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GENERATOR OF HIGH-PURITY ABLATION PLASMA OBTAINED FROM A DIELECTRIC MATERIAL AT ATMOSPHERIC PRESSURE

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A pulsed plasma source providing generation of a high-purity erosion plasma from a dielectric material at atmospheric pressure by analogy with a capillary discharge has been developed. The chemical and ionization compositions of the plasma obtained with this source were determined by the spectroscopic method and its energy parameters were determined by electrophysical methods. The indicated plasma source provides generation of a low-temperature plasma at a comparatively low pressure in a discharge volume.

Keywords: *source of ablation plasma, high-purity plasma, spectroscopic investigations of plasma, surface discharge.*

Introduction. Generators of a low-temperature plasma, operating at atmospheric pressure, exists in a large variety [1]. Of special importance among them are pulsed generators of ablation-plasma flows because they, in the process of their work, regenerate the medium in which the discharge is initiated. Works [2–5] are among the first works in which such flows were obtained and investigated. In these works an electric-discharge device representing a discharge chamber made from a dielectric material, in which a central and a ring electrodes are installed, was used. In [6], the results of complex investigations of a pulsed plasma generator operating at atmospheric pressure were generalized, and, in [7], the results of optical, spectroscopic, and electrophysical investigations of the plasma obtained with the use of a combined two-stage electric-discharge system at atmospheric pressure are presented. A comparative investigation of such plasma generators was carried out with the use of pure dielectric inserts and inserts with a metal deposition. The pulsed generators considered in the indicated works operate in the air at atmospheric pressure and make it possible to obtain, under these conditions, relatively dense low-temperature (6000–8000 K) plasma flows of definite composition. Spectroscopic investigations of pulsed erosion-plasma generators operating at atmospheric pressure have shown that the plasma inflowing from these generators contains a large amount of electrode-material atoms and ions.

A high-purity ablation plasma was obtained from a dielectric material in the air atmosphere for the first time in a high-power pulsed capillary discharge [8–10]. Spectroscopic investigations have shown that the composition of the plasma inside a dielectric capillary is determined practically completely by the material of the inner wall of the dielectric. A jet formed in this case represents an axisymmetric plasma flow, in the radiation spectrum of which, along with a continuum, lines of atoms and ions of the dielectric (textolite) and the electrodes as well as molecular bands of CN are present. The atomic lines and the molecular bands were detected in the spectrum of the colder peripheral part of the plasma flow. A capillary discharge is characterized by a large concentration of the charged particles ($\sim 1.5 \cdot 10^{20}$ cm^{-3}), a high temperature ($\sim 40 \cdot 10^3$ K), and a high pressure ($\sim$500 atm) in the capillary. The main drawback of a capillary degrade is the high pressure acting on the inner surface of the dielectric, which, however, does not degrade the work of a standard light source based on this discharge and only imposes significant limitations on the choice of materials for it: they should be stable to breakage by pulsed pressure. This is especially the case for brittle materials such as quartz, glass, and others. In certain respects, the relatively small cross section of a capillary can also be considered as a disad-

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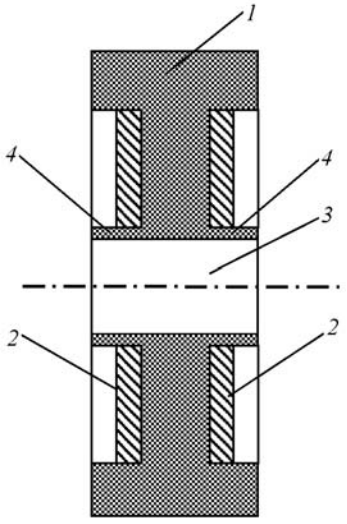

Fig. 1. Scheme of a discharge device: 1) dielectric body; 2) electrodes; 3) discharge channel; 4) dielectric ledges over the electrodes.

vantage. An increase in this cross section can cause a mixing of the ablation plasmas of the dielectric and of the electrodes. To decrease the action of these factors, it is necessary to develop a new plasma source.

