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PROCESSES OF TRANSFER IN A LOW-TEMPERATURE PLASMA

RADIATION-SPECTROSCOPIC CHARACTERISTICS OF AN ABLATION PULSE PLASMA GENERATOR (ACCELERATOR) AT LOW PRESSURE

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The results of a radiation-spectroscopic investigation of the plasma generated by an ablation (erosion) pulse plasma generator of cylindrical geometry operating at low pressure have been presented. The electron temperature for different dielectrics has been determined from integral spectra with radial conversion of intensities and without it.

Electric discharge on the dielectric surface provides the basis for the operation of ablation (erosion) pulse plasma generators. It is the dielectric material that mainly determines the composition of a plasma formed in cylindrical-geometry sources operating at low pressure [1–3]. Since the material of the dielectric used may contain different chemical elements and they are at different ionization steps in the plasma, the spectroscopic methods are assumed to be the most efficient ones for investigation of such plasmadynamic systems [4, 5]. In the present work, we have carried out the optical-spectroscopic study of an ablation pulse plasma accelerator of cylindrical geometry with different plasma-generating dielectrics. The values of the electron temperatures have been determined both with the use of radial conversion of the relative spectral-line intensities and without it.

Description of the Generator and the Experimental Procedure. Experimental investigations were carried out with a pulsed surface discharge of cylindrical geometry; the diagram of the discharger (Fig. 1) was analogous to that described in [2, 3]. The inside diameter of the discharge chamber was 1.3 and 0.9 cm (in [2, 3], it was 2 cm); the electrode spacing was 9.6 cm. The discharger was placed in a vacuum chamber the residual pressure in which was brought down to a minimum value of $\sim 2 \cdot 10^{-5}$ Torr.

Teflon, textolite, and a combination of dielectrics (Plexiglas, Teflon, and porcelain) were used as a plasma-generating working substance. The electrodes were manufactured from copper. The discharge was initiated between the central hollow electrode and the annular electrode. A rod electrode (located along the axis of symmetry) of diameter 0.3 cm was the igniter.

A bank of 48 K-74-I2 capacitors of total capacity 24 μF was the energy-storage system. The duration of the discharge-current half-period was 5 μsec, and that of the discharge was 20 μsec (four half-periods); the value of the discharge current was ~50 kA in the first half-period, 44 kA is the second half-period, 14 kA in the third half-period, and 9 kA in the fourth half-period ($U = 5$ kV). The discharge was initiated by feeding a high-voltage pulse from the control desk of an ultrafast photorecording unit to the igniter. The axisymmetric erosion jet was experimentally studied mainly by photography and spectrography methods.

Experimental Results and Analysis. A plasma jet formed at low pressure flows out into a medium with a weak counterpressure. The velocity of its motion on the nozzle exit section is ~20,000 m/sec in the initial period of time (inside diameter of the dielectric insert 0.9 cm). As the discharge volume increases, the velocity decreases somewhat (to ~18,000 m/sec, diameter of the dielectric insert (spacer) 2 cm [3]).

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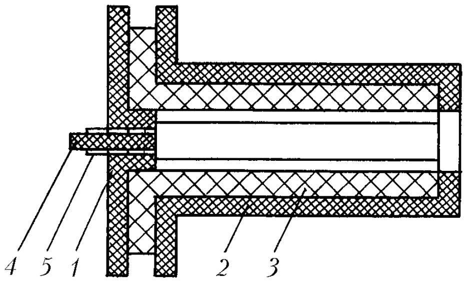

Fig. 1. Diagram of the discharger: 1) central hollow electrode; 2) annular electrode; 3) dielectric insert; 4) central rod electrode; 5) insulating sleeve.

