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DISTORTION OF PLASMA DUE TO INSTALLATION OF AN ORIFICE IN HELIUM DISCHARGE POSITIVE COLUMN

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Abstract

Complicated potential structure formed at a constriction of positive column of a DC discharge with heated cathode in He at low discharge currents is investigated. According to the potential structure, electrons and ions are accelerated by the electric field and their energy distribution functions acquire multi humped shapes. Additional maximums on distribution functions quickly disappear due to collisions and radial losses. The nature of current passing through the Potential Structure (PS) is cleared up on the base of measured distributions. Attempt was made to calculate potential drop in DL taking into account electron energy distribution variations.

Keywords: Double layers; Positive column; Particle distribution function

1. Introduction

Constriction in a homogenous positive column (PC) due to the installation of an orifice is known to cause drastic changes in plasma parameters such as electric field, charged particle density and electron energy distribution function (EEDF), resulting in a double sheaths or double layers (DL) [1-3]. A great deal of investigations has been done for DLs formed in collisionless fully ionized plasma due to their applications in space plasmas. As collision processes can be neglected in this case, the only way of adjusting between two kinds of plasmas is forming double layer of space charges. This phenomenon being accompanied by trapped particles, and wave particle interaction is currently well understood [4-6].

On the other hand, contrary to collisionless plasmas, in a weakly ionized collision controlled plasma, collision processes between charged and neutral particles and recombination do not necessitate existence of double layers of space charges. In this kind of discharges each part of chamber has its own axial potential distribution and it is only near the constriction region that the sharp changes occur in potential. For this case, potential structure (PS) formed by the change of discharge tube diameter has been studied in He [7]. EEDFs were calculated from the kinetic equation using the measured profile of potential when the momentum-transfer quasielastic collision frequency and characteristic scale are much longer than the electron mean free path. Double-humped distribution functions were obtained. These distributions show a quite good

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agreement with measured ones.

Double-humped EEDFs due to the electron acceleration through rapid PS were also observed in numerous investigations. In [1] such distributions were observed in an Hg-Ar mixture collision controlled positive column. A one-dimensional model has been introduced to explain this kind of EEDFs by taking into account the absence of local equilibrium between the electrons and the electric field. A solution of the Boltzmann equation including the spatial derivative under the assumption of a rectangle-shaped electric field has successfully predicted a partial shift of low energy electrons to higher energies.

The potential structure (PS) formed at a constriction of PC of a DC discharge in He at low pressure and discharge current was investigated in both stationary or self-oscillating states in [3]. The discharge has developed a strong electric field in order to provide the continuity of discharge current. The second maximum of double-humped electron energy distribution was vanished and electron gas quickly cooled due to inelastic processes and radial loss of fast electrons of the anode side of PS. Self-oscillating state was characterized by occurrence of moving striations which were periodically weakening and strengthening the PS, thus large fluctuations of PS voltage discharge current occurred.

In all investigations, only the main potential drop of the anode side of the orifice was considered. In the mean time, as showed our experiments, besides the sharp potential change near the orifice on the anode side, a number of less defined potential oscillations take place in both sides of the orifice. These weak PSs have considerable influence on the plasma properties near the orifice. Moreover, all measurements were performed for EEDF, but ion distributions were neglected although ion densities and IEDFs play important role in PS forming and its behaviour.

In this paper, we report the observed complicated structure of PS near the orifice and its influence on electron and ion distribution function. Nature of current passing through the PS is elucidated on the base of measured distributions. Attempt was made to calculate potential drop in DL by taking into account EEDF variations but not T_e.

