Modeling of Plasmadynamic System with Fast Electrons

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This paper presents the results of modelling a plasma dynamic system with fast electrons. It is shown that the presence of fast electrons in the plasma volume introduces additional energy for efficient evaporation and removal of microdroplets from the plasma flow.

Introduction. Erosive plasma sources are a high-performance method for the synthesis of various functional coatings. The generation of metallic plasma in a vacuum-arc discharge is always accompanied by the formation of microparticles (due to cathode erosion). Their presence in beam-plasma systems is a significant obstacle for many technological applications of the vacuum arc. The coatings of microelectronic devices are especially vulnerable to the presence of microparticles, since the thickness of the deposited films is 0.01÷1 μm, which is of the order of the size of the microparticles.

The problem of filtering microdroplets from a plasma flow dates back more than a some dozen years and has not yet been completely solved. Existing filters are based on the removal of the substance of the drop phase from the flow. This approach results in significant losses in plasma flow and process throughput. Therefore, in recent years, in parallel with the latest filtration systems, alternative filterless methods of plasma purification has been intensively developed. Such methods do not provide complete plasma purification but are much simpler and cheaper.

An alternative method has been proposed at the Institute of Physics of the NAS of Ukraine, which consists in using the fundamental principles of plasma optics to build a filtration system that is not associated with the removal of the droplet substance from the flow, but on the contrary, with the addition of this substance to the flow, thereby increasing the synthesis performance coatings [1]. The main idea is the efficient destruction or evaporation of microdroplets in a plasma flow passing through a plasma-optical system by a high-energy electron beam, which is self-consistently formed near the inner cylindrical surface of the system and injected along the radius towards the axis. This principle of ion-plasma flow filtration will make it possible to obtain high-quality coatings of any thickness without losing the productivity of the technological process.

Model approach. Plasma lenses (PL) based on the fundamental plasma-dynamic idea of magnetic electron isolation and equipotentialization along isolating magnetic field lines, have proved successful in focusing and controlling high-density ion beams and ion-plasma flows. The use of such systems may be attractive for their practical application as advanced plasma-optical filters capable of removing micro-debris from the plasma streams of erosion plasma sources. During the erosion of the cathode material, the plasma flow is directed perpendicular to the cathode surface, while most of the microparticles in the vacuum arc leave the cathode at small angles to this surface (see Fig.1 (a), left), thus micro-droplets fly in an expanding cone. Therefore, to evaporate most of the microdroplets, it is sufficient to act on a flow layer of a certain thickness near the surface of the hollow cylinder (see Fig. 1 (a), on the right).

We will consider electrostatic PL configuration through which a low-energy arc ion plasma flow pass. In Fig. 1(b) simplified model are shown. A dense arc plasma flow with micro-droplets propagates from the cathodic arc source and passes through diaphragm into the plasma-optical system, on which part of the micro-droplets remains. After the diaphragm, the flow propagates into the plasma-optical system.

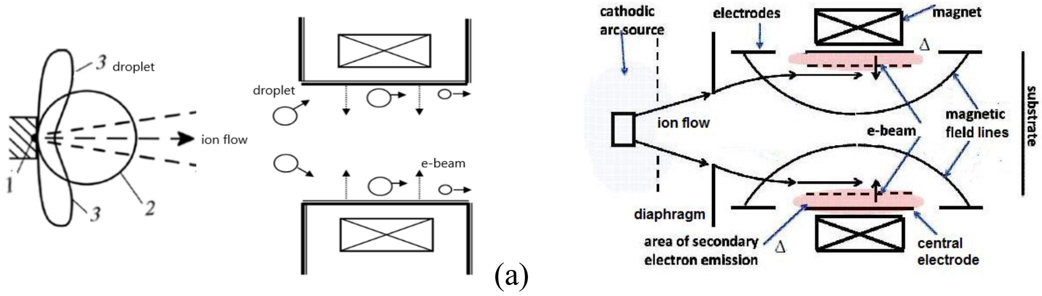

Fig. 1. (a): left - distribution of ions and microdroplets in the erosive plasma flow: 1 – cathode spot; 2 – ion flux; 3 – flow of microdroplets; right - scheme of a system with a self-consisted e-beam for evaporation of droplets in an arc plasma flow; (b): simplified model (Δ - spatial layer, where the strong radial electrical field is supported)

The plasma-optical system consists of a cylinder (central electrode) of length L and diameter D, on which the negative voltage U ~ 1.5÷3 kV is applied, and a pair of external ring grounded electrodes, arranged symmetrically to the central electrode. The system is in the magnetic field of a short coil or permanent magnets. When arc plasma flow reaches the zone of the magnetic field action, the electrons are magnetized and the ions are not magnetized. As a result, a dense plasma flow propagating inside the cylinder creates a layer of thickness Δ with a large radial electric field E_r. The magnetic field lines are equipotential inside the flow and created electrical field perpendicular to the magnetic field lines. The peripheral ions of the plasma flow, accelerating in the created field, bombard the inner walls of the cylinder and knock out electrons. As a result of the secondary ion-electron emission in the wall layer, a beam of fast electrons is formed with the current density $j_b=\gamma j_{is}$, (γ - the coefficient of the secondary ion-electron emission and the speed $V_{eb}\approx(2e\varphi_0/m_e)^{1/2}$. In previous wok we had shown possibility creation of the high-energy e-beam and made estimations of efficiency that