research of the effects of ion bombardment on microstructure, elemental and phase composition, physical properties of the film.

The purpose of the present research was to develop and characterize a new combined magnetron-ion-beam sputtering system (CMSS) which combines a Hall-type ion source and planar magnetron sputtering system. This system is primarily intended to study coating growth under different ion bombardment conditions.

1. EXPERIMENTAL SETUP

The schematic diagram of the developed deice with diagnostic equipment is presented in Fig. 1. The technological vacuum chamber with dimensions 240×240×120 mm is pumped by a turbomolecular pump TMN-1500, with pumping rate of 700 l/s in the pressure range $1\cdot10^{-5}…2\cdot10^{-3}$ Torr.

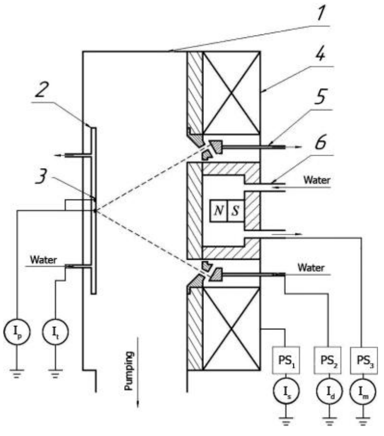


Fig. 1. Schematic diagram of the experimental setup with CMSS: 1 – vacuum chamber; 2 – water cooled sample holder; 3 – flat probe for ion current density measurement; 4 – solenoid; 5 – anode of the ion source; 6 – magnetron

The ion source forms a conical coinciding beam of gas ions with the angle of 60°, diameter of 100 mm (near the anode 5) and thickness of 5 mm. The flat conductive electrode 2 with diameter of 140 mm located at a distance of 100 mm from the end of the ion source is used for sample holding and ion beam monitoring.

During the investigation of integral characteristics of the CMSS, the following parameters were monitored:

I_s – solenoid current;
I_d – anode current of the ions source;
I_m – magnetron;
I_t – ion current to the sample holder 2;
I_p – ion current to the flat probe (5 mm diameter);
U_d – positive voltage on the ion source anode;
U_m – negative voltage on the magnetron target.

Measurements of I_d, U_d, U_m, I_m, I_s were carried out with the help of internal meters of DC power supplies.

The magnetic system design of the CMSS provides simultaneous formation of magnetic field of the ion source and of the magnetron. Using the solenoid 4 (see Fig. 1), it is possible to change the configuration of the magnetic field lines (MFL) in the magnetron, and to realize different types of magnetron discharge. The MFL topology at various solenoid currents, calculated using the "Femm 4.2" software, are given in Fig. 2.

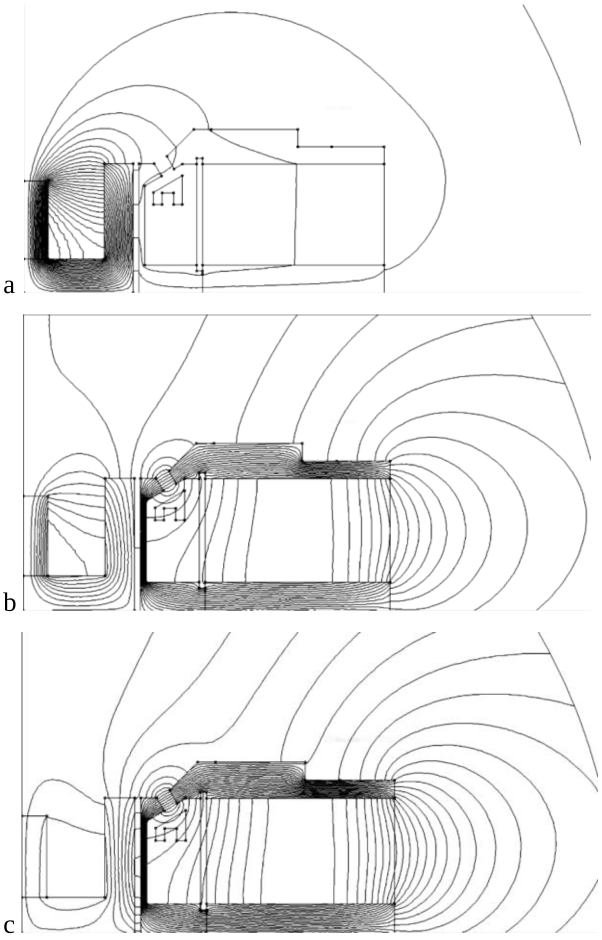


Fig. 2. The topology of magnetic field lines in CMSS at different solenoid currents (a – 0 A; b – 0.5 A; c – 3 A)

Magnetic field strength in the center of the magnetron target can be adjusted in the range of 300…600 Oe, while the radial magnetic field strength in the discharge gap of the ion source varies linearly in the range of 0…4000 Oe with the solenoid current of I_s = 0…4 A.