2. Experimental Methods and Results

Experiments were performed in a discharge chamber 80 cm length and 8 cm diameter in which a plastic orifice with 2 cm width and different (1, 2, 3 cm) inner diameters was installed (Fig. 1a).An insulated iron ring was fitted on the orifice in order to change the position of the orifice with the help of an external magnet. On both sides of the orifice Langmuir probes and analysers were placed to measure electron parameters and ion energy. The discharge chamber was equipped with a hot tungsten filament cathode and a cylindrical anode. Discharges were obtained in helium at pressures 0.1-1 Torr and in a discharge current ranging up to 11 mA.

a) Energy Analyser Measurements

One can obtain relation between the first derivative of collector current $J'(V)$ and ion energy distribution function (IEDF)

$$f_i(v) = \frac{dn}{ndv} \tag{1}$$

where, dn is the number of ions in the range of v, $v + dv$ and n is the ion density. Current density of collector is:

$$J_i = ne\sqrt{\frac{2e}{m_i}}\int_0^v \sqrt{v}\ f_i(v)\ dv \tag{2}$$

where, m_i -is the ion mass. Taking the first derivative of this expression we obtain:

$$f_i(v) = ne\sqrt{\frac{2e}{m_i}}\ \frac{1}{\sqrt{v}}\ \frac{dJ_i}{dv} \tag{3}$$

$J'(v)$ measured in the anode side of the orifice (D=2 cm , x=4 cm) is shown in Figure 2. Ion temperature obtained from this curve is 2.0 eV. This value is of the same order of the results obtained by other authors but somewhat higher [2]. At our conditions except the main DL at the edge of the orifice, there were a number of less defined weak DLs. Ions gain additional energy spread due to this PS, and ion temperature seems higher.

First derivatives of collector current measured at the anode side of the orifice (D=3 cm) at different distances are shown in Figure 3. One can see that DF at x=0.5 cm have two groups of ions. The first group has an energy about 4.0 eV and is rather monokinetic. The second group having energy about 12 eV has more energy spread. In distribution function measured, DF at 3.5 cm (Fig. 3) the first group is broadened and two groups partially overlap each other. At x=5 cm (Fig. 3) these groups are confluenced and there is only one group of ions.

Ion number densities, measured at different distances from the orifice at the anode side are shown in Figure 1c. For all cases, there are periodical oscillations of ion density according to additional DLs.

First derivatives of collector current, measured at different distances from the orifice (D=3 cm) at the

