FEATURES OF COATINGS DEPOSITION IN COMBINED STATIONARY-PULSED OPERATION MODE OF THE MAGNETRON SPUTTERING SYSTEM

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The results of researches of the combined stationary-pulsed operating mode of longitudinal planar magnetron sputtering system (MSS) with a magnetically isolated anode and with the additional pulsed high-current, high-voltage power supply are presented. It is shown that the increasing of duration of the pulse discharge with decaying current and voltage is not advisable for effective intensification of MSS target sputtering process and increase of mass transfer of substance on substrate**.** The existence of the optimal ratio between parameters of the stationary and pulsed magnetron discharge is shown.

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INTRODUCTION

Magnetron sputtering systems (MSS) are widely used for receiving of thin coating [1]. Technologies of coatings deposition in MSS allow creating metallic films for various purposes. Among the all kinds of pulsed discharges MSS occupy a special place. Pulsed magnetron sputtering devices attract more and more attention of specialists not only as a tool for the deposition of coatings with unique characteristics, but also as a high-density plasma source. Extremely high concentration pulsed magnetron plasma discharge provides opportunities to develop new methods of surface modification. For realization of these technologies the experimental study of spatial and temporal parameters of the discharge and plasma in the magnetron sputtering system in a pulsed mode should be carried out.

MSS with a magnetically insulated anode and with an additional high-current high-voltage pulsed power supply (PPS) are studies early in [2, 3]. Designed PPS can operate in different modes of initiation of pulsed magnetron discharge:

1. Creating of preliminary plasma and filling the magnetic trap of MSS are realized by means of Bostic gun. A high voltage is applied to the electrodes of MSS from a capacity battery and is initiated the single pulsed discharge. The duration of discharge pulse is defined by capacity battery.
2. A single pulse of high voltage from the capacitive battery is applied to the electrodes of MSS on the background of stationary magnetron discharge. The pulse duration is determined by capacity of battery.
3. A single pulse of high voltage with fixed duration or a sequence of such pulses is applied to the electrodes of MSS on the background stationary magnetron discharge with a controlled duty cycle.

Researches of MSS worked in the mode of the combined stationary-pulsed discharge with the full capacity of PPS (mode 2) showed that the pulsed discharge of MSS had uniform distributed diffuse nature, as well as stationary mode [4]. After application of the pulse of voltage (U_{imp} = 1.1 *kV*) on the electrodes of MSS, current disrupts which is typical for the arc mode. However, the value of voltage decreased only to 800 *V*, and further there was a discharge of PPS capacity storage on active resistance of the discharge gap during 5…6 *ms*.

The maximum discharge current value of the pulse was varied by including the resistance varied in the range 0.5...2.0 Ω with increment of 0.5 Ω in discharge circuit. The dependence of copper coating mass on maximal value of the discharge current was measured. It has shown that the coating mass is proportional to the maximum of the discharge current. Mass transfer during of stationary and pulsed processes increases by three orders of magnitude in comparison with only stationary mode of magnetron operating. However, a pulsed discharge current has a maximum value only at the initial moment of discharge, and then decreases exponentially to zero together with voltage, during 5...6 *ms*. Thus, the processes that determine the effectiveness of sputtering and target material transfer on a substrate during the subsequent course of pulsed discharge remained unexplored.

This paper presents the results of studies of the combined stationary-pulsed operating mode of longitudinal planar MSS with magnetically insulated anode with an additional application to the electrodes a single pulse of high voltage fixed duration on the background stationary mode of magnetron discharge.

1. EXPERIMENTAL EQUIPMENT

Experiments were carried out in the installation of type UVN-71 by using a planar MSS with copper sputtering target (45×180) mm^2. The magnetic field of the arched configuration above the surface of target was created by means of the permanent magnets. Working pressure in the installation's chamber was provided by the continuous inlet of working gas (argon) in the range of pressures $(1…8)\cdot10^{-3}$ *Torr* directly in the area of discharge. The pulsed power module of capacity type with a thyristor switchboard provided application of single voltage (1.5 *kV*) pulse on the cathode-anode interval.

