Characteristics and Parameters of the Combined Operating of Vacuum Arc Evaporator or Magnetron Sputterer with Gas Plasma Generator[1]

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Abstract – There are the investigations results of electrophysical parameters and work regimes, typical for join operation of traditional metal plasma sources (arc evaporator or magnetron) and the source of low-temperature gas-discharge plasma based on non self-sustained discharge with a thermocathode (gas plasmagenerator).

Assisting by gas plasma during the operation of metal plasma sources leads to additional ionization of discharge space, changing of discharge formation and maintaining conditions. Besides join functioning of metal plasma sources and gas plasmagenerator expand the range of work pressures where these hybrid discharges are realized. The most obviously this effect becomes apparent on the example of initiating and maintaining of magnetron discharge with using of gas plasmagenerator in the low pressures range, and it can be considered as "non self-sustained magnetron discharge". Such combination of plasma sources is the base for high-production vacuum-plasma technologies differing by the relatively simple realization and at the same time wide functional possibilities and uniqueness of obtained results.

Results obtained in the work were successfully used at the development of new technologies of plasma-assisted coatings deposition of different functional purpose, in particular for the deposition of superhard nanocomposite coatings.

1. Introduction

For obtaining of different nanostructural coatings by PVD methods it takes development of new electrophysical equipment with a wide range of operating possibilities of variation in ion-plasma flows composition, particle flow ionization degree, their density, work pressure range and temperature-energy parameters of technological process.

Industrial domestic equipment for ion-plasma deposition of coatings, such as arc coatings deposition installation of "Bulat", NNV type, and magnetron sputtering installation "MIR" type don't meet demands for nanotechnologies realization and they were intended for metal coatings deposition and compound of nitrides, carbides or carbonitrides type with a traditional microcrystal structure.

Recently hybrid equipment with the arrangement of different independent (plasma, ion, and electron) sources in one work chamber and in the single vacuum cycle has been developed. The main purpose of these installations is surface cleaning and activation, stimulation of coating synthesis processes, increase of efficiency and deposition quality of function coating. Such devices are described for example in papers [1–4].

In the beginning of 90-s the gas plasmagenerator based on non self-sustained arc discharge with a hot cathode [5,6] was developed in HCEI SD RAS. This device has a number of unique characteristics and a capability of operation in work pressure range typical for arc evaporators and magnetron-sputtering systems operation [7,8]. Wide possibilities of gas plasmagenerator are used at realization of combined technological processes including preliminary ion-plasma nitriding, mixing and deposition of coatings with gas-discharge plasma assisted treatment [7, 9–11].

There are the results of investigations of the most important parameters and characteristics of gas plasmagenerator with the arc evaporator and magnetron-sputtering system join operation in this paper. These investigations were carried out by authors because of the aims on perfection of vacuum-plasma technologies and adjustment of ways of creation of superhard nanostructured coatings on materials and production surfaces.

2. Experiment

NNV-6.6-I1 installation vacuum chamber was used in the experiment (Fig. 1). The investigated functional devices (sources of plasma): arc evapora-

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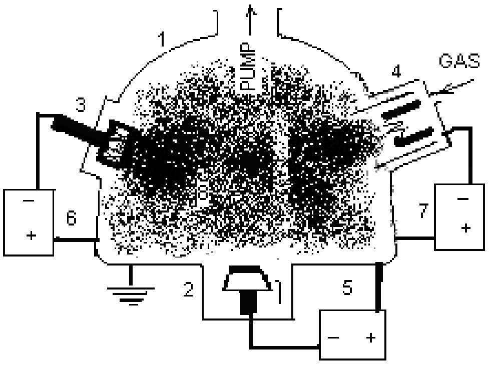
tor, magnetron and gas plasma generator were installed in its lateral flanges.

The construction of NNV installation vacuum chamber determines such arrangement of all sources that all their axes are directed to the chamber center angularly 120° relatively each other. Depending on the experiment aims the order of sources arrangement on the chamber can be changed.



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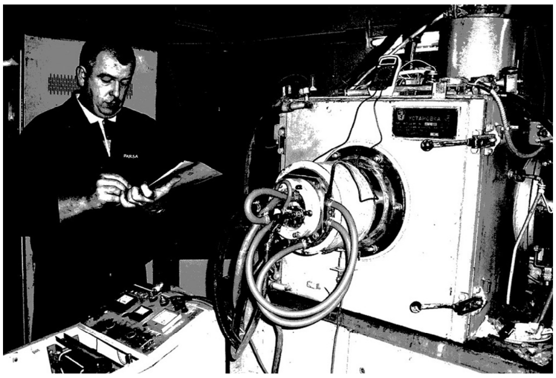

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Fig. 1. Scheme (a) and photograph (b) of experimental setup: 1 – vacuum chamber; 2 – arc evaporator; 3 – magnetron-sputtering system; 4 – gas plasmagenerator; 5,6,7 – power supplies; 8 – discharges plasma

The standard arc evaporator of NNV-6.6 installation was used as an arc evaporator. The magnetron sputterer was a classic magnetron system of planar type. A plane titanium disk with a diameter of 120 mm and thickness of 8 mm was used as a cathode (target) in investigations.