We have developed a source for obtaining a high-purity ablation plasma from a dielectric material, in which the plasma generation is provided by a high-power pulsed surface discharge of cylindrical geometry [1–7]. In the present work, a scheme of the discharge device described in [11] and results of spectroscopic [12] and electrophysical investigations of the new source of a high-purity plasma, providing its generation by analogy with a capillary discharge, are presented.

Experimental Setup and Investigation Methods. On the basis of analytical investigations and preliminary experiments we have developed and fabricated discharge devices in the form of cylinders with an outer diameter of ~32 mm and a discharge channel of diameters 10 and 8 mm (Fig. 1). The height of the dielectric body 1 was 10–16 mm and the interelectrode distance was varied from 13 to 24 mm. Recesses of height 2–3 mm were made on the faces of the body for installation of electrodes. A feature of this design is that the length of the channel in the dielectric body is larger than the distance between the outer surfaces of the electrodes. The rise of the nozzle exit section over the surface of the electrodes is ~2 mm. We used Plexiglas as the dielectric material, and the electrodes were made from Duralumin in the form of hollow cylindrical disks. The geometrical parameters of the discharge device were varied and different materials were used for it during the experiments.

In the present work, an accumulator consisting of two capacitors of total capacitance 24 μF and a charging unit providing an initial voltage of up to 10 kV were used. A high-voltage pulse from the control pulpit of a super-high-speed photoregister was used for initiation of the discharge.

The device works in the following way. An electric discharge is initiated between the two disk electrodes 2. It passes through the channel in the dielectric 3, bends perpendicularly to this channel along a length equal to the width of the bulge of the discharge channel 4, then bends once again along this bulge, and closes electrodes 2. Electrode spots are formed on electrodes 2; from these spots, plasma jets outflow perpendicularly to the surface of the electrodes [1]. The transverse size of an electrode jet is ~1 mm. The electrode-jet plasma moving in the surrounding atmosphere mixes with the plasma outflowing from the discharge channel. To prevent the mixing of the main plasma jet outflowing from the dielectric with the electrode plasma, we have made dielectric ledges above the electrodes at a height of ~0–2 mm.

The chemical and ionization compositions of the plasma were determined by the spectroscopic method and its energy parameters were determined by electrophysical methods. The complex emission spectra of the ablation plasma were recorded with the use of an ISP-51 spectrograph. The radiation was recorded by the photographic method and the radiation spectrograms were processed on a computer. The discharge current was measured with the use of a Ro-

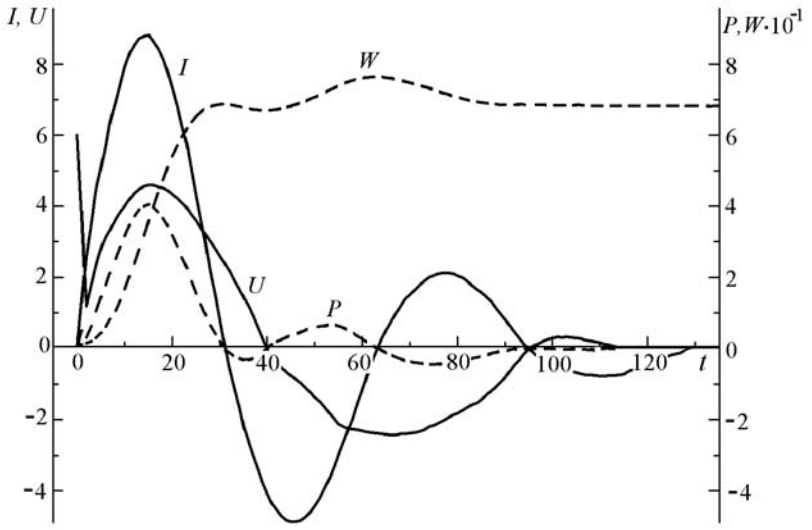

Fig. 2. Oscillograms of the current I and the voltage U of a discharge; time dependences of the power P and energy W supplied to the discharge. I, kA; V, kV; P, MW; W, J.

