HIGH-CURRENT PULSED OPERATION MODES OF THE PLANAR MSS WITH MAGNETICALLY INSULATED ANODE WITHOUT TRANSITION TO THE ARC DISCHARGE

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In this work, the characteristics of high-current operation modes of planar magnetron sputtering system with magnetically insulated anode without going to the arc discharge mode is investigated. The possibility of using an additional spatially modulated magnetic field in the anode region to prevent a transition from the magnetron to the arc is shown experimentally. It is shown that the use of such a magnetic field configuration provides efficient interruption of the arc current without external forced shutdown of the discharge.

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INTRODUCTION

Magnetron sputtering systems (MSS) are widely used in coating technology on substrates of different materials [1]. Recently, the pulsed mode of operation MSS becomes of interest, because it can reduce the energy impact on the surface of the treated sample [2]. The synthesis coatings of complex composition, expanding the range of process parameters, the uniformity of the coating of complicated topography, as well as the relative stability of arcing on the target is provided by the high-density pulsed plasma. Pulse magnetron discharge can exist in a wide range of parameters; it has many forms, depending on the type of electrode materials and design, configuration and magnitude of the magnetic field, the characteristics of the power supply. One of the main factors determining the performance of the MSS is the configuration of the magnetic field above the cathode of the magnetron, which defines temperature influence on treated surface and uniformity of the deposited coating [3, 4].

In this paper we investigate the features of high-current modes of a planar MSS with a magnetically insulated anode without transition to the arc discharge mode. Experimentally was demonstrated the opportunity of using additional spatially modulated magnetic field in the anode region to prevent the transition of the magnetron discharge operation mode to the arc one.

1. EXPERIMENTAL METHODS

The experiments were performed using a longitudinal planar MSS with copper sputtering target size of 45×180 *mm*. Cross-section and planar magnetic field configuration of MSS has been calculated using the standard software package FEMM 4.0 [5].

The MSS and equipment were shielded with a screen biased at floating potential. MSS design assumed the setup of external anode magnetic circuit under which 16 permanent magnets with a cubic shape (10×10×10 *mm*) were installed. The distance between adjacent magnets was 27 *mm*. The polarity of the magnets was selected in such a way that the direction of the near-anode additional external magnetic field and the magnetic field above the cathode coincide.

MSS was located in a vacuum chamber pumped down to a pressure of 10^{-5} *Torr*. Working pressure was maintained due to inlet of the argon gas through the gas distribution system directly above the sputtering target. MSS was operated by a pulsed power supply (no forced limitation of the discharge current or interruptions was used). None of the clamps of the power supply unit is grounded.

In order to provide stable discharge ignition the magnetic trap above the surface of the cathode pre-filled by plasma, which was generated using pulse igniter device similar to a Bosticks gun [6]. Voltage to the electrodes of the MSS from the pulsed power source applied with the delay of 10 *μs* after the end of the pulse ignition.

In the experiments, we measured the voltage and current of discharge using capacitive voltage divider, providing isolation from the ground, and a current transformer, allowing registration of pulse processes in a wide range of durations.

2. RESULTS AND DISCUSSION

Fig. 1 shows typical waveforms of the current (upper trace) and voltage (lower trace) at a pressure of $(2\ldots5)\cdot10^{-3}$ *Torr* in the chamber. The duration of the sweep is 5 *ms*. Amplifiers of both signals are positioned on 1 *V/div*, which corresponds to a current of 16 *A* and voltage of 200 *V*.

Shape and duration of the waveforms of current and voltage indicate that after discharge ignition MSS works in a high-voltage mode when the voltage across the electrodes is 200…300 *V* and a current of 18…30 *A* during few milliseconds. At the same time, the high-frequency noise over the constant component of voltage and current evidences short-term micro-breakdown (sparking) on the cathode surface, due to which the discharge voltage value is relatively low in comparison with the stationary mode (300…400 *V*). The value of the discharge current for MSS with such dimensions of the sputtering target significantly exceeds the typical values of the steady-state current level (up to several times). So discharge is unstable with respect to the transition to the arc mode.

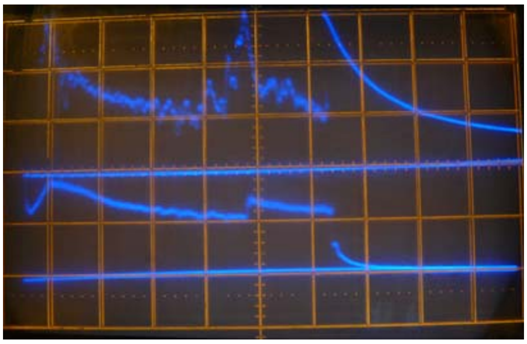

Fig. 1. Waveforms of the current (upper trace) and voltage (lower trace) at a pressure of (2…5)·10^{-3} Torr in the chamber

The transition to the arc mode is accompanied by a sharp increase of the discharge current up to a value of hundreds of amperes and breakdown voltage down to tens of volts. Such failures are regularly seen in a few milliseconds after the ignition of the discharge. However, their duration does not exceed 0.5 *ms* after which a reduction of the discharge current and restoring the high voltage values on the electrodes is observed. Thus, MSS with proposed configuration of the magnetic field may work in conditions with high discharge current. Discharge disruption to the arc mode effectively suppressed by additional near-anode spatially modulated magnetic field, providing additional resistance to the arc current. It is lead to the death of the cathode spots of the second kind. After some time of discharge (from 3 to 12 *ms*) the plasma density in the discharge increases to the value at which the collision frequency becomes comparable to the electron-cyclotron frequency. The effect of additional near-anode spatially modulated magnetic field disappears and the next transition to the arc discharge shortens the discharge gap.

