PROBE MEASUREMENTS OF PARAMETERS OF DENSE GAS-METALLIC PLASMA IN THE INHOMOGENEOUS MAGNETIC FIELD OF A PLANAR MAGNETRON DISCHARGE

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The paper presents measurements of the electron temperature and plasma concentration in both stationary and pulsed operation modes of a longitudinal planar MDC with a magnetically insulated anode in stationary and high-current pulsed operation modes with a high-voltage impulse voltage addition. The measurements were carried out according to the standard procedure for Langmuir double probes. The obtained volt-ampere characteristics of a double probe show that the electron temperature increases by a factor of two in the pulsed mode of operation of the magnetron in comparison with the steady-state regime, and the density of the pulsed plasma increases by three orders of magnitude.

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INTRODUCTION

Currently among the ion sputtering systems in thin-film technology, the so-called high-power pulse spraying (HiPIMS - High Power Impulse Magnetron Sputtering). The bottom line is to take advantage of the evaporation and spraying method in one process. It is known that the sputtering takes no more than 15 % of the energy flux of the ion bombarding ions, and the remainder causes the target to be heated up to the melting point. In addition to physical sputtering, the flow of matter is formed due to a vaporized substance. This significantly increases the rate of deposition of coatings, and also improves the adhesive properties of films. In high-power sputtering, the principle is the same, the only difference is that, because of the large pulse power densities, the fraction of ionized atoms in the flow sharply increases (from 5% in systems with a classical magnetron to 60...80%), which also significantly affects surface morphology and the crystallization form of the synthesized coatings. The energy spectrum of ions coming from the discharge plasma to the target cathode determines the sputtering coefficient of the target material and, consequently, the performance of such devices.

In the model of magnetron sputtering for a plasma of a certain composition, its state is determined mainly by the electron temperature and the plasma concentration, and these two parameters are affected by the discharge power, gas pressure, discharge current density, displacement, etc.

In paper [1], a thousandfold increase in the sputtering rate of the MDC target and the mass transfer of metal to the sample under study was experimentally obtained with a combined stationary-pulsed discharge regime in comparison with the steady-state regime. However, the reasons for such a significant increase in the efficiency of the sputtering process of the target remained unclear.

This work is devoted to measurements of the electron temperature and ion density both in the stationary and pulsed modes of operation of the longitudinal planar MPC with a magnetically insulated anode in stationary and pulsed operation modes with an additional pulsed high-current high-voltage power supply [1-3]. The measurements were carried out according to the standard procedure for Langmuir double probes [4].

1. EXPERIMENTAL EQUIPMENT

In Fig. 1 presented a block diagram of an installation for studying the discharge parameters by a double Langmuir probe. The experiments were carried out at a facility of the type NNV-6.6-I1, modernized for the purpose of using a planar MSS with a copper sputtering target of size (45×180) mm^2.

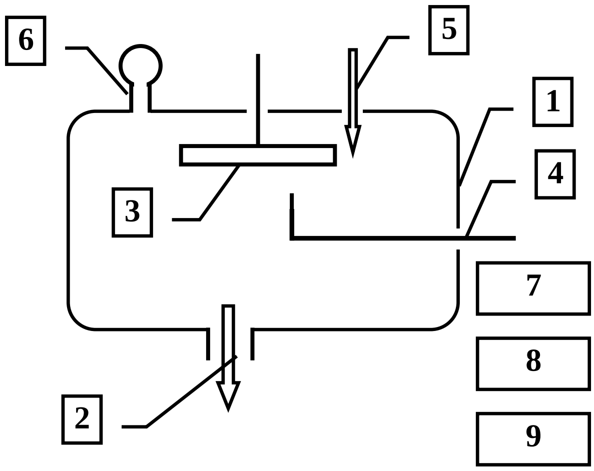

Fig. 1. Block diagram of the installation for studying the plasma parameters by the Langmuir double probe: 1 – vacuum chamber; 2 – vacuum pumping; 3 – MSS; 4 – probe; 5 – gas inlet; 6 – vacuum sensor; 7 – magnetron power supply; 8 – switching power supply; 9 – power supply of the probe

The magnetic field of the arch configuration above the target surface was created with the help of permanent magnets located under the target. An additional arched pre-anode magnetic field was also created by a system of permanent magnets located on the anode magnetic circuit [3]. The working pressure in the chamber was set at a level of $5 \cdot 10^{-3}$ *Torr* and was ensured by the continuous discharge of the working gas (argon) directly into the discharge region. A pulsed power supply unit of a capacitive type with a thyristor switch ensured the supply of a single pulse of a voltage of 3 *ms* duration and an amplitude of up to 1.5 *kV* to the cathode-anode gap. Power supply of probes, MPC and pulse block was carried out through a separation transformer, which ensured reliable isolation on the power circuits and protection against spurious signals.

To determine the temperature and concentration of electrons in magnetron discharge plasma, a double Langmuir probe was used, which consisted of two cylindrical tungsten pins 3 *mm* in length, 0.5 *mm* in diameter each. The distance between the pins was 3 *mm*. The probe was located perpendicular to the target surface at a distance of 120 *mm* from it.

The reliability of probe measurements was provided by monitoring the discharge current at a high voltage pulse with the help of Rogowski's belt. At the same time, an oscillogram of the potential of the Langmuir probe was recorded in the pulsed mode of the magnetron discharge against the background of the stationary voltage applied to the probe. According to the volt-correction on the oscillogram of the probe in the pulsed mode and the magnitude of the input resistance of the oscilloscope, the probe current was determined.