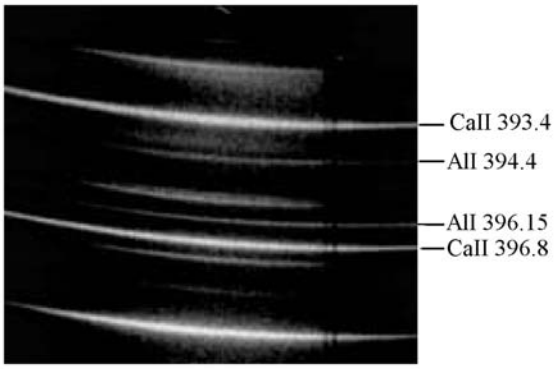

Fig. 3. Fragment of the emission spectrum of the high-purity ablation plasma (Duralumin electrodes, Plexiglas dielectric, discharge-device hole of diameter 10 mm).

gowskii coil and the voltage across the discharge device was measured by a compensated RC divider. The indications were recorded with the use of an oscillograph subassembly connected to a personal computer.

Experimental Results and Their Analysis. Figure 2 presents oscillograms of the current and voltage of a discharge as well as the calculated time dependences of the instantaneous power and energy supplied to the discharge at an initial voltage across the capacitor bank of 5 kV.

The duration of the half-cycle of the current was ~32 μsec. It remained constant during the discharge and was independent of the initial voltage. The number of the half-cycles was 3 at an initial voltage of 3 kV, and the fourth half-cycle was recorded at an initial voltage of 5 kV. The discharge current reached a maximum value of ~9 kA approximately at the 16th microsecond.

The time dependence of the voltage across the discharge device is more complex. The first half-cycle lasts for 42 μsec and the second one lasts for 52 μsec. The third half-cycle also exists, and its duration increases with increase in the initial voltage across the accumulator. As the discharge develops, a phase difference between the current and the voltage appears. The current and voltage are made to vanish, respectively, at the 32nd and 42nd microseconds. With time this shift becomes larger. Thus, if the discharge represents a practically active resistance at the beginning of the first half-cycle, at its end and then in the impedance a significant imaginary part appears. The maximum voltage across

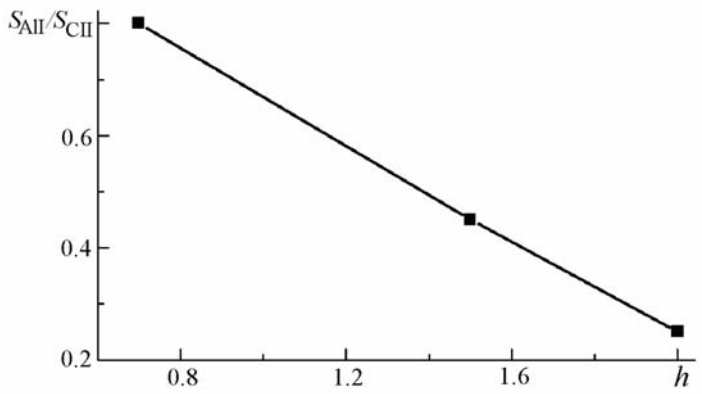

Fig. 4. Dependence of the ratio between the blackenings of the spectral lines of the aluminum atoms AlI 396.15 nm and the carbon ions CII 426.7 nm $S_{AlI396.15}/S_{CII426.7}$ on the height of the dielectric bulge. h, mm.

TABLE 1. Ratio between the Blackenings of Different Spectral Lines versus the Energy Stored in the Energy Accumulator

Spectral lines	Energy, J		
	48	108	192
AlI 396.15 nm/CII 426.7 nm	0.16	0.25	0.25
AlI 396.15 nm/NII 399.5 nm	0.15	0.26	0.27
CII 426.7 nm/NII 399.5 nm	0.95	1.02	1.08

the discharge device (460 V) is attained at the 17th microsecond of the discharge practically simultaneously with the current.