Radial distributions of ion beam current density were measured either moving flat probe or by etching of silicon dioxide films of 0.35 μm thickness on silicon substrates.

2. EXPERIMENTAL RESULTS

2.1. ION SOURCE

Typical ignition curves of discharge in the ion source for different gas pressures are presented in Fig. 3. One can see that when the pressure is reduced, the curves are shifted to the region of higher values of U_d and I_s, but their shape does not change qualitatively.

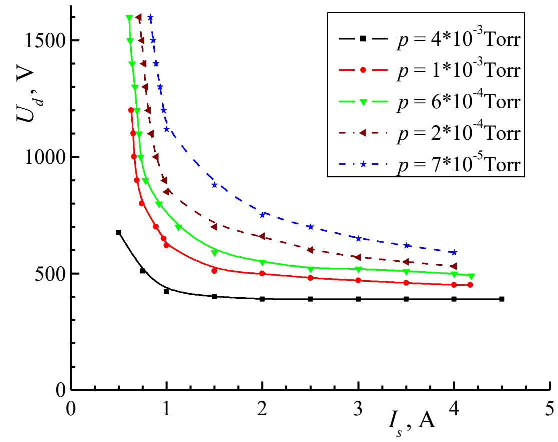


Fig. 3. Ignition curves of discharge in the ion source at different Argon pressures

The dependences of the discharge current I_d and target current I_t on the pressure in the working chamber for three cases are presented in Fig. 4: 1 – the gas is fed into the discharge gap through the anode hollow; 2 – the gas is fed directly into the chamber; 3 – the combined supply of gas into both regions. From the comparison of these graphs, it turns out that the pressure drop between the ion source and the chamber is the about p_i / p_k ≈ 7 and depends on the pumping speed and cross section of the ion source channel.

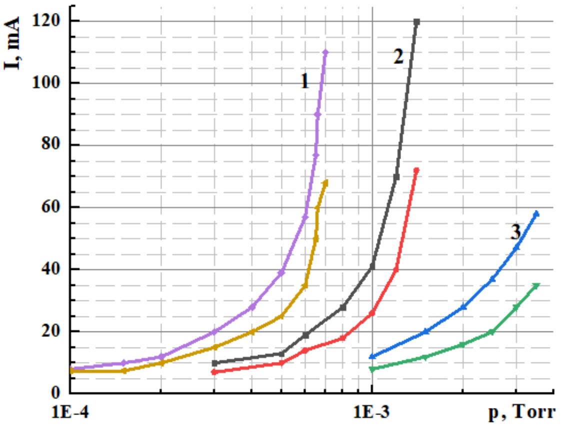


Fig. 4. The dependences of the discharge current I_d and target current I_t on the pressure in the working chamber for three directions of gas input

When the gas pressure in the discharge gap reaches the critical value p_i = (3…4) × 10^{-3} Torr the discharge jumps from acceleration to plasma regime. The current-voltage characteristics (CVC) and ion current distribution outside the source are essentially different in these regimes.

Fig. 5 shows the CVC of the discharge at different pressures p_k for acceleration mode. In Fig. 6 dependencies of the discharge voltage U, current on the table of I_t and magnetron current I_m on the discharge current I_d are presented.

Fig. 7 exhibits radial distributions of the ion current density for the acceleration and plasma modes of operation of the ion source.

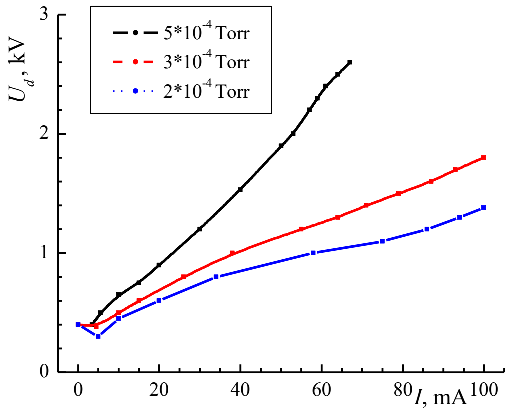


Fig. 5. Current voltage characteristics of ion source in acceleration mode under different Argon pressures

