INCREASING OF MASS TRANSFER EFFICIENCY AT MAGNETRON DEPOSITION OF METAL COATING

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The results of technological tests of longitudinal planar magnetron sputtering system (MSS) with a magnetically isolated anode working in pulse-modes with additional pulse heavy-current high-voltage supply source are presented. It is shown that efficiency of mass transfer in the pulse mode overcoating increases by three orders of magnitude as compared to stationary mode of magnetron discharge. Hereat there is no droplet phase at the copper coating that is typical for an arc evaporation of a cathode.

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INTRODUCTION

The coating deposition technology using magnetron sputtering systems (MSS) is widely used in the manufacturing the microelectronic devices, displays, obtaining the functional and decorative coatings of different types of materials [1]. The productivity of the deposition method using MSS is proportional to the power input into the discharge. Taking into account the feature of magnetron discharge to work as a voltage stabilizer one can conclude that the deposition productivity is proportional to the discharge current. The technological task of deposition velocity increasing requires the sufficient increase of discharge current. At the same time when the discharge current in MSS exceeds some critical value then the discharge transition to arc mode happens. The discharge transition to arc mode causes cathode spots of the second type formation and generation of target material droplets which sufficiently worsen the quality of coatings.

In this paper, results of technological tests of longitudinal planar MSS with a magnetically isolated anode working in pulse-modes with additional pulse heavy-current high-voltage supply source are presented. MSS design and its operating modes were reported in [2, 3]. The corrugated magnetically isolated anode was shown to provide the effective current aborting at discharge disruption to the arc mode without magnetron discharge quenching [3, 4]. The scheme of pulse supply source (without a force limiting and current aborting) works well in the technological area of magnetron discharge.

1. EXPERIMENTAL EQUIPMENT

Experiments are carried out using the UVN-71 type unit with installed planar MSS with copper sputtering target with dimensions of (45×180) mm^2. The arched magnetic field above the target surface is produced with permanent magnets located under the target. Working pressure in the chamber is provided by the continuous working gas (argon) supply in the range of pressures $(1…8)\cdot 10^{-3}$ *Torr* directly at the area of the discharge.

The pulse supply source of capacitive type with a thyristor switchboard provides the supply of single-pulse of voltage with amplitude of 1.5 *kV* in the cathode-anode space.

The transformer of current (Rogovsky coil) is used to measure the pulse current amplitude. The voltage on the electrodes of MSS is registered with resistance divider.

In the experiments, the copper coating is deposited on standard subject glasses during 30 *s* of stationary magnetron discharge with the following parameters: $U_p = 350\ V$, $I_p = 0.5\ A$ at argon pressure of $P = (2…5)\cdot 10^{-3}$ *Torr*. The single-pulse of voltage with magnitude of $U_{pulse} = 1{,}1\ kV$ is supplied between the cathode and anode of MSS at the background stationary voltage of magnetron discharge. The limit current of the discharge at the high-voltage pulse is regulated in the range of $I_{pulse} = 60…20\ A$ by the limiting resistance in the pulse supply source changed in the range of 0.5…2.0 Ω to step of 0.5 Ω. Hereat the duration of high-voltage pulse changes in the range of $t_{pulse} = (5…50)\ ms$.

2. RESULTS OF EXPERIMENTS AND DISCUSSION

The measured characteristics of pulse discharge with copper target in argon environmental show that application of pulse supply provides stable work of co-planar MSS during 5…50 *ms*. Hereat the current of magnetron discharge of 60 *A* maintains the high discharge voltage of 350…800 *V*.

The typical oscillograms of voltage (blue line) and current (red line) orf pulse discharge are shown on Fig. 1.

The shape and duration of oscillograms of discharge voltage and current testify that the pulse discharge of MSS has equipartition diffusive character of discharge current, as it takes place in stationary mode. Aborting of the voltage occurs after supplying the pulse voltage of $U_{pulse} = 1.1\ kV$ on the electrodes of MSS, that is typical for an arc mode. However, the voltage falls only to 800 *V*, and then the capacitor of the pulse source discharges on active resistance of the discharge cell during 5…6 *ms*. Splashes of current typical for arc mode transition are not observed on the oscillograms, what also testifies the high-voltage character of pulse heavy-current discharge. Brief voltage disruptions

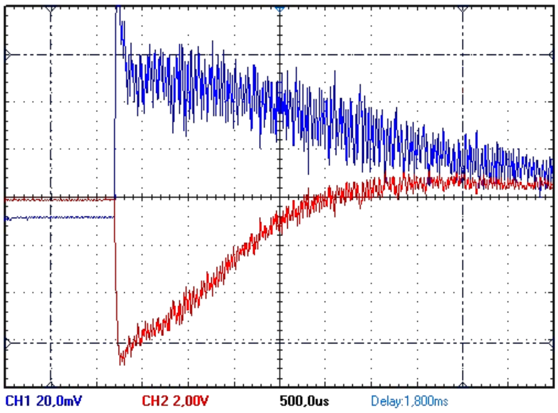

Fig. 1. The typical oscillograms of voltage (blue line) and current (red line) of pulse discharge

of about 100 *V* and current splashes and disruptions which one can see on the oscillograms allow to conclude that there are brief explosions of micro roughness (sparkling) on the surface of the sputtering target (cathode of MSS). However, formation of cathode spots of the second type and transiting to the arc mode with pinching of discharge current do not take place.