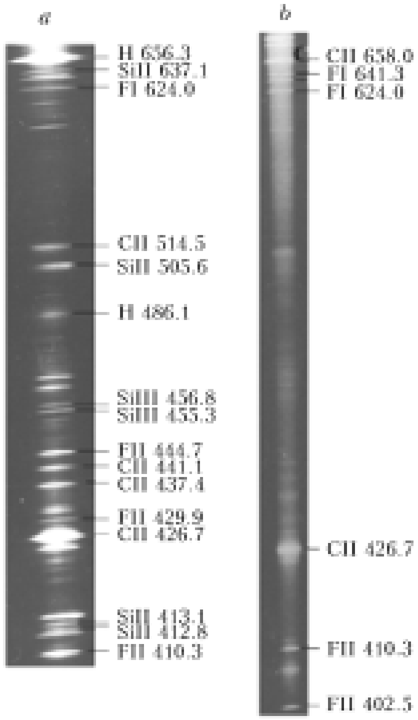

Fig. 2. Emission spectra of the jet of an ablation pulse plasma accelerator at the section of the annular electrode (cross section, pressure $\sim10^{-3}$ Torr, wavelength in nanometers): a) the inside diameter of the combination insert is 1.3 cm and U = 3 kV; b) the inside diameter of the Teflon insert is 0.9 cm and U = 5 kV.

Slit photoscans have shown that the erosion plasma continues to flow out even after the cessation of the discharge current. An analogous delay is typical of all ablation pulse plasma accelerators operated by a high-current discharge on the dielectric surface. Some authors explain this outflow by the geometry of the discharge and by thermal inertia [3]; others point to the evaporation due to the energy contained in the skin layer, mainly in free radicals. From the evaluations for a coaxial accelerator, the mass of the substance evaporated after the completion of acceleration amounts to 30–40% [1]. The outflow time increases with energy contributed to the discharge. When the inside diameter of the dielectric insert is equal to 2 cm, a discontinuous structure is clearly recorded on the photoscans after the cessation of the current [3]. However, if the inside diameter of the cylindrical insert is only 0.9 cm, we do not observe such a structure.

As the experimental investigations show, the generation and outflow of the plasma proceed concurrently, in practice, with the beginning of the traversal of a discharge current [3]. Change in the intensity of the plasma-jet glow is inconsistent with current oscillations, unlike the surface discharge of planar geometry [6].

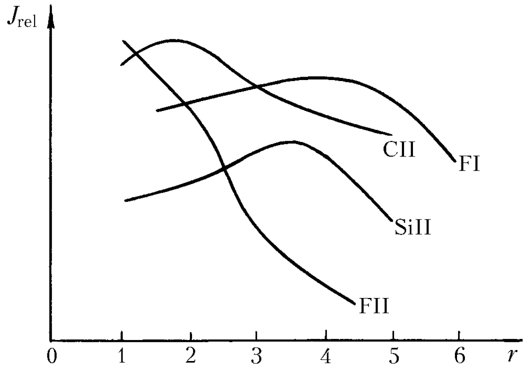

Fig. 3. Radial distribution of the time-integral intensities of the spectral lines of a plasma jet at the nozzle exit section: 623.97 nm FI, 426.77 nm CII, 634.7 nm SiII, and 429.9 nm FII. *r*, mm.

A qualitative analysis of the emission spectra of the plasma jet of a low-pressure pulsed surface discharge in a bounded volume shows that the composition of the jet is mainly determined by the material of the dielectric insert. This is characteristic of a high-current low-pressure surface discharge of cylindrical geometry [2, 3]. When the material of a cylindrical insert assembled from different materials (Teflon, Plexiglas, and porcelain; inside diameter 1.3 cm) is used as the plasma-generating dielectric, we record the spectral atomic and ionic lines of all the materials forming part of the substrate and a weak continuous background. Lines of the elements forming part of the material of the portion of the insert that is in direct contact with the annular electrode (it had a positive polarity in relation to the central hollow electrode in all the experiments) are the most intense in the spectrum. Thus, when a porcelain portion of the substrate is in contact with the annular electrode, we record 455.26, 456.78, and 457.47 nm SiIII lines of a double silicon ion and 408.88 and 411.6 nm SiIV lines. If the porcelain substrate is located in another portion of the discharge chamber, the lines are very weak. Of the spectral lines of the elements forming part of the electrodes, we observe the most sensitive copper lines (e.g., 521.82 nm CuI)

When the inside diameter of the dielectric insert (plasma-generating working substance is Teflon) decreases and is equal to 0.9 cm, the plasma-emission spectrum is strongly different form the previous one. A considerable enhancement of continuous emission is recorded. Only comparatively intense atomic and ionic lines of the elements of the insert material are distinguished against the background of the continuous spectrum. Also, we observe a relative increase in the brightness of the copper atomic line 521.82 nm CuI. Figure 2 gives the typical emission spectra of the plasma jet.