2. RESULTS OF EXPERIMENTS AND DISCUSSION

In Fig. 2 shows typical oscillograms of the potential of the Langmuir probe and the discharge current of the MSS in a high-current pulse mode of operation with a high-voltage impulse voltage.

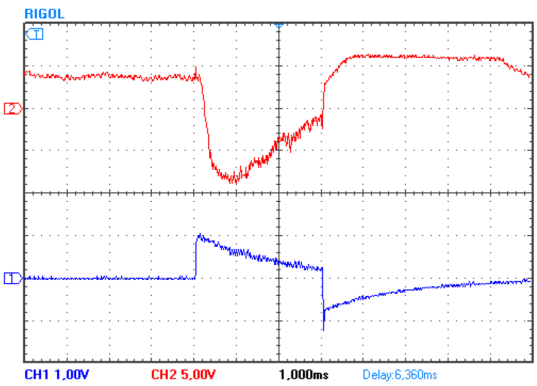

Fig. 2. Typical oscillograms of the potential of the Langmuir probe and discharge current of the MSS in the high-current pulse mode of operation with a high-voltage impulse voltage (blue line – discharge current, red – probe oscillogram in pulsed mode)

The current-voltage characteristic of the Langmuir probe in the steady-state mode of operation of the MSS and the current-voltage characteristic of the double Langmuir probe of the combined magnetron discharge obtained in accordance with the described procedure are shown in Fig. 3.

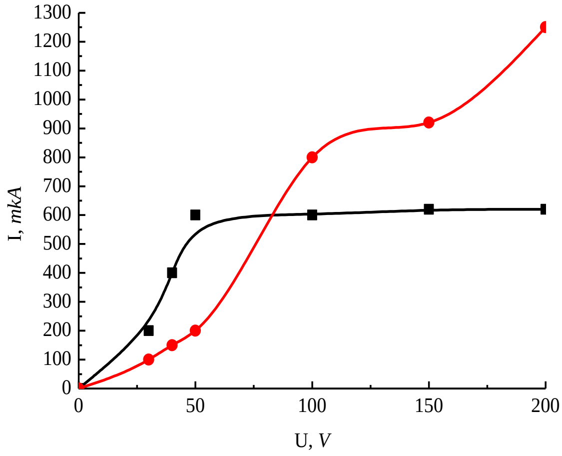

Fig. 3. Volt-ampere characteristic of combined magnetron discharge (black line – steady-state discharge burning mode, red – pulse mode)

The volt-ampere characteristics (Fig. 3) of the probe have a classical form and allow us to determine electron temperature and plasma density by standard methods both in the stationary and in the high-current pulsed mode of operation with a high-voltage impulse voltage [4].

As a result of processing the volt-ampere characteristics of the probe, the following values of the electron temperature and plasma density were obtained: in the steady-state discharge mode of the MSS: $T_e = 15.5$ *eV* and $n_i = 2.34 \cdot 10^{11}$ cm^{-3}; in the high-current pulsed mode of operation of the MSS with a high-voltage impulse voltage addition: $T_e = 38$ *eV* and $n_i = 2.22 \cdot 10^{14}$ cm^{-3}.

CONCLUSIONS

Thus, it is shown that in the combined stationary-pulsed mode of operation of a high-voltage pulse voltage additive, the temperature of the plasma electrons increases more than twofold. In this case, the density of the pulsed plasma turns out to be three orders of magnitude higher in comparison with the steady-state discharge regime in the MSS.

The obtained experimental data reliably explain the thousandfold increase in the efficiency of the sputtering of the MBS target in the high-current pulse mode of the magnetron discharge.

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ЗОНДОВЫЕ ИЗМЕРЕНИЯ ПАРАМЕТРОВ ПЛОТНОЙ ГАЗОМЕТАЛЛИЧЕСКОЙ ПЛАЗМЫ В НЕОДНОРОДНОМ МАГНИТНОМ ПОЛЕ ПЛАНАРНОГО МАГНЕТРОННОГО РАЗРЯДА

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Представлены измерения температуры электронов и концентрации плазмы как в стационарном, так и в импульсном режимах работы продольной планарной МРС с магнитоизолированным анодом в стационарном и сильноточном импульсном режимах работы с высоковольтной импульсной добавкой напряжения. Измерения проводились по стандартной методике для двойных зондов Ленгмюра. Полученные вольт-амперные характеристики двойного зонда показывают, что температура электронов увеличивается в два раза в импульсном режиме работы магнетрона по сравнению со стационарным режимом, а плотность импульсной плазмы возрастает на три порядка.

ЗОНДОВІ ВИМІРИ ПАРАМЕТРІВ ЩІЛЬНОЇ ГАЗОМЕТАЛЕВОЇ ПЛАЗМИ В НЕОДНОРІДНОМУ МАГНІТНОМУ ПОЛІ ПЛАНАРНОГО МАГНЕТРОННОГО РОЗРЯДУ

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Представлено виміри температури електронів і концентрація плазми як у стаціонарному, так і в імпульсному режимах роботи повздовжньої планарної МРС з магнітоізольованим анодом у стаціонарному та сильнострумовому імпульсному режимах роботи з високовольтною імпульсною добавкою напруги. Виміри проводилися за стандартною методикою для двійних зондів Ленгмюра. Отримані вольт-амперні характеристики двійного зонда показують, що температура електронів збільшується в два рази в імпульсному режимі роботи магнетрона в порівнянні у стаціонарним режимом, а концентрація імпульсної плазми зростає на три порядки.