All the energy supplied to the discharge (Fig. 2) is expended for it mainly during the first half-cycle of the current (for 32 μsec). In this case, the maximum instantaneous power reaches 4 MW at the 16th microsecond of the discharge. The energy expended for the discharge (67 J) comprises 62% of all the energy supplied to it. When the voltage across the capacitor bank decreases (from 4 to 3 kV), this part of the energy decreases insignificantly and remains at a level of ~60%.

A qualitative analysis of the emission spectra of plasma jets has shown that spectral lines of the ions of the first ionization multiplicity of the dielectric elements CII, OII, and CaII (representing impurities) and of the air elements NII and OII are mainly present in these spectra. A weak continuum and the most intense lines of the aluminum atoms AlI 394.4 and 396.15 nm were also detected (Fig. 3).

It should be noted that other lines of AlII atoms as well as lines of the single and double aluminum ions AlII and AlIII were not observed on the photographs of the spectra at a height of the bulge of the discharge channel above the electrode surface of 2 mm. Molecular bands of CN, the intensity of which decreases with increase in the height of the bulge, were detected in the outer layer of the plasma jet where it mixes with air [10].

A shock wave arising in the plasma of the plasma jet was not visualized on integral spectrograms obtained by projection of the image of the jet along the slot of a spectrograph. As the energy stored in the accumulator increased (the initial voltage increased), the intensity of the NII lines changed insignificantly as compared to the intensity of the CII lines. It is seen from the integral spectrograms obtained by projection of the image of a jet transverse to the spectrograph slot, that the electrodes influence the structure of the spectra in the places of their disposition near the nozzle exit.

Computer processing of the emission spectrograms allowed us to obtain the dependence of the ratio between the blackening of the spectral lines of the aluminum atom AlI 396.15 nm and the blackening of the spectral line of the carbon ion CII 426.7 nm on the height of the bulge of the discharge channel (Fig. 4). As the height of the bulge increased, the relative content of the electrode material in the plasma decreased gradually. The chemical composition of the erosion plasma can be changed by changing the height of the bulge, which makes it possible to control this

composition. The use of disk electrodes, at the front surface of which microspots are formed, opens up new opportunities for fundamental investigations of the near-electrode processes and the effects occurring on the electrodes in the simple form, i.e., under conditions where the mutual influence of the anode and cathode plasmas is absent.

It is interesting that the ratio between the blackenings of the spectral lines of the carbon ions CII 426.7 and the nitrogen ions NII 399.5 nm changes insignificantly with change in the height of the bulge or in the diameter of the hole as well as with change in the energy stored in the accumulator. The excitation potentials of these lines are close in value (20.95 and 21.60 eV respectively). However, the first of these lines is observed in the spectrum of the erosion plasma, and the second one is observed in the gas part of the plasma formed. Such closeness of the blackenings points to the good reproduction of the spectral characteristics of the discharge, which is typical for surface discharges [1]. This conclusion is supported by the ratio between the blackenings of the spectral lines of the elements of all the parts of the plasma formed: the metallic, dielectric, and gas ones (see Table 1). It is seen from Table 1 that, when the energy stored in the energy accumulator decreases (the initial voltage decreases), the relative contents of the dielectric material and the material of the electrodes in the plasma formed decrease.

The pressure at the section of the channel in the dielectric body, necessary for removal of the compression shock from the nozzle exit section, was estimated, in accordance with the plasma-chemical investigations [13], at ~4 atm, which is smaller by approximately two orders of magnitude than that of a capillary discharge (500 atm [10]).

Conclusions. A new source for obtaining a high-purity erosion plasma from a dielectric material at atmospheric pressure has been developed. The discharge device representing a part of this source makes it possible to control the amount of the impurity material of the electrodes in the plasma jets by changing the geometric parameters of the device.

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NOTATION

C, capacitor capacitance, μF; *d*, diameter of the nozzle, mm; *h*, height of the bulge, mm; *I*, strength of current, kA; *l*, length, cm; N_e, electron concentration, cm^{-3}; *P*, power, W; *S*, blackening of a spectral line, rel. units; *T*, temperature, K; *t*, time, sec; *U*, voltage, kV; *W*, energy, J.

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