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CHARACTERISTICS OF EROSION PLASMA IN THE REGION OF INTERACTION OF A FLOW WITH AN OBSTACLE

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Results of investigation of the characteristics of an erosion plasma flow directed to an obstacle are presented. Stable quasi-stationary spherical plasma formations existing for more than 50 μsec were obtained for the first time. It is shown that the parameters, length, and localization of the cumulative zone in this plasma can be controlled by changing the dynamic characteristics of the incident flow.

Keywords: *cumulative zone, plasma, erosion-plasma accelerator.*

Introduction. At present the physical and technical principles of formation of new plasma systems for obtaining high-density particle energy fluxes are a major preoccupation of scientists engaged in solving a number of pressing problems of photochemistry, high-temperature thermal physics, and synthesis of new materials as well as problems associated with the development of new technologies and technological processes based on the use of the indicated fluxes for investigating the state of different substances and modification of their properties under extremum conditions [1–3].

The study of the physical processes of interaction of erosion plasma flows is of fundamental and practical interest for solving a number of important scientific and applied problems of quantum electronics, photochemistry, and radiation plasma dynamics. Radically new possibilities in this direction are offered by the interaction of accelerated counter plasma flows for obtaining plasma formations with extremely high energy content [4, 5].

In [6], the interaction of two rarefied-plasma counter flows are investigated in the range of change in the ratio of their concentrations $n_1/n_2 = 1–15$ at a Mach number $M \approx 1.9–3.5$. It was shown that a density jump is not formed in the case of collision of plasma flows having equal concentrations, which is explained by the equalization of their spatial-density disturbances because of the formation of diverging symmetric shock waves causing the substance behind them to move in different directions [6].

In [7–9], collisions of plasma flows were investigated for obtaining high-intensity dynamic plasma sources for optical pumping of molecular-laser active media.

The deceleration of plasma and the thermalization of its kinetic energy as a result of the interaction of two counter plasma flows were described in detail in [7]. It was shown that the region of interaction of these flows (their cumulative zone) represents a dense formation confined on both sides by strong shock waves, the velocities of which are smaller by an order of magnitude than the velocities of the incident flows. This is evidence of the high efficiency of the dissipation processes causing practically complete thermalization of the kinetic energy of the colliding flows and heating of the plasma in the interaction zone. The cumulative zone is a source of high-power continuous radiation; in this case, the brightness temperature of the plasma compressed by the shock waves is approximately 32–35 kK in the visible region of the spectrum and 25 kK in the near-ultraviolet region. The plasma in such discharges is heated due to the thermalization of the kinetic energy of the dense plasma flows as a result of their collisional interaction with the gas medium serving as an obstacle [7].

In [8, 9], the possibilities of using of dynamic high-current plasma discharges for generation of laser radiation and high-power thermal radiation were investigated experimentally. The method proposed in these works makes it possible to excite an active medium of large volume and, consequently, to obtain a high-power laser radiation with no significant limits on the lasing efficiency. The latter is due to the broad spectral absorption bands of the active molecules and the relatively small Stokes shift of the radiation and absorption spectra.

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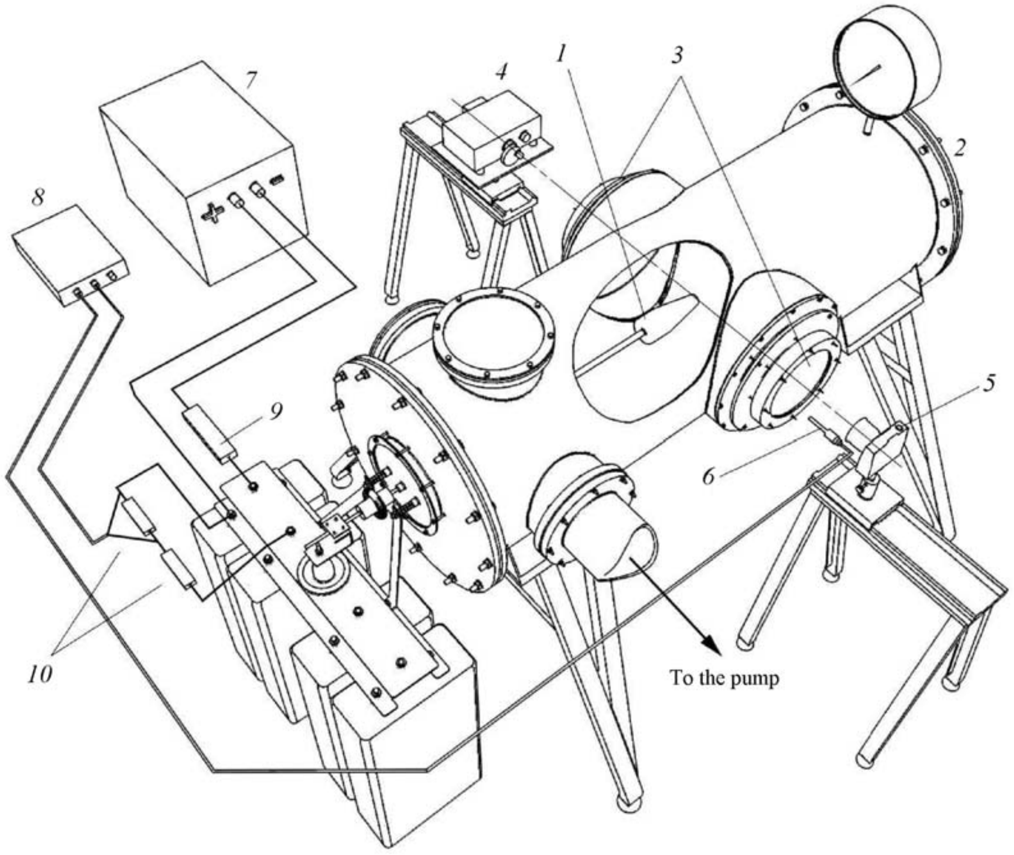

