THEORY OF THE NEAR-PROBE LAYER
IN ELECTRONEGATIVE GASES

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Experimental data on an investigation of a plasma, containing negative ions, in the active discharge phase and in the afterglow stage are reported. The applicability of the orbital-motion theory to probe investigations in electronegative gases is discussed.

Works concerned with a low-temperature plasma that contains negative ions have appeared recently in the scientific literature. In the overwhelming majority of these works, the main method of diagnostics is investigations using electrical probes. As is known, probe diagnostics makes it possible to obtain information about local characteristics of a plasma. On the other hand, in the literature one can find diametrically opposite data on the processes occurring in a plasma and its parameters. This indicates that the procedure of measurements in a plasma of electronegative gases is insufficiently developed. In our opinion, the least studied aspect is the influence of the probe and its electric field on the plasma properties and the parameters determined.

As the object of the present investigation, we chose a pulsed-discharge oxygen plasma. The gas pressure was 0.07 torr, the pulse frequency was 1.5 kHz, and the relative pulse spacing was 10. The discharge was initiated in a cylindrical tube with a radius of 1.75 cm and a length of 40 cm; the pulse current was 80 mA. Measurements were performed with the aid of two sliding molybdenum probes with a length of 1.5 and 0.35 cm, whose radii were 0.01 and 0.005 cm, respectively. For diagnostics, a measuring unit was manufactured that allowed the recording of volt-ampere characteristics (VAC) and their second derivatives in the active discharge phase and in the afterglow stage. Figure 1 shows the radial dependence of VAC measured in the active discharge phase by the probe with a length of 1.5 cm and a radius of 0.01 cm. As is seen, the characteristics have no saturation current of the negative particles. The electron temperature, measured by the method of taking the logarithm of the steep part of the VAC, was 1.96 eV. We failed to measure the second derivative (by the method of modulation of the second harmonic) because of the high level of noise in the active discharge phase. The estimated mean free path of the electrons in the collision cross section [1] was 1.3 cm. The magnitude of the electric field of the positive column measured between two probes was 3 V/cm. The electron concentration estimated by the magnitudes of the current, electric field, and electron mobility [2] was 6.10^9 cm^-3.

Since the VAC has no saturation current of the negative particles, we can presume that, under the given discharge conditions, the mode of orbital motion (OML) of the charged particles toward the probe is implemented. According to the OML theory for a cylindrical probe, the plot of \( I^2(U) \) in the region \( kT \gg eU \) is a straight line. Figure 2 shows plots of \( I^2(U) \) constructed from Fig. 1. The main contribution to the current of negative particles is made by electrons; the current of negative ions can be neglected. In the region \( kT \gg eU \), the experimental values of \( I^2(U) \) coincide with straight lines; their asymptotic form crosses the axis of potentials at one point, i.e., the electron temperature is practically the same over the tube radius. The electron concentration was determined from the slope of \( I^2(U) \) [3] and along the tube axis it was 8.2.10^9 cm^-3, which agrees well with the estimated value given above. The radial profile of the electron density is shown in Fig. 3. It is seen that in the near-wall region it is substantially steeper than a Bessel distribution.

Fig. 1. Radial dependence of the VAC in the active discharge phase: 1) $r = 0$; 2) 0.5; 3) 1.0; 4) 1.5 cm. $I$, A; $U$, V.

Fig. 2. Radial dependence of $I(U)$ in the active discharge phase: 1) $r = 0$; 2) 0.5; 3) 1.0; 4) 1.5 cm; 5) $I(U)$ of the ion current at $r = 0$; 6, 7) $I^2(U)$ obtained in displacement of the axis of potentials. $I$, A; $U$, V.

Fig. 3. Profile of the electrons in the active discharge phase: 1) $n_e(R)$; 2) Bessel function. $n_e(R)$, cm$^{-3}$; $R$, cm.

Fig. 4. Radial dependence of the VAC in a disintegrating plasma: 1) $r = 0$; 2) 0.5; 3) 1.0; 4) 1.5 cm. $I$, μA.

Determination of the density of the positive ions is a more complicated problem. Thus, according to the OML theory their concentration on the tube axis exceeds $10^{11}$ cm$^{-3}$, which (as shown below) is a highly overestimated value. In [3], the authors give attention to a similar effect; however the correction formula proposed by them does not allow one to obtain densities that substantially approach the actual value. It might be supposed that the overestimated value is a result of incorrect determination of the axis of potentials (the current’s zero), and then in this case it is easy to carry out a test: upon artificial displacement of the axis of potentials the dependence $I^2(U)$ ceases to be a linear function (see curves 6 and 7 in Fig. 2). This, in turn, allows us to propose a prescription for determination of the floating potential.