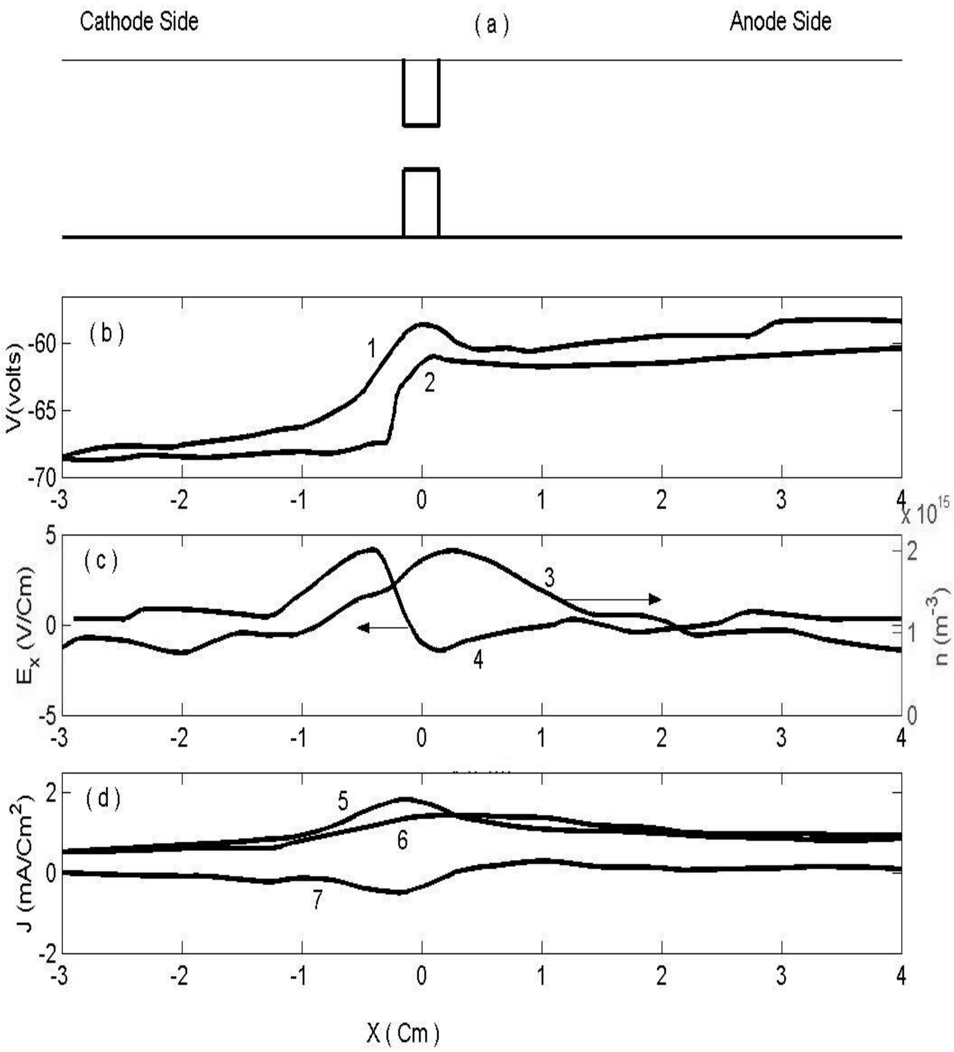

Figure 1. a) Meridional cross-section of discharge; **b)** Axial distributions of: 1) plasma potential, 2) floating potential. **c)** Axial distributions of: 3) charge particles number density n, 4) longitudinal electric field E. **d)** Axial variations of current densities 5) conductive current, 6) diffusion current, 7) total current.

cathode side are shown in Figure 4. As seen, at x=2.5 cm (Fig. 4) DF has thin structure. There are four groups of ions. DFs measured at distances far from the orifice show that at large distances first the high energy group disappears due to interaction with the gas atoms. So, in Figure 4 the third group gradually disappears and second group is broadened. In Figure 4, only the first group corresponding to 3.0 eV is remained, and second group having 8.0 eV is existed in a very wide form. The third group is definitely disappeared.

Measurements of IEDFs at the cathode side for orifices D=1 cm and 2 cm gave similar results. Only the thin structures of DFs were less defined. Probably this is related to lesser resolution of the analyser, as smaller scale orifice causes smaller scaled potential variations.

b) Probe Measurements

Directed beam part of EEDF has the same relation with the first derivative of probe current $J'(v)$ as for collector current of ions (see Equation 3). We were interested only in electrons, accelerated through the DL and for obtaining electron parameters, probe characteristics and their first derivatives were measured. Probe characteristics were used for obtaining electron density and floating potential, their first derivatives were used for obtaining distribution functions and plasma potential.

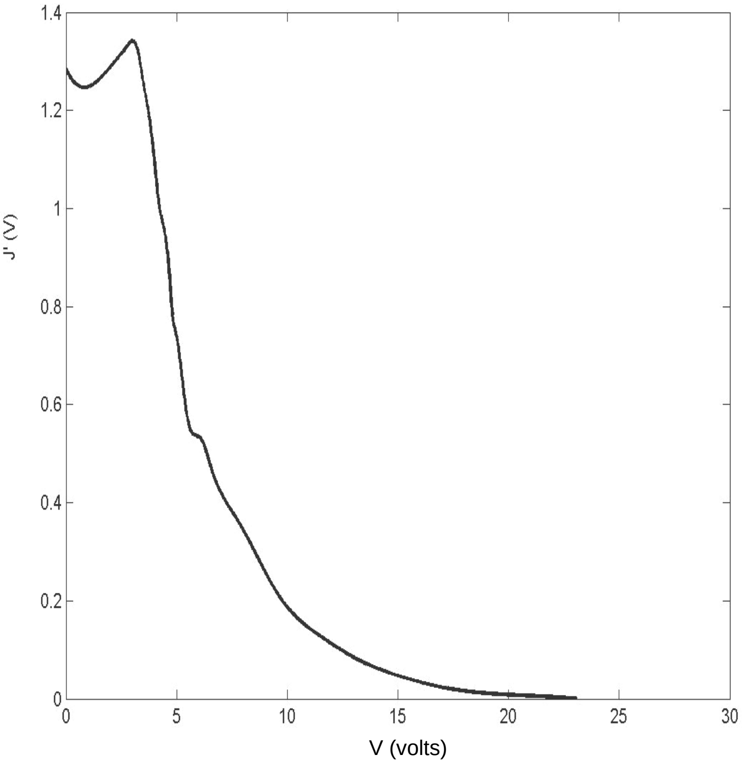

Figure 2. Measured $J'(V)$ at x=4 cm, I =11 mA, P=0.3 Torr, D=2 cm.