Two wide used variants of the magnetron sputterer were investigated. In the first one the whole internal surface of the work chamber was magnetron system anode, and gas inlet was carried out through the gas plasmagenerator. In the second one a special ring anode located near the surface of cathode-target of magnetron, was used. The ring anode was made of metal tube with a diameter of 8 mm with holes on the internal diameter, and it allowed to inlet the work gas as through the plasmagenerator as directly to the discharge space of magnetron.

The plasmagenerator [5] is able to generate gas plasma with the density distribution uniformity in working volume NNV installation vacuum chamber not less than ±20 % of the average value. Argon, nitrogen or argon-nitrogen mixture with a ratio of partial pressure of $p_{Ar}/p_{Nitrogen}=3/1$ were used as work gases in the experiments. Investigated pressures range was within from $8\cdot10^{-2}$ up to $4\cdot10^{-1}$ Pa. Plasma density ($n_e=10^9$–10^{10} см$^{-3}$) [5] was determined by discharge current value I_p of this plasmagenerator. For example, at discharge current of $I_p=100$ A ion current density in the centre of the vacuum chamber was up to $j_i=5$ mA/cm^2, and plasma density was $n_e\approx10^{-10}$ cm^{-3}.

3. Result and Discussion

It was not observed significant impact of gas plasmagenerator discharge on the external electrophysical characteristics (current and discharge voltage) of the arc evaporator in these experiments. Due to current in the cathode spot is not practically limited, the operation of the arc evaporator of direct current is defined mainly by the parameters of current limiting regime of high power supply with dropping volt-ampere characteristic. The plasmagenerator practically doesn't impact on arc evaporator parameters due to big difference of densities of cathode spot plasma and plasmagenerator diffusive gas discharge. On the other hand, arc discharge also with diffusive type of discharge on some distance from the cathode spot also has a weak impact on gas plasmagenerator characteristics. These two devices operate practically independent.

The investigations of gas plasmagenerator and magnetron join operation confirmed the effects of clearly defined impact of operating plasmagenerator on magnetron discharge characteristics. These effects were obtained earlier on the identical hybrid system in the chamber of MIR-2 installation [8]. The specific form of arc discharge maintained by electrons emission from the filament cathode exists in lower range of work pressures than the range stable work of used technological magnetron. It creates conditions when high current plasmagenerator arc discharge can control a magnetron discharge. The magnetron discharge due to relatively small ($<10^9$ cm^{-3}) concentration of created plasma doesn't impact significantly on plasmagenerator operation.

There are the dependences of magnetron current without ring anode on discharge voltage (the voltage between magnetron cathode and chamber walls) obtained at argon pressures in the chamber of $1{,}5\cdot10^{-1}$ Pa and different currents of plasmagenerator assisting discharge I_p on the Fig. 2.

It should be mentioned that magnetron discharge without plasmagenerator switching on at this pressure was not ignited, and its characteristics significantly depend on plasmagenerator current. It shows that is none a self-sustained discharge. As that is clear from dependences at increase of plasmagenerator current it was observed a decrease of magnetron currents for the same values of voltage on the magnetron. That is increase of plasmagenerator current and gas plasma concentration in all work volume of the vacuum chamber impede magnetron discharge operating.

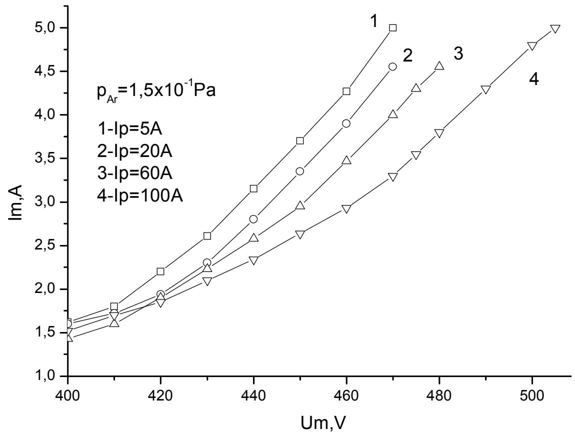

Fig. 2. The dependences of magnetron current I_m on its discharge voltage U_m at different currents of the plasmagenerator I_p; $p_{Ar}=1{,}5\cdot10^{-1}$ Pa. Magnetron anode is vacuum chamber walls

