EFFECTIVE THICKNESS OF THE ELECTRODE LAYER IN SUPERSONIC PLASMA FLOW BY THE CAPACITOR METHOD

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In the study of near-electrode processes under conditions of uniform current distribution over the surface of the electrodes in some cases one must know the thickness of the volume charge layer. Of special interest is the thickness of the near-electrode layer in the development of diagnostics of pulsed supersonic plasma flows with the aid of wall probes.

One method of determining the thickness of the near-electrode zone under conditions of supersonic plasma flow is to measure the capacitance of the plasma capacitor. A good deal of work has been done on this method. In particular, [1] studied the connection between the impedance of the capacitor and plasma oscillations in the entire volume, [2, 3] studied the connection between the impedance and plasma parameters in the near-electrode layer, and [4, 5] measured the capacitance in the plasma—electrode system. In the main all these investigations were conducted in stationary flow on different experimental facilities in which the plasma parameters were difficult to control. In most studies the measurement accuracy was low because of leakage capacitance. The existing methods require the use of complex electronic schemes, and not all of the schemes are suitable in pulsed facilities.

In a number of cases the investigation of the near-electrode processes under pulsed conditions was conducted in a shock tube [6], which offers the advantage of obtaining supersonic plasma flow of high uniformity with reliably controlled gasdynamic parameters and high values of electrical conductivity. The calculated values of the gasdynamic parameters agree well with experimental data. In order to study the near-electrode phenomena in a pulsed supersonic plasma flow behind the incident shock in a shock tube we used a constant section channel with a dielectric measuring section containing two electrodes located flush with the wall and on opposite sides of a square section (7.2 × 7.2 cm).

The initial pressure in the low-pressure chamber in the shock tube was $p_1 = 1.3 \cdot 10^3$ Pa. In the low-pressure chamber we used technical grade argon and argon with hydrogen impurity, the shock Mach number was $M_1 = 10\text{-}12$, the pressure behind the shock front was $p_2 = (1.8\text{-}2) \cdot 10^5$ Pa, and the duration of the gasdynamic plug passing through the measuring section was 200-250 μsec. Here on the channel walls was formed a mixed laminar-turbulent boundary layer, and also a near-electrode layer with a volume charge. In order to determine the thickness of the near-electrode layer in the supersonic plasma flow we used a comparatively simple electronic scheme, suggested by the author of [7], with which we could measure small capacitances. In this scheme, in Fig. 1, a transistor operates in the avalanche regime. The transistor discharge current is linear for low values of current, and depends on the capaci-

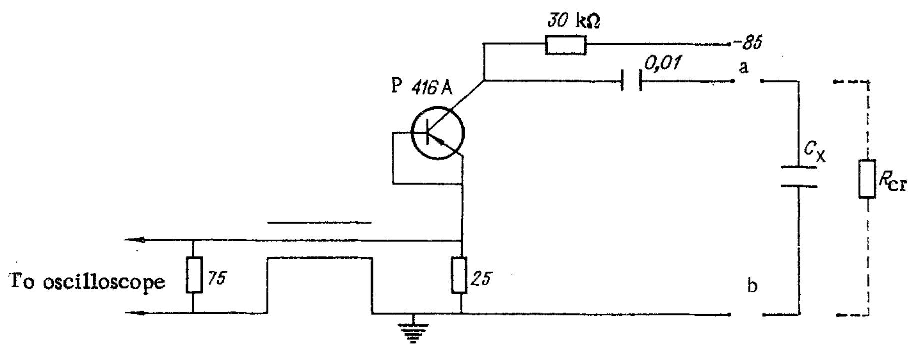

Fig. 1

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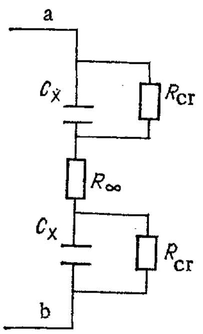

Fig. 2

tance. The thickness of the near-electrode layer was determined from the measured capacitance and the ratio for a planar capacitance. Planar wall electrodes (72 × 4 mm) were located on opposite walls of the shock tube. The time resolution was 2-3 μsec. The duration of the current pulses formed by the transistor was fractions of a microsecond.