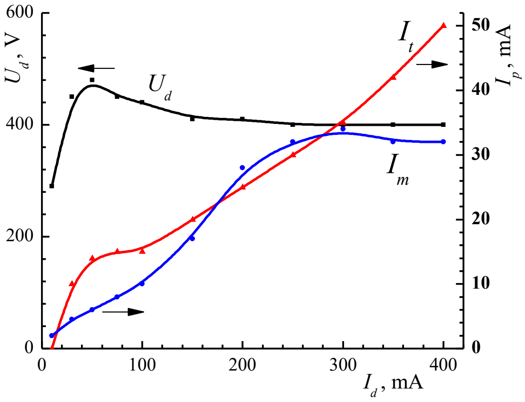


Fig. 6. Current voltage characteristics of ion source in plasma mode. Argon pressure $p = 2 \times 10^{-3}$ Torr

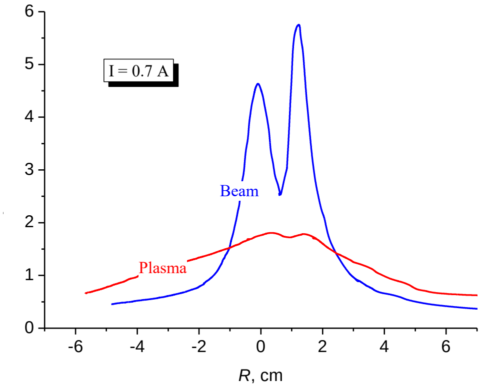
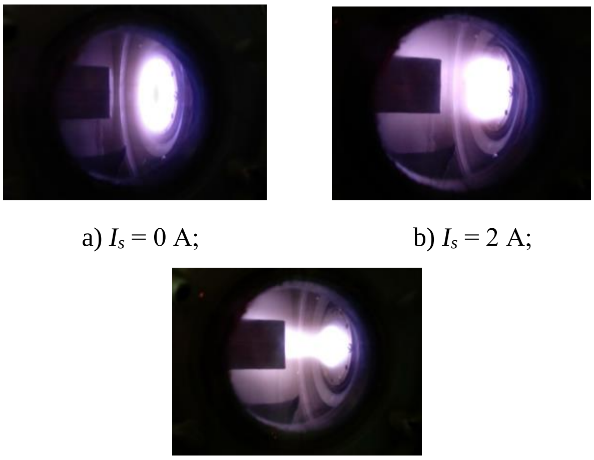


Fig.7. Radial distribution of ion current density for the acceleration and plasma modes of ion source

2.2. MAGNETRON DISCHARGE

The planar magnetron with a stainless steel target (76 mm in diameter and 6 mm in thickness) was mounted near the focus point of the conical ion beam (see Fig. 1). The magnetron anode, depending on the MFL topology, was the walls of the chamber or the table for samples. DC power up to 300 W was applied to the magnetron.

Depending on the configuration of MFL, which is determined by the ratio between the solenoid magnetic field strength and the field of central permanent magnet, three types of magnetron discharge can exist (Fig. 8).



a) $I_s = 0$ A;

b) $I_s = 2$ A;

c) $I_s = 4$ A.

Fig. 8. Photo of the magnetron discharge for three values of solenoid current I_s

In the case (a) (see Figs. 2,a; 8,a) the unbalanced magnetron of the first type is realized, when a significant part of the MFL starting from the target terminate at the walls of the vacuum chamber.

In the case (b) (see Figs. 2,b; 8,b), when almost all MFL starting from the center of the target terminates at the target the balanced magnetron mode takes place.

In the case (c) (see Figs. 2,c; 8,c) the unbalanced magnetron discharge of the second type is realized, when a significant part of the peripheral MFL finishes on the sample table and focuses the electron flow.

As experiments have shown, with the change of MFL topology the main characteristics of the magnetron discharge are substantially changed, particularly the region of the existence of magnetron discharge by the gas pressure and CVC.

Ignition curves of the magnetron discharge for different solenoid currents are presented for three cases: for grounded table, for floating table, and for simultaneous operation of the ion source and of the magnetron discharge are presented in Fig. 9. As can be seen from the figure, the deviation of the MFL topology from the balanced magnetron (I_s = 0.5 A) leads to a significant increase in the minimum pressure of magnetron discharge existence. Magnetron CVC with stainless steel target at different gas pressure are presented in Fig. 10.