Fig. 1. Diagram of an experimental setup for investigating erosion-plasma flows: 1) face erosion-plasma accelerator; 2) vacuum chamber; 3) optical windows; 4) spectrometer; 5) photographic camera; 6) photodiode; 7) high-voltage power unit; 8) digital oscillograph; 9) ballast resistance; 10) resistive divider.

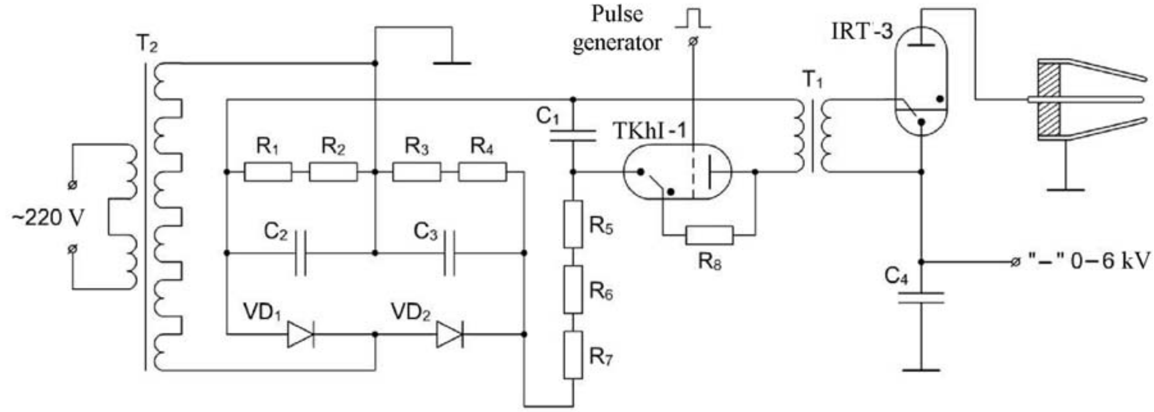

Fig. 2. Schematic circuit diagram of the power supply for the erosion-plasma accelerator.

In the present work, results of investigation of the parameters of an erosion plasma flow directed to an obstacle are described.

Generation of Erosion Plasma Flows. The diagram of an experimental setup for investigating erosion-plasma flows is shown in Fig. 1. The face erosion-plasma accelerator 1 represents a system of two coaxial copper electrodes isolated by an insulator of diameter 30 mm. The outer copper electrode is made in the form of a confuser with an

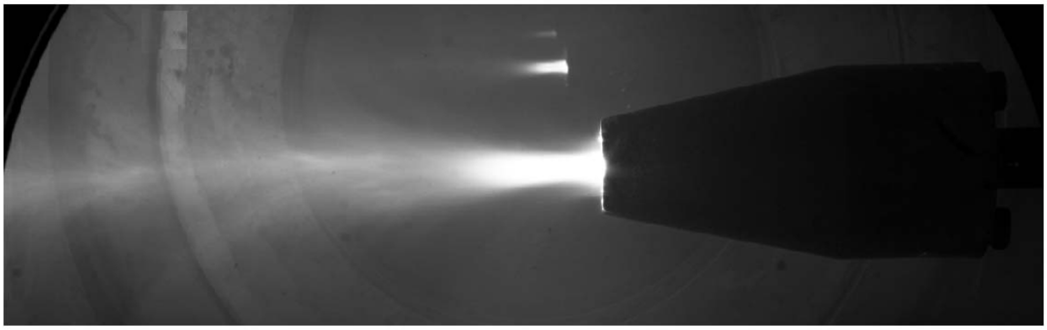

Fig. 3. Photograph of an erosion-plasma jet.