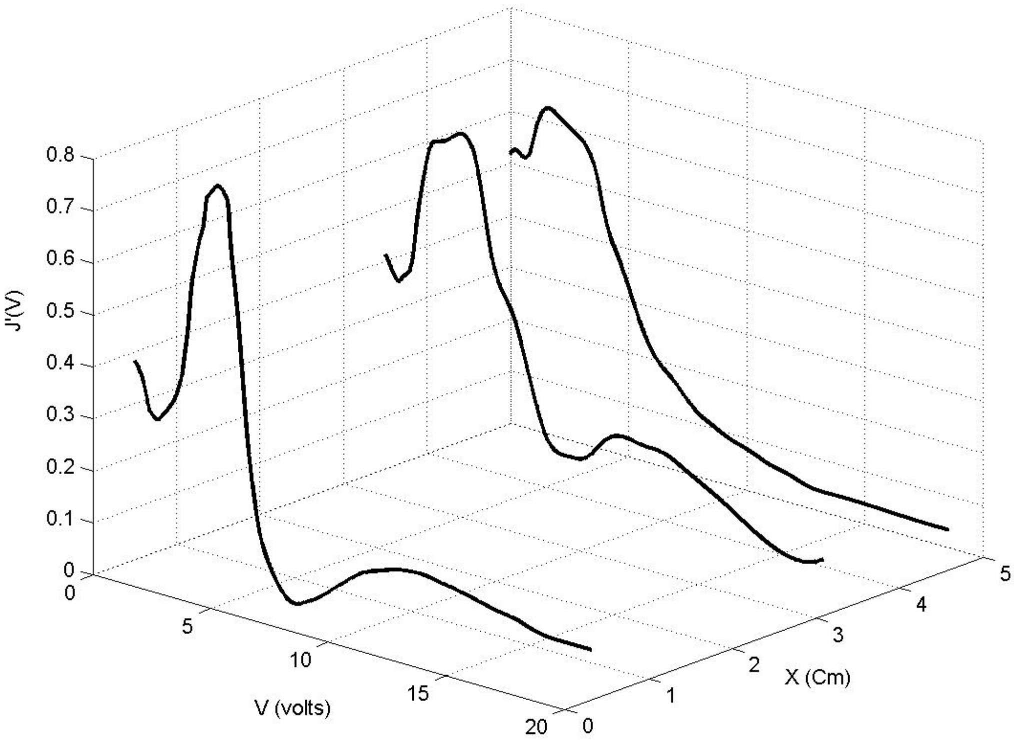

Figure 3. $J'(V)$ measured at different distances from the orifice at the anode side, P=0.3 Torr, I=11 mA, D=3 cm.