Fig. 2 shows the waveforms of current and voltage at increased pressure in the chamber. The final arc transition occurs much faster, however the serial failures of the arc current are observed. That indicates the death and subsequent rebirth of the cathode spots of the second kind on the target surface.

Fig. 2. Waveforms of the current (upper trace) and voltage (lower trace) at a pressure of 8·10^{-3} Torr in the chamber

Taking into account that the cathode spots move along the zone of erosion in a transverse magnetic field of the magnetron with a velocity of (7…10)·10^3 cm/s, the duration of the bursts and disruptions of arc current on the waveform corresponds to the period of the spatial modulation of the additional near-anode magnetic field.

Fig. 3 shows a photo of the discharge in the MSS. Exposure duration exceeds the duration of the voltage pulse discharge, therefore, one can see place of birth, death and the subsequent rebirth of the cathode spots, as well as their trajectories on the surface of the target.

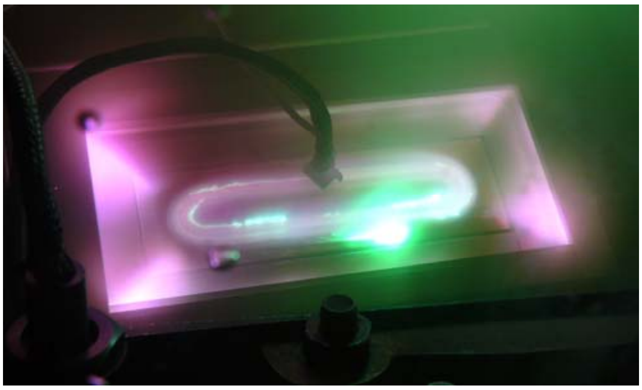

Fig. 3. Image of the discharge in MSS

CONCLUSIONS

In present work pulsed discharges with an average current of the magnetron discharge up to few tens of amperes and durations of up to 10 *ms* are obtained. Such current value substantially exceeds the current in steady-state regimes of the MSS. Taking into account that the characteristic time of formation of the cathode spots of the second kind is 0.1 μs received modes can be considered as quasi-stationary.

Proposed magnetic field configuration using provides an effective interruption of the arc current without externally forced interruption of the magnetron discharge. Voltage and current waveforms of the discharge show that the frequency of pulses of arc failures correspond to the spatial modulation of the magnetic field, and their duration is less than the characteristic time of formation of cathode spots of the second kind. Photographing of the sputtered target during the discharge pulse allow to classify failures as the cathode spots of the first kind (sparks), which significantly increases the erosion of the target material in comparison with the regime of ion-atom sputtering, without generating a droplet phase. Microscopic studies of the deposited coatings shown absence of droplets and solid fragments of the target material.

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СИЛЬНОТОЧНЫЕ ИМПУЛЬСНЫЕ РЕЖИМЫ РАБОТЫ ПЛАНАРНОЙ МРС С МАГНИТОИЗОЛИРОВАННЫМ АНОДОМ БЕЗ ПЕРЕХОДА РАЗРЯДА В ДУГОВОЙ РЕЖИМ

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Исследованы особенности сильноточных режимов работы планарной магнетронной распылительной системы с магнитоизолированным анодом без перехода разряда в дуговой режим. Экспериментально показана возможность использования пространственно-модулированного дополнительного магнитного поля в прианодной области для предотвращения перехода режима работы из магнетронного в дуговой. Показано, что использование такой конфигурации магнитного поля обеспечивает эффективное прерывание дугового тока без принудительного внешнего выключения магнетронного разряда.

СИЛЬНОСТРУМОВІ ІМПУЛЬСНІ РЕЖИМИ РОБОТИ ПЛАНАРНОЇ МРС З МАГНІТОІЗОЛЬОВАНИМ АНОДОМ БЕЗ ПЕРЕХОДУ РОЗРЯДУ В ДУГОВОЙ РЕЖИМ

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Досліджені особливості сильнострумових режимів роботи планарної магнетронної розпилювальної системи з магнітоізольованим анодом без переходу розряду в дуговий режим. Експериментально показана можливість використання просторово-модульованого допоміжного магнітного поля в прианодній області для запобігання переходу режиму роботи з магнетронного в дуговий. Показано, що використання такої конфігурації магнітного поля забезпечує ефективне переривання дугового струму без примусового зовнішнього вимикання магнетронного розряду.