Observed effects can be explained in the following way. Discharge voltage of magnetron discharge as a form of glow discharge automatically sets thus to provide production conditions necessary for self-maintenance of charge carriers number and current conducting through the discharge gap. At the injection of discharge particles to the discharge gap and as a consequence the ionization of neutral gas filling gap, conditions of current conducting in magnetron discharge are changed. Density increase of gas plasma leads to increase of positive space charge density near magnetron cathode. To transmit current stipulated by this charge it is necessary to increase voltage. A power supply should provide this increase. If the voltage is not enough current drops and we observe an effect of magnetron current limiting by ions space charge. Such regime of magnetron assisted operation can be used in ways of ion-plasma treatment, when it is necessary a slow deposition speed at high intensity of gas plasma radiation exposure for intensification of diffusion processes, synthesis and mixing.

If we need to obtain the same currents provided by the magnetron at weaker assisting in regime of more intensive assisting, that is necessary to apply higher voltage to the discharge gap. It is obvious from the Fig.2 that if assisting current of plasmagenerator discharge is of I_p=5 A it takes the voltage of U_m=470 V for obtaining of magnetron discharge current of I_m=5 A, and if plasmagenerator current is of I_p=100 A it takes to increase magnetron voltage up to U_m=510 V for obtaining the same magnetron current values. Thus it is possible artificially to increase or decrease power of magnetron discharge operating in continuous operation by the external impact of plasmagenerator. In carried out experiments at high assisting current of plasmagenerator (I_p=100 A) magnetron discharge power of this configuration was limited just by power supply power, but not magnetron discharge conversion to the arc form, and it took place at work of just one magnetron. Besides, it should be expected that increase of magnetron discharge voltage of such configuration should lead to the intensification of ionization of magnetron metal plasma.

At installation of the ring anode near the surface of magnetron cathode in spite of that argon inlet was carried out to discharge work space near cathode surface in system of cathode-ring anode lower currents are obtained at the same voltages comparing with a case, when vacuum chamber walls were an anode. When the anode is placed close to the cathode the space for charge carriers appearing is limited. Besides anode area is significantly less than in case when work chamber walls are the anode. Thus the role of hollow anode in discharge formation and maintaining is excluded. This role is the next one: conditions for the formation of negative anode dropping and occurrence of electrons oscillation in the anode cavity are created. As a result, we have a difficult discharge with the overpotential in the cathode layer and high probability of discharge conversion to the arc form with a cathode spot. Assisting impact of gas discharge plasma makes easy magnetron discharge operating leading to the decrease of its voltage comparing with the variant of traditional (single) magnetron at the same currents and (or) current increase at the same voltages. Besides, as that is clear from Fig. 3 at plasmagenerator current increase the break of magnetron discharge to the arc discharge occurs at higher values of current I_m and voltage U_m.

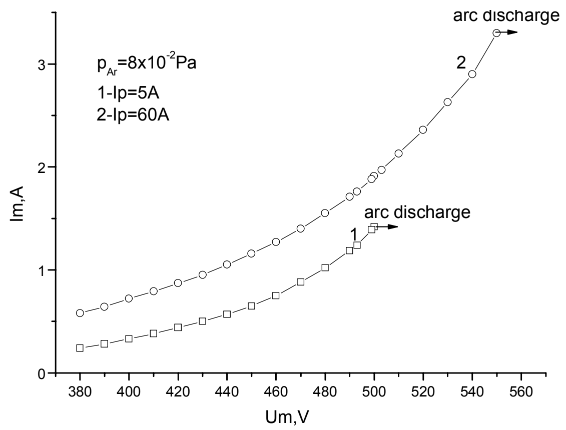

Fig. 3. The dependences of magnetron current with an ring anode Im on its discharge voltage of U_m at different plasmagenerator currents I_p; $p_{Ar}=8\cdot10^{-2}$ Pa

As it is clear from Fig. 4 the normal magnetron discharge is not initiated even with the ring anode in range of argon pressures less than $1,8\cdot10^{-1}$ Pa. Just in this range ($<1,8\cdot10^{-1}$ Pa) the effect of "non self-sustained magnetron discharge" [8] controlled by gas plasmagenerator current is appeared. The minimal work pressure of such discharge is more than at 2 times lower comparing with the normal magnetron discharge. At that, the currents available for technological using are kept and their slide changing is provided.