The use of a combination dielectric insert enabled us to diagnose the generated plasma jet by the set of spectral lines with different analytical potentialities. It is common knowledge that the lines used for diagnostic purposes provide information on the plasma parameters in the source regions where they are efficiently excited. The distribution of luminescence zones in an inhomogeneous source is caused by different factors — excitation potentials, the constants of quadratic Stark effect, and others — that determine their analytical potentialities. The transformation of the intensities observed to the radial intensity distribution in the plasma was carried out by numerical solution of the Abelian integral equation [7].

Calculation of the radial distribution of the time-integral spectral-line intensities has shown that the intensity maximum of the 429.9 nm FII line of a single fluorine ion is closer to the jet axis than the maxima of the remaining lines (Fig. 3). The brightness maxima of the CII and SiII ionic lines are at a distance of the order of 1.5–4 mm from the jet axis, i.e., these ions emit quanta from medium-diameter zones. For a fluorine atom, the intensity maximum is less pronounced and the luminescence region is relatively large. Such a distribution is also typical of the discharge under different conditions (initial voltage U = 5 kV and diameter of the dielectric insert 2 cm; the dielectric is homogeneous) [3].

Quantitative spectroscopic investigations of plasma formations were carried out from the time-integral spectra for the source with a combination dielectric insert. The temperature was measured by the relative-intensity method from the fluorine ionic lines 402.5 and 410.3 nm FII both with radial conversion of intensities and without it. Accord-

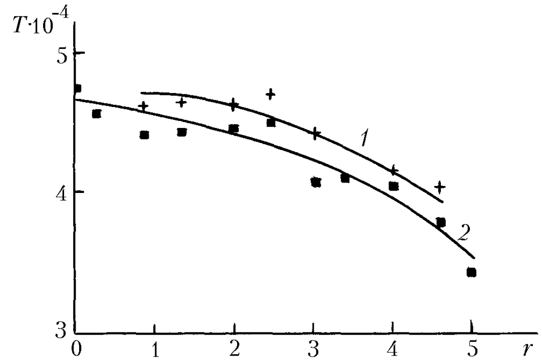

Fig. 4. Radial distribution of the electron temperature on the nozzle exit section (U = 3 kV; the annular electrode is the anode): 1) with radial conversion; 2) without it. T, K; r, mm.

ing to the evaluations, the excitation temperature measured from these lines characterizes the electron temperature under these conditions (electron concentration $N_e \sim 10^{17}–10^{18}$ cm^{-3} [3, 5]). The transition probabilities for the FII lines were borrowed from [8].

The differences in the values of the electron temperatures on the exit section of the erosion-source nozzle, obtained with radial conversion of intensities and without it (Fig. 4), lie within the measurement error (~25%). It is common knowledge that temperatures measured from the relative intensities of the fluorine ionic spectral lines FII belong to the initial stage of outflow [3]. The character of the radial distribution of the electron temperature at the section of the annular electrode, obtained with radial conversion and without it, is identical, and the temperature variation along the radius is slight.

In the case of a Teflon insert (U = 3 kV) the temperature determined by this method is ~40,000 K, i.e., the same as in the case of a combination insert (diameter 1.3 cm), but somewhat lower than that in [3]. When textolite is used as the insert material, the temperature of the plasma jet abruptly changes. Its maximum value measured from the relative intensities of the 283.7 and 251.2 nm CII lines [9] and characterizing the first stage of plasma outflow (to 6 μsec) hardly attains 15,000 K, i.e., is much lower than that in the case of a Teflon working substance.

Thus, the qualitative analysis of the emission spectra of a low-pressure pulsed surface discharge of cylindrical geometry has shown that, just as in [3], the composition of the plasma is mainly determined by the material of the cylindrical insert. The intensity of spectral lines, particularly ionic ones, grows with distance to the annular electrode (nozzle). The influence of the dielectric substance on temperature values has been established. Under identical conditions, the electron temperature in the case of a Teflon cylindrical insert and of a cylindrical insert manufactured from a combination of dielectrics is 40,000 K, whereas in the case of a textolite insert it is 15,000 K, which is, probably, due to the presence of detectable easily ionizable elements in the latter.

NOTATION

J_{rel}, emission intensity, rel. units; N_e, concentration of electrons per cm^3; r, radius of the dielectric insert, mm; T, temperature, K; U, voltage, kV. Subscripts: e, electron; rel, relative.

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