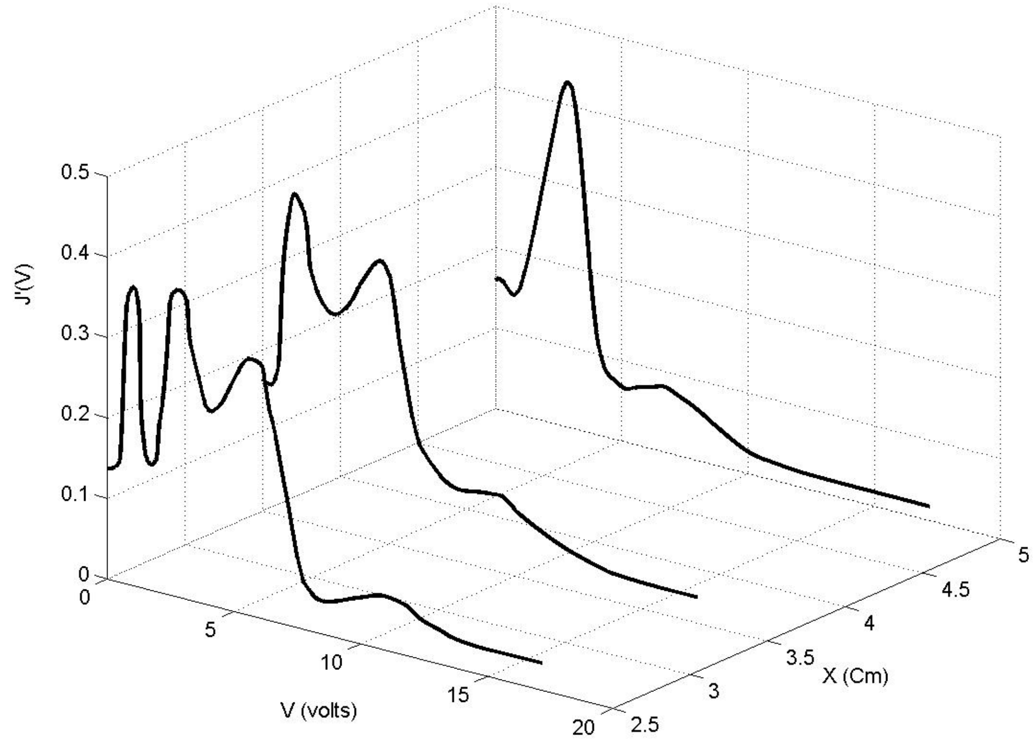

Figure 4. Measured $J'(V)$ at different distances from the orifice on the cathode side, P=0.3 Torr, I=11 mA, D=3 cm.

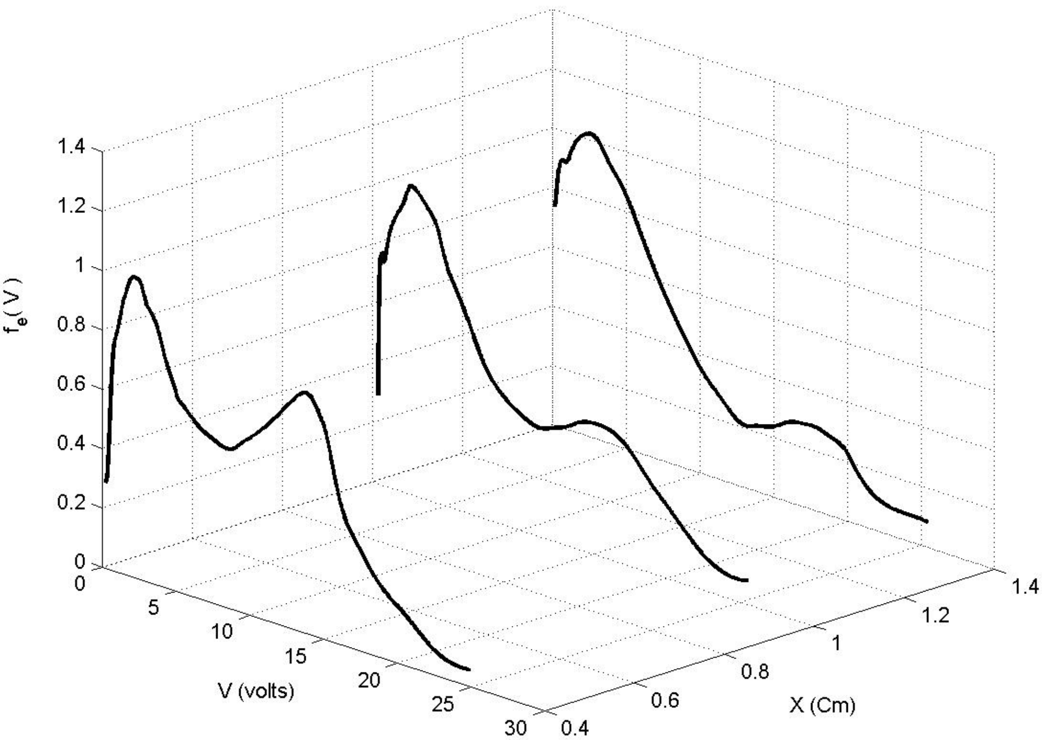

Figure 5. Distribution functions measured at different distances from the orifice at the anode side , P=0.3 Torr, I=11 mA, D=3 cm.