Figure 2 shows the equivalent measurement scheme (a and b are the terminals of the capacitor electrodes, C_x is the capacitance of the near-electrode layer, R_{cr} is the capacitative reactance of the near-electrode layer, and R_∞ is the resistance of the plasma flow core), and Fig. 3 shows typical oscillograms of the capacitor and probe signals obtained in the shock tube in a hydrogen–argon plasma (10% hydrogen; a is the signal from the electrostatic potential probe, b is the signal from the plasma capacitors, and c is the shock wave front). The electrostatic probe, of diameter 1 mm, was located on the insulated wall of the measuring chamber at the electrode section. The two signals, whose shape was determined by the gasdynamic processes in the boundary layers, were identical. It was noted in [7] that the resistance R_∞ of the equivalent scheme has no significant influence on the measurements made using this electronic circuit. Neglecting the impedances R_{cr} and R_∞ in the equivalent circuit, we determined the effective thickness of the near-electrode layer using the relation for a planar capacitor

$$d = \pi\varepsilon_0 S/C_{tot},$$

where $C_{tot} = 2C_x$; and C_x is the capacitance in the twin electrical layer in the near-electrode region.

The experimental data were processed in the absence of external voltage on the electrodes and referenced to 50 μsec after the shock passed the electrodes, which time corresponded to a laminar boundary layer on the electrodes. Here the thickness of the near-electrode layer was determined with an accuracy of 15%. This value of thickness for $p_1 = 1.3 \cdot 10^3$ Pa in an argon–hydrogen mixture (10% H_2) and $M_1 \approx 11$ was $(6.6 \pm 0.5) \cdot 10^{-5}$ cm. In calculating the Debye radius the average value of the charged particle density in the near-electrode region was estimated from the profiles of dimensionless electron density in the boundary layer according to [8] for a laminar layer thickness of $\delta \approx 0.13$ cm and a density $n_{e\infty} \approx 4 \cdot 10^{15}$ cm^{-3} in the unperturbed plasma flow. The calculated value of the Debye radius here was $8.5 \cdot 10^{-5}$ cm.

Thus, we have confirmed the conventional position that the effective thickness of the near-electrode layer in a supersonic plasma flow agrees with the Debye radius.

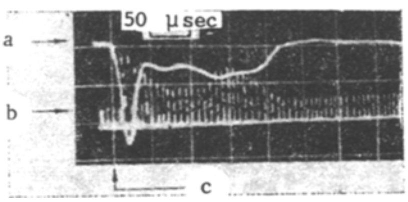

Fig. 3

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NUMERICAL STUDY OF A GLOW DISCHARGE IN A CO_2–N_2–He GAS MIXTURE

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Increased interest has developed in the volume glow discharge in CO_2–N_2–He gas mixtures because of their wide use as active media in gas discharge lasers. The presence of intense dissipative electron attachment in electronegative gases (among which is the CO_2–N_2–He mixture) has a strong effect on the structure and evolution of the glow discharge. Thus, under certain conditions, attachment instability develops in the discharge [1, 2], while in the stable state the positive column of the discharge may be inhomogeneous along the direction of the current [2, 3].

Attachment instability was analyzed in the linear approximation in [4, 5] with the assumption of homogeneity of the discharge positive column. A qualitative study of the structure of domains which develop with attachment instability was performed in [6-9]. Numerical calculations of evolution of a volume glow discharge in an electronegative gas were presented in [10-12].

When the non-steady-state equations describing such a discharge are integrated [10, 11], a complete physical picture of discharge evolution can be obtained. The total time required for exit of the solution to steady-state (or steady-state oscillations) is determined by the slowest process (ion drift). The more rapid drift of electrons imposes rigid limitations on the integration step used for time. Therefore it is clear that use of the established method to obtain the steady-state solution will require significant expenditures of machine time.

To obtain the steady-state solution the present study employs an effective method for solution of the steady-state problem, allowing study of volume glow discharges over a wide range of parameters and construction of current-voltage characteristics (CVCs) for the discharge. In calculating discharges in the attachment instability region the nonsteady-state equations were integrated numerically using an implicit difference method.

1. Mathematical Model and Methods of Solution. Within the framework of the assumptions generally used [1, 2], the nonsteady-state equations describing a volume glow discharge in an electronegative gas have the following form:

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