In the experiments the deposition of copper coatings was produced on a subject glasses during 90 *s* of stationary magnetron discharge with the parameters of $U_p = 350\ V$, $I_p = 0.5\ A$ at pressure of argon of $P = (2\ldots5)\cdot10^{-3}$ *Torr*. Single-pulse voltage value of $U_{pulse} = 1.1\ kV$ and duration $\tau_{imp} = 1, 2, 3, 4$ or 5 *ms* was put between a cathode and anode of MSS on a background stationary voltage of burning of magnetron discharge. The pulse of voltage with fixed duration was formed by the guided force pinch-off and lock of capacity on the equivalent of loading. Using of voltage pulses with greater duration is not correct due to maximal duration of discharge defined by capacitor battery amount 5 *ms*.

Current of pulsed discharge is measured by means of Rogovsky coil. The received values have achieved of $I_{imp} = 6\ldots7\ A$ and exponentially fell during of pulse. The oscillogram of floating potential of isolated substrate holder was also monitored for control of processing of subject glasses. Average current was calculated from the received oscillograms on the base of 10 points during pulse.

Determination of efficiency of mass transfer of copper was produced by the method of weighing of subject glasses with the deposited coatings on analytical scales. Weighing results allowed to define mass transfer of copper on unit of area of subject glasses during an pulse (ρ ($g\cdot cm^{-2}$)), and also stream of mass of the copper deposited during an pulse (j($g\cdot s^{-1}\cdot cm^{-2}$)).

2. RESULTS OF EXPERIMENTS AND DISCUSSION

Oscillograms of the current (blue curve) of single pulsed discharge of different duration on a background of stationary discharge and potential (red curve) of substrate holder are shown in Figs. 1-4. Those results were received at different pulse duration (τ), average current during of pulse (I_{av}), stream of mass of the deposited copper during of pulse (j) and mass transfer during of pulse (ρ).

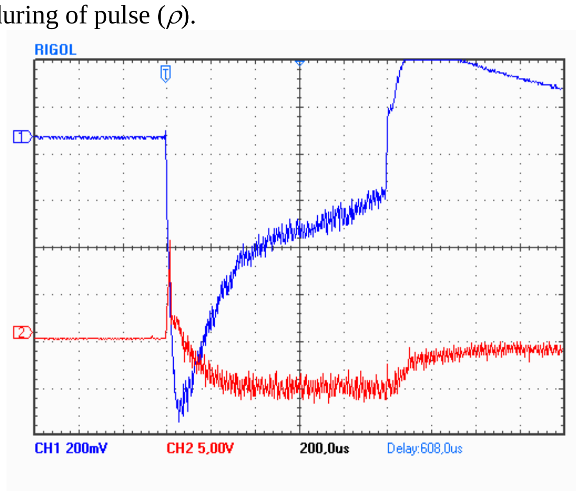

Fig.1. Oscillograms of current of single pulse discharge on a background a stationary discharge (top) and potential of substrate holder (bottom) (τ = 1 ms, I_{av}*= 1.4 A, j =0.021* $g\cdot s^{-1}\cdot cm^{-2}$*, ρ = 0.021* $g\cdot cm^{-2}$*)*

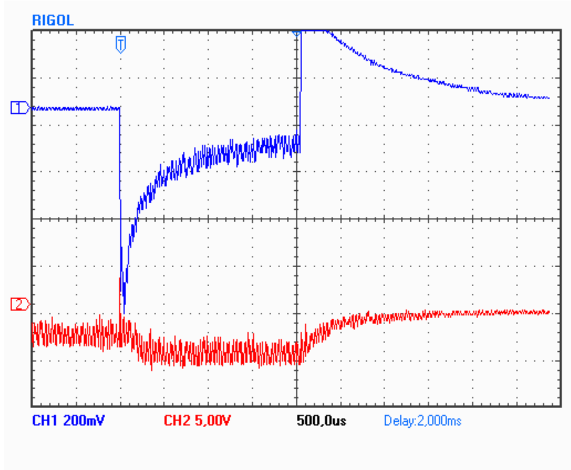

Fig. 2. Oscillograms of current of single pulse discharge on a background a stationary discharge (top) and potential of substrate holder (bottom) (τ = 2 ms, I_{av} *= 0.8 A, j = 0.015* $g\cdot s^{-1}\cdot cm^{-2}$*, ρ = 0.029* $g\cdot cm^{-2}$*)*