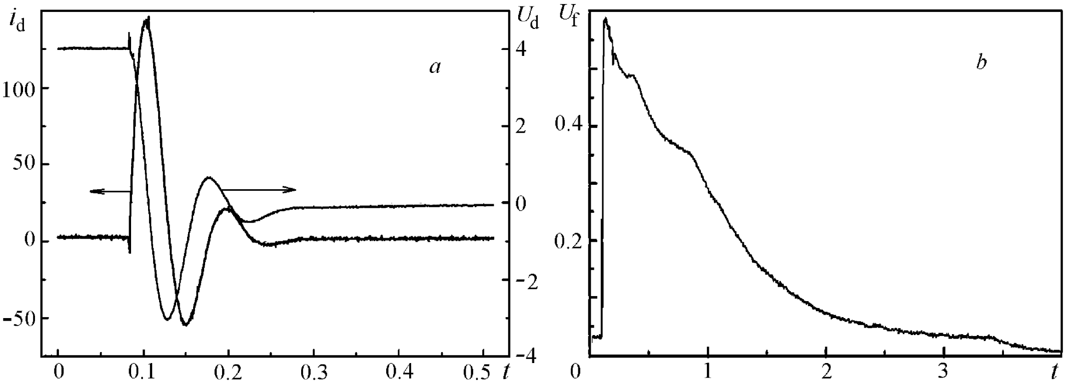

Fig. 4. Oscillograms of the voltage across a capacitor bank and the discharge current (a) and time dependence of the total luminous emittance of a plasma jet (b). i_d, kA; U_d, kV; U_f, V; t, μsec.

output cross section of diameter 20 mm. The accelerator was mounted in chamber 2 with the use of a coaxial copper current lead. The visual observation, photography, and spectral investigation were carried out through a special optical window 3 installed on the vacuum chamber.

The schematic circuit diagram of the power supply of the erosion-plasma accelerator is presented in Fig. 2. A plasma flow was generated as a result of the high-current discharge of a capacitor bank C_4 of total capacitance 600 μF into the accelerator electrodes. The capacitor bank was charged by a high-voltage source to 0–6 kV.

Parameters of a Free Erosion-Plasma Flow. The parameters of a free erosion-plasma flow were investigated at a residual-air pressure in the vacuum chamber of $\sim 3 \cdot 10^{-3}$ Torr. The amplitude discharge current of the erosion-plasma accelerator changed from 90 to 140 kA when the initial voltage of the energy storage system changed from 3 to 4 kV. In this case, the duration of the discharge was ~150 μsec. Under the indicated conditions, a compression plasma flow of diameter 1 cm and length 10 cm was formed at the output of the erosion-plasma accelerator; then this flow separated with an opening angle of 10–15° (Fig. 3).

The characteristic oscillograms of the voltage across the capacitor bank and the discharge current as well as the time dependence of the total luminous emittance of the plasma jet are presented in Fig. 4. The discharge current was measured with the use of a Rogowski coil, and the voltage across the capacitor bank was determined with the use of a high-resistance resistive divider 10 (see Fig. 1). The luminous emittance was measured with the use of a FD-27 photodiode and a B-423 digital oscillograph.

The spectroscopic investigations of plasma formations were carried out with the use of a S150A-IV spectrometer. The characteristic spectrum of glow of the erosion plasma is presented in Fig. 5. The photograph was obtained at an exposure of 1 μsec within 70 μsec after the beginning of the process. In the emission spectra of the plasma recorded in the region of 300–1200 nm, lines of continuous radiation, atomic-hydrogen lines, and intense (resonance) lines of atoms of the elements entering into the composition of the dielectric material were mainly observed.

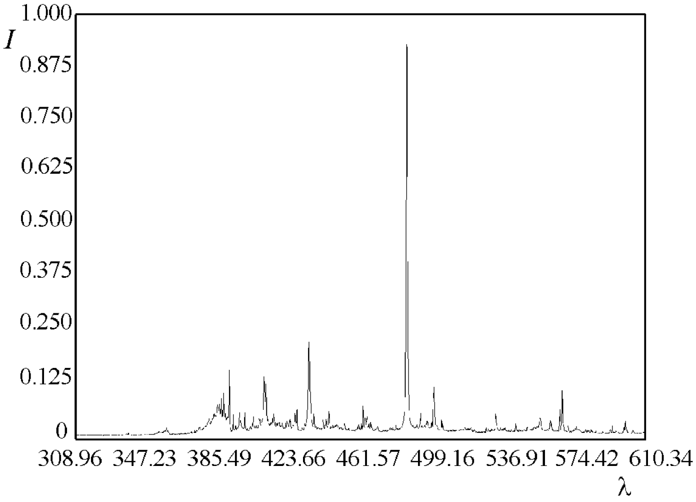

Fig. 5. Spectrum of glow of erosion plasma. λ, nm.