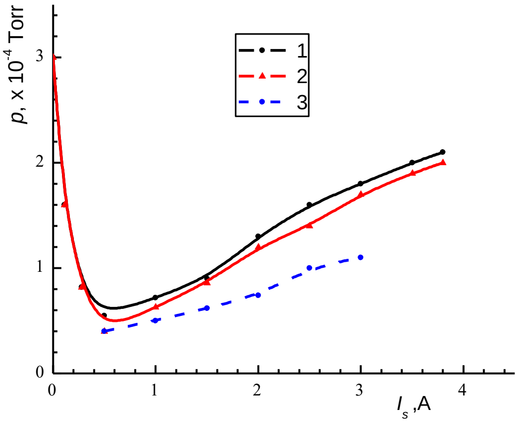


Fig. 9. Ignition curves of magnetron discharge depending on solenoid current I_s at different gas pressures

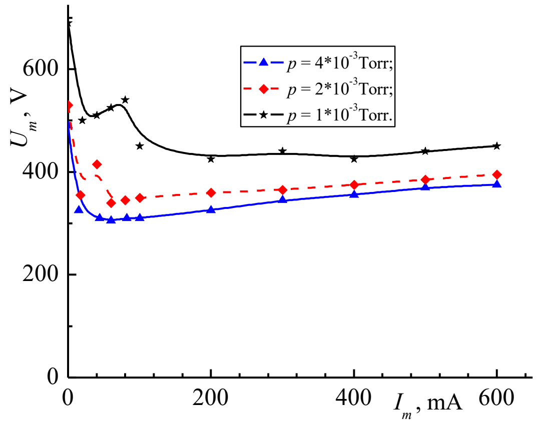


Fig. 10. CVC of magnetron discharge at different gas pressure

CONCLUSIONS

Investigation of the discharge characteristics at simultaneous operation of magnetron and ion source has shown a number of positive features of this approach:

1. The activation of the ion source (even with a small discharge current of about 10 mA) leads to a significant 1.5…2 times decrease in the minimum pressure of the existence of the magnetron discharge (see Fig. 9).
2. The presence of the ion beam leads to decrease in the magnetron discharge voltage of 50…100 V and stabilizes its operation at a gas pressure less than 10^{-3} Torr.
3. Operation of the magnetron discharge can compensate the current of ion beam due to electron flow to the table generated by the magnetron discharge. This is of great importance during ion beam processing of dielectric samples and at deposition of dielectric coatings.

Thus, the main result of the work is the creation of a compact combined magnetron-ion-beam sputtering system with specific parameters satisfying requirements of industrial application. The system allows a coating to be deposited both by means of magnetron sputtering and by sputtering of composite targets by high-energy ion beam.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ КОМБИНИРОВАННОЙ МАГНЕТРОННО-ИОННО-ЛУЧЕВОЙ РАСПЫЛИТЕЛЬНОЙ СИСТЕМЫ

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Разработаны и исследованы характеристики новой комбинированной магнетронно-ионно-лучевой распылительной системы с удельными параметрами, отвечающими требованиям промышленного производства. Система позволяет наносить покрытия как с помощью магнетронного разряда, так и путем перераспыления сложнокомпозиционных мишеней высокоэнергетическим ионным пучком. Исследованы кривые зажигания, разрядные характеристики в зависимости от типа и давления рабочего газа, величины и топологии магнитного поля как при автономной, так и при совместной работе планарного магнетронного разряда и источника ионов. Исследованы пространственные характеристики потоков ионов.

РОЗРОБКА ТА ДОСЛІДЖЕННЯ КОМБІНОВАНОЇ МАГНЕТРОННО-ІОННО-ПРОМЕНЕВОЇ РОЗПОРОШУВАЛЬНОЇ СИСТЕМИ

С. Дудін, О. Ткаченко, А. Щибря, С. Яковін, О. Зиков, Н. Єфименко

Розроблено та досліджено характеристики нової комбінованої магнетронно-іонно-променевої розпорошувальної системи з питомими параметрами, які відповідають промисловому виробництву. Система дозволяє наносити покриття як за допомогою магнетронного розряду, так і шляхом перерозпорошення складнокомпозиційних мішеней високоенергетичним іонним пучком. Досліджено криві запалювання, розрядні характеристики в залежності від типу та тиску робочого газу, величини та топології магнітного поля як при автономній, так і при сумісній роботі планарного магнетронного розряду та джерела іонів. Досліджені просторові розподіли потоків іонів.