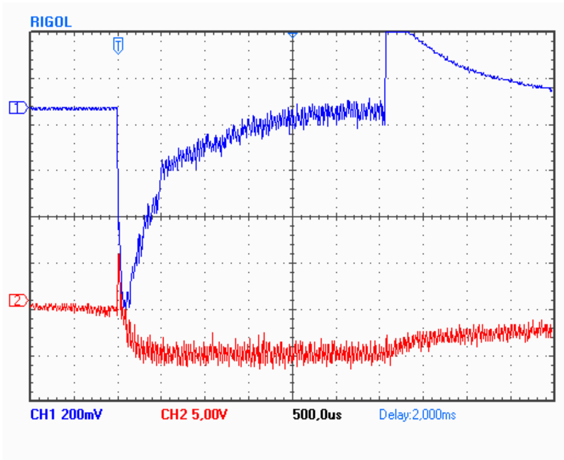

Fig. 3. Oscillograms of current of single pulse discharge on a background a stationary discharge (top) and potential of substrate holder (bottom) (τ = 3 ms, I_{av} *= 0.5 A, j = 0.011* $g\cdot s^{-1}\cdot cm^{-2}$*, ρ = 0.033* $g\cdot cm^{-2}$*)*

Waveforms of current of pulsed discharge are similar to the waveforms of current obtained in the PPS operation mode 2. At short pulses with duration of 1…3 *ms* current has non-zero value at the end of pulse. However, a current achieved of zero at the duration of pulse of 4 *ms* due to the capacity of PPS is full run down. Initial maximal value of current of pulsed discharge is determined by many factors related to the processes of pumping, gas inlet, stability and exactness of the set pressure of working gas in a chamber. Thus it becomes difficult to control together with other main parameters of stationary discharge in MSS. The initial maximum of current pulse was oscillated in a range $I_{imp} = 6\ldots7\ A$ even with careful repetition of the initial parameters for the pulsed discharge. Therefore, in the experiments we did not attempt to maximize absolute repetition of the initial pulse current, but its value is taken into account when determining the average pulse current.

The oscillograms of floating potential of substrate holder are similar regardless of pulse duration. In initial moment of pulse of voltage the substrate holder has

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potential U_{sub} = +(10…20) *V*, and through 200…300 μs potential of substrate holder becomes negative U_{sub} = –10 *V* and saved to such during all pulse of voltage.

Dependences of average current during of pulse (*I* (*A*)), flow of mass of the deposited copper are brought during an pulse ($j(g{\cdot}s^{-1}{\cdot}cm^{-2})$) and mass transfer during an pulse ($\rho(g{\cdot}cm^{-2})$) from a pulse duration τ are shown in Fig. 5 .

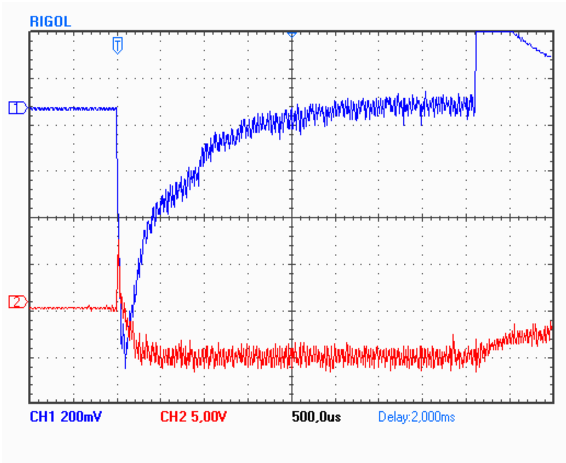

Fig. 4. Oscillograms of current of single pulse discharge on a background a stationary discharge (top) and potential of substrate holder (bottom) (τ = 4 ms, I_{av} = 0.45 A, j = 0.008 $g{\cdot}s^{-1}{\cdot}cm^{-2}$, ρ = 0.032 $g{\cdot}cm^{-2}$)

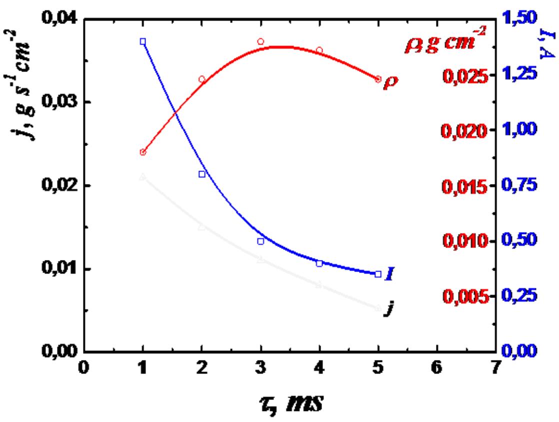

Fig. 5. Dependencies of average current (I (A)), flow of mass of the deposited copper ($j(g{\cdot}s^{-1}{\cdot}cm^{-2})$) and mass transfer ($\rho(g{\cdot}cm^{-2})$) during of pulse from the pulse duration τ