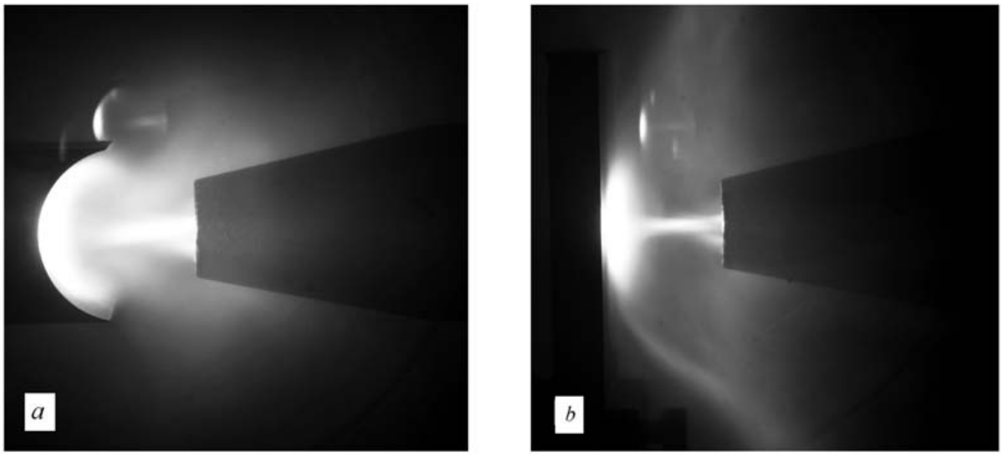

Fig. 6. Photographs of interaction of an erosion-plasma flow with a semicylindrical surface (a) and a cobalt-magnesium surface (b).

Caprolon (poly-ε-caproamide), the chemical formula of which has the form $[–NH(CH_4)CO–]_n$, was used as the dielectric material; therefore, the resonance lines of hydrogen, nitrogen, oxygen, and carbon were observed in the spectrum of glow of the erosion plasma.

The temperature of electrons in the plasma flow was determined by the intensity of the continuous spectra on both sides of the Balmer-series boundary on the assumption that local thermodynamic equilibrium exists. When the discharge current reached a maximum value equal to 140 kA, the temperature of the electrons found in the flow at a distance of 1 cm from the cathode was $\sim 3 \cdot 10^4$ K. The concentration of electrons was determined by the Stark broadening of the Balmer line H_β. At a maximum discharge current of 140 kA, the electron density was $2 \cdot 10^{15}$ cm^{-3} [9].

Interaction of Erosion-Plasma Flows with an Obstacle. A semicylindrical steel surface and a plane surface of cobalt magnesium were used as obstacles. Photographs of interaction of an erosion-plasma flow with the obstacles are presented in Fig. 6.

Our experiments have shown that the collision of a plasma flow with an obstacle leads to the formation of stable quasi-stationary plasma structures existing no more than 50 μsec, which is in good agreement with the results of [10]. By varying the parameters of an incident plasma flow and the operating time of a magnetic-plasma compressor, one can control the extent, position, and other characteristics of the cumulative zone.

Conclusions. The main parameters of a free erosion-plasma flow (the temperature of the plasma and the concentration of electrons in it) were determined. According to the experimental results obtained, the temperature of the plasma is equal to $3 \cdot 10^4$ K and the electron concentration in it is $2 \cdot 10^{15}$ cm^{-3}. Stable quasi-stationary spherical plasma formations existing for more than 50 μsec were obtained for the first time as a result of the interaction of an accelerated erosion-plasma flow with an obstacle. The results described in the present work allow the conclusion that the parameters, extent, and location of the cumulative zone in a free erosion-plasma flow can be controlled by changing the dynamic characteristics of the incident plasma flow.

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NOTATION

I, relative intensity of radiation; i_d, discharge current, kA; M, Mach number; n_i, concentration of ions in the plasma, cm^{-3}; t, time, μsec; U_d, discharge voltage, kV; U_f, voltage across a photodetector, V; λ, wavelength of optical radiation, nm. Subscripts: d, discharge, i, ion; f, photodetector.

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