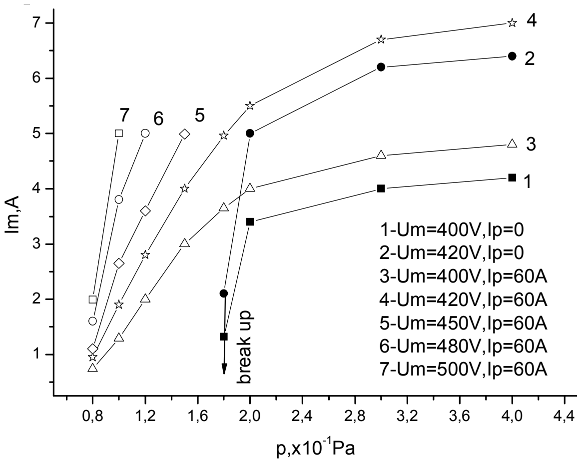

Fig. 4. The dependences of the currents of traditional magnetron (1,2) and non self-maintained magnetron discharge with the ring anode at I_p=60 A (3–7) on pressure (p) at different discharge voltages U_m; gas Ar

The parameters and construction of magnetic system of the magnetron used in our experiments stipulate its imbalance, and it made the big extension of magnetic field lines diverging from the centre of magnetron target through work chamber all space. Due to it in all experiments on investigation of non self-maintained magnetron discharge the glowing plasma channel between the plasmagenerator and magnetron was observed (Fig. 5).

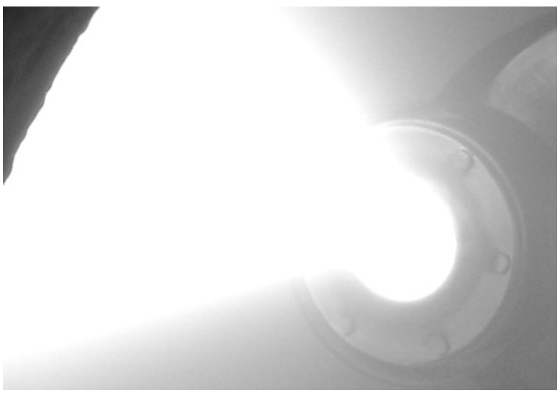

Fig. 5. The photo of hybrid magnetron-arc discharge

The temperature of gas discharge plasma electrons typical for the used plasmagenerator has a value of T_e=(3–5) eV. Such plasma is easy captured to the magnetic trap and concentrated in the space in the form of a cone made by diverging lines of magnetron magnetic fields. The observed plasma formation per physical se is closed to plasma realized in the discharge scheme called "plasma boiler" [12].

The oscilation of charged particles and high degree of metal and gas flows ionization are provided in close volume of this plasma formation caused by the presence of crossed electric and magnetic fields. One can say that we have some hybrid magnetron-arc discharge effectively generating as well metal as gas ions.

Well resettability of results was provided and qualitative coatings with high hardness were obtained in the carried out experiments in conditions of functioning of investigated discharge.

For example, the hardness values of composite nanocrystalline coatings Ti-Si-B-N, deposited by magnetron sputtering in argon and nitrogen mixture for number of cases of the normal magnetron and hybrid discharge (arc and magnetron discharge) were correspondingly 38 and 50 GPa at the same process temperature of T=200 °C. At process temperature increase up to 400 °C the hardness of this coating deposited in hybrid discharge increased from 50 up to 60 GPa.

The effects of hybrid plasma were obtained and at the electroarc deposition. For example, the hardness of TiN coatings deposited in nitrogen atmosphere on traditional technology of arc discharge deposition by the method of condensation with ion bombardment (CIB) at work pressure of $\sim2\cdot10^{-1}$ Pa was 30GPa, and the hardness of TiN coatings deposited at assisted impact of gas plasmagenerator and lower work pressure of $7,5\cdot10^{-2}$ Pa, increased up to 32,7 GPa. Thus the additional inclusion of plasmagenerator during arc discharge deposition allows to decrease nitrogen work pressure at ~3 times at obtaining of titanium nitride coating with improved quality and increased adhesion.

The plasmagenerator influences significantly at obtaining of composite nanocrystalline coatings. Thus, the hardness of Ti-Al-Si-N coating, deposited by CIB technology is 50 GPa, and the hardness of this system coating obtained at assisted impact of gas plasma, i.e. with using of hybrid discharge increased up to 60 GPa.

4. Conclusion

Obtained in this work main characteristics and regularities of ignition and operating of low pressure hybrid discharges (non-self-maintained arc discharge with a thermocathode and magnetron or arc discharge with a cathode spot) give the base for development of new high-performance ion-plasma devices and technologies.

Reequipment of available industrial equipment by gas plasmagenerator of type presented in [5] allows:

- to realize low pressure hybrid discharges and actively influence on characteristics of metal plasma sources increasing the efficiency of homogenous plasma generation in big vacuum volumes;
- to increase the efficiency of vacuum ion-plasma technological ways of composite coating formation (including nanostructural) on the surface of materials and production due to increase of generated plasma density and possibility of its main parameters purposeful control.

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