Average current of pulse with the pulse duration from τ_{imp} = 1 *ms* to τ_{imp} = 5 *ms* reduces approximately in 5 times. At the duration of pulse more than 4…5 *ms*, current goes out on a satiation, that it is caused the slump of pulsed current at such durations to a zero value.

Dependence of flow of the deposited copper mass ($j(g{\cdot}s^{-1}{\cdot}cm^{-2})$) on a pulse duration τ behaves like to dependence of value of average current and with the height of pulse duration from τ_{imp} = 1 *ms* to τ_{imp} = 5 *ms* also diminishes approximately in 5 times.

These results eloquently testify to pointlessness of increase of PPS capacity for the purpose of increasing the duration of pulsed discharge with negative-going of pulsed current and voltage.

Dependence of specific mass transfer for pulse of τ show more dramatic result to us (Fig. 5). Specific mass transfer increases at first with the height of pulse duration, arriving at a maximal value at τ_{imp} = 3 *ms*, and then diminishes substantially.

Such character of dependence of specific mass transfer from pulse duration testifies not only to pointlessness of increase of duration of impulsive discharge with negative-going an impulsive current and voltage but also about existence of certain optimal parameters between stationary and impulsive magnetron discharges.

The obtained results allow supposing that the process of deposition of coatings is accompanied by theirs sputtering by the ions of working gas in the planar MSS with combined stationary-pulsed mode of operations. .

CONCLUSIONS

Features of the combined stationary-pulsed operating mode of longitudinal planar MSS with magnetically insulated anode with an additional application of a single pulse of high voltage with fixed duration have been studied.

Increase the duration of the pulsed discharge is an inadvisable for intensification of process of target sputtering and increases of mass transfer on substrate in MSS.

It is shown the existence of the optimal ratio between the parameters of stationary and pulsed parts of magnetron discharge. At the same time, the increase of maximum of initial current of pulsed discharge lead to improve of efficiency of MMS.

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ОСОБЕННОСТИ ОСАЖДЕНИЯ ПОКРЫТИЙ ПРИ КОМБИНИРОВАННОМ СТАЦИОНАРНО-ИМПУЛЬСНОМ РЕЖИМЕ РАБОТЫ МАГНЕТРОННОЙ РАСПЫЛИТЕЛЬНОЙ СИСТЕМЫ

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Представлены результаты исследований комбинированного стационарно-импульсного режима работы продольной планарной магнетронной распылительной системы (МРС) с магнитоизолированным анодом с дополнительным импульсным сильноточным высоковольтным источником питания. Показано, что для эффективной интенсификации процесса распыления мишени МРС и увеличения массопереноса вещества на подложку нецелесообразно увеличивать длительность импульсного разряда со спадающими импульсными током и напряжением. Показано существование определённого оптимального соотношения между параметрами стационарного и импульсного магнетронных разрядов.

ОСОБЛИВОСТІ ОСАДЖЕННЯ ПОКРИТТІВ ПРИ КОМБІНОВАНОМУ СТАЦІОНАРНО-ІМПУЛЬСНОМУ РЕЖИМІ РОБОТИ МАГНЕТРОННОЇ РОЗПИЛЮВАЛЬНОЇ СИСТЕМИ

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Представлено результати досліджень комбінованого стаціонарно-імпульсного режиму роботи повздовжньої планарної магнетронної розпилювальної системи (МРС) з магнітоізольованим анодом з допоміжним імпульсним сильнострумовим високовольтним джерелом живлення. Показано, що для ефективної інтенсифікації процесу розпилення мішені МРС та збільшення масопереносу речовини на підкладку небажано збільшувати тривалість імпульсного розряду зі спадаючими імпульсним струмом та напругою. Показано існування визначеного оптимального співвідношення між параметрами стаціонарного та імпульсного магнетронних розрядів.