In Figure 1b, axial distributions of floating potential and plasma potential (D=3 cm) at the anode side are shown. In Figure 1 axial distribution of electron number density and distribution of longitudinal electric field E_x, are plotted. As seen, electron density distribution is shifted to the anode side relative to E_x distribution. Electrons accelerated towards the anode acquire higher energies, so ionization rate and electron density increases. In this part E_x decreases and even obtains reverse direction. At large distances from the orifice in both directions, plasma potential changes linearly.

Different characters of floating potential and plasma potential distributions are the result of different EEDF shape at different points. Distribution functions, measured at different distances from the orifice at the anode side, are shown in Figure 5. One can see the shape difference between these distributions.

3) Discussions

Complicated variations of EEDF, charged particle number densities, longitudinal (E_x) and radial (E_r) electric fields give some peculiarities to current transition through the constriction. So in the orifice region, discharge current consists of the sum of two components: diffusion current which flows towards decreasing density of charged particles, and conductivity component. In Figure 1d, axial distributions of these currents and total current density are shown.

Here, diffusion current density is calculated from:

$$j_{dif}(x) = \frac{2e^{3/2}}{3m_e}\int_0^\infty \frac{V^{3/2}}{\nu_m(eV)}\frac{\partial f}{\partial x}dV \tag{4}$$

and the conductivity current from:

$$j_{cond}(x) = \frac{2e^{7/2}E_x}{3m_e}\int \frac{V^{3/2}}{\nu_m(eV)}\frac{\partial f}{\partial V}dV \tag{5}$$

where, ν_m is the collision frequency.

As can be seen, in some regions, the direction of diffusion current is reversive to the main discharge current.

Disturbance, introduced by DL is not local. EEDF at the anode side of the orifice considerably differs from Maxwellian one because of the existence of accelerated electrons. Nevertheless, the mean electron energy $\bar{\varepsilon}$ can relax to the some range as in the homogenous PC of the same E/P. In this case discharge current density can be written as [8]:

$$j_e = en_e b_e E - \left\{ eD_e\frac{\partial n_e}{\partial x} + eb_e\frac{\partial}{\partial x}\left(\frac{2\bar{\varepsilon}}{3e}\right)\right\} \tag{6}$$

Here, b_e and D_e - are mobility and diffusion coefficients of electrons. The first term of the right side is the expression of the electron current due to electric field. Second and third terms express diffusion of electrons due to density and temperature gradient of electron gas.

$$D_e = \frac{2\bar{\varepsilon}}{3e}b_e \tag{7}$$

We shall solve Equation 6 by assuming that, DL potential drop is independent of discharge current from [8], we obtain for the extremely low discharge currents i→0:

$$E = \frac{2}{3e}\left(\frac{\bar{\varepsilon}}{n}\frac{\partial n_e}{\partial x} + \frac{\partial\bar{\varepsilon}}{\partial x}\right) \tag{8}$$

Integrating this expression in the DL boundaries (from x_1 to x_2) we obtain expression of potential drop *via* undisturbed plasma parameters on the both sides of DL:

$$\Delta V = \frac{2}{3e}\left\{\bar{\varepsilon}(x_2) - \bar{\varepsilon}(x_1) + \int_{n_e(x_1)}^{n_e(x_2)}\frac{E(x)}{n_e(x)}dn_e\right\} \tag{9}$$

Calculation of ΔV using Equation (9) and our experimental values of $E(x)$ and $n_e(x)$ gave quite close quantities to measured ones. Unfortunately more accurate comparison is impossible as complicated shape of PS do not permit exact determination of integrating boundaries.

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