Fig. 2. Photo of the sputtering target of MSS after the cycle of technological tests (320 impulses)

On the Fig. 2 the photo of the sputtering target of MSS is shown after the cycle of technological tests (320 impulses). Studying the target surface shows the absence of both substance melting cavities and marks of cathode spots of second type. At the same time, in the area of target erosion there is a sharp display of material structure (grittiness) not typical for stationary MSS. This testifies the intensification of back sputtering. Width of area of target erosion after the cycle of technological tests in the pulse-mode also appears approximately by 20% more than for the stationary magnetron discharge.

Mass transfer efficiency is measured by the method of weighing of subject glasses with the deposited coating on analytical scales. The measuring shows that semilucent copper coating with mass of 0.195 *mg* (±1.5%) is deposited on the test sample set at the distance of 50 *mm* from the center of the sputtering target during 30 *s* of stationary magnetron discharge with the following parameters: U_p = 350 *V*; I_p = 0.5 *A*, argon pressure $P = (2…5)·10^{-3}$ *Torr*. During determining the mass of the coating deposited on test sample in the pulse-mode, one should take into account that this part of mass is provided exactly by a stationary discharge and the high-voltage single-pulse of voltage is put on it's background.

In the pulse-mode, overcoating is produced under steady pressure and parameters of stationary discharge. The peak value of pulse current is in the range of I_{pulse} = 60…20 *A*. This current flows through the limiting resistor of the pulse power supply unit. The resistance can be changed in the range of 0.5…2.0 Ω with a step of 0.5 Ω. Registered duration of high-voltage pulse varies in a range of t_{pulse} = (5…50) *ms*.

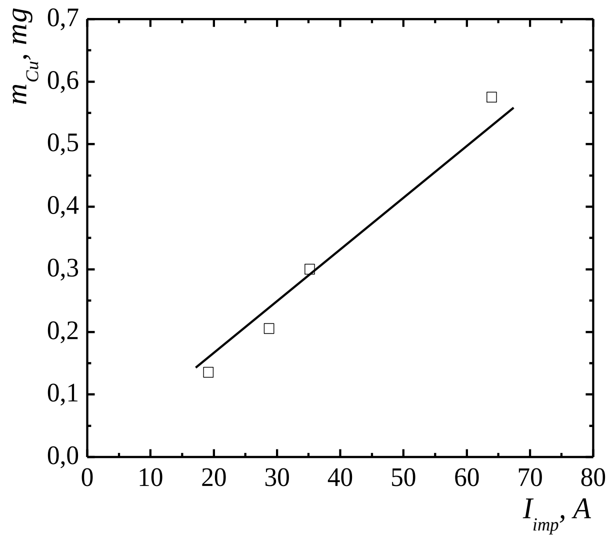

Fig. 3. Dependence of the mass of the copper coating on the maximal value of discharge current in a pulse

On the Fig. 3, the dependence of deposited copper coating mass on the maximal value of the discharge current per a pulse is shown. One can see that the mass of the coating depends linearly on the value of discharge current. The measuring shows that supplying the single-pulse of high voltage increases mass of copper transferred to the treatment sample from the sputtered target of MSS by 2…6 times. The supplying produces from 0.135 *mg* at 19.2 *A* of pulse current to 0.575 *mg* at 64 *A* of pulse current.

Taking into account that the duration of high voltage pulse has a value about a few dozen of *ms* (on the average 23 *ms*) and duration of stationary discharge is 30 *ms*, one can conclude that the main part of the deposited substance is transported to the treatment sample just during the pulse high-voltage heavy-current discharge.

Dividing the transported mass by the duration of stationary and pulse processes shows that the efficiency of mass transport in the pulse mode is by three orders of magnitude higher than in the stationary mode of magnetron discharge.

The microscopic study of the obtained coatings show increasing of coating thickness with the pulse discharge current. The coatings are characterized by good continuity and uniformity. Cavities and friability of structure in the coatings which are typical for ones with high-rate of deposition are not observed. Note that the obtained coatings are characterized by good adhesion and resistance to abrasion. Hereat the droplet phase typical for arc evaporation is not observed in the deposited copper coating.

CONCLUSIONS

Application of the high-voltage heavy-current pulse-modes of MSS working in combination with corrugated magnetic isolation of the anode allows increasing the efficiency of the method of magnetron deposition by several times. Hereat the velocity of mass transfer is comparable to the at arc evaporation one, but, in our case there is no droplet phase.

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УВЕЛИЧЕНИЕ ЭФФЕКТИВНОСТИ МАССОПЕРЕНОСА ПРИ МАГНЕТРОННОМ ОСАЖДЕНИИ МЕТАЛЛИЧЕСКИХ ПОКРЫТИЙ

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Представлены результаты технологических испытаний продольной планарной магнетронной распылительной системы с магнитоизолированным анодом в импульсных режимах работы с дополнительным импульсным сильноточным высоковольтным источником питания. Показано, что эффективность массопереноса при импульсном нанесении покрытий возрастает на три порядка по сравнению со стационарным режимом горения магнетронного разряда. При этом в нанесенном медном покрытии капельной фазы, характерной для дугового испарения катода, не наблюдалось.

ЗБІЛЬШЕННЯ ЕФЕКТИВНОСТІ МАСОПЕРЕНОСУ ПРИ МАГНЕТРОННОМУ ОСАДЖЕННІ МЕТАЛЕВИХ ПОКРИТТІВ

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Представлено результати технологічних випробувань поздовжньої планарної магнетронної розпилювальної системи з магнітоізольованим анодом в імпульсних режимах роботи з додатковим імпульсним сильнострумовим високовольтним джерелом живлення. Показано, що ефективність масопереносу при імпульсному нанесенні покриттів зростає на три порядки в порівнянні зі стаціонарним режимом горіння магнетронного розряду. При цьому в нанесеному мідному покритті краплинної фази, характерної для дугового випаровування катода, не спостерігалося.