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A CURRENT-VOLTAGE CHARACTERISTIC OF NON-SELF-MAINTAINED DISCHARGE.

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1. The analytical expression of the non-self-maintained current-voltage characteristic is obtained. The ion current flowing into cathode sheath from plasma is important factor in the considered model. This ion current was not taken into consideration in the classical Thomson's paper /1/, when the analogous problem was solved in paper /2/ the ion current from plasma was taken into consideration for construction of probe theory in non-self-maintained discharge, but the rate of ionization in the cathode sheath was not taken into account.

Let us consider the plane system of electrodes. We'll solve equations for plasma and cathode sheath separately and then make join of solutions on the plasma-sheath boundary.

2. The equations for plasma region are given by:

\[ j_e = e n_e b E + e D_0 \frac{dn_e}{dx} \]  

\[ j_i = e n_i b E - e D_0 \frac{dn_i}{dx} \]  

\[ \frac{d\nu_e}{dx} = \frac{d\nu_i}{dx} = q (q - d_k n_e^K) j_e + j_i \]  

Here \( q \) is the rate of ionization created by external source, \( d_k \) is the effective recombination coefficient. Index \( K \) depends on the type of the recombination.

We'll consider the cases when \( K = 2 \) and 1.

Take the origin of coordinates at the plasma-sheath boundary and introduce nondimensional concentration \( N \) and nondimensional length \( y \):

\[ N = \frac{n_e}{n_{\infty}} ; \quad y = \frac{x}{a} ; \quad z = \left( \frac{Z_{re}}{\alpha_k n_{\infty}} \right) N \]  

Here \( \alpha_k \) is ambipolar diffusion coeﬃcient, \( Z_{re} \) is the recombination length, \( n_{\infty} \) is unperturbed plasma concentration. From (1) and (2), taking into account (5), we get:

\[ j_i = j_d \frac{b_i}{a_i b_i} + n_e \frac{e D_0}{Z_{re}} N' \]  

\[ E = E_\infty N' + \frac{Z_{re} - 2Z_{re}^2}{\alpha_k b_i} N' \]  

\[ N' \frac{dN}{dy} = (1 - N) \frac{1}{K(N^2)} \]  

Here \( N' \) is the electric field in plasma far from boundary. Integrating (7), we can obtain the potential drop on the plasma.

\[ V_p = E_\infty (L - x_0) + E_\infty (L - x_0) \ln \frac{n_e}{n_{\infty}} + \frac{Z_{re} - 2Z_{re}^2}{\alpha_k b_i} \ln N' \]  

Here \( L \) is the anode-cathode distance, \( x_0 \) is the cathode sheath thickness, \( n_ne \) is the concentration on the plasma-sheath boundary.

3. If the heat energy of electrons is far less than the cathode drop, then electrons will be found in the sheath in the strong repulsive field and \( n_e \gg n_{\infty} \) on the whole sheath except narrow region near plasma-sheath boundary. Therefore we can neglect \( n_{\infty} \) in comparison with \( n_e \) in Poisson's equation for sheath. The distribution of the field and \( n_e \) must be determined from joint solution of equations:

\[ \frac{dE}{dx} = -n_e j_e \]  

\[ \frac{dj_i}{dx} = -q (q - d_k n_e^K) j_e + j_i \]  

with boundary condition \( j_e(x_0) = (1 + p)^{-1} j_d x_0 \) where \( \gamma \) is the secondary emission coefficient.
under bombardment of the cathode by ions.

The solutions must be joined at the plasma-sheath boundary. So, joining derivative of the field, we obtain algebraic equation for ion concentration at the boundary \( N_0 \):

\[
\frac{N_0^3 e}{f-N_0} \frac{\partial^2 \rho}{\partial x^2} = E_0 - \frac{2}{A_0} \int \frac{1}{\alpha_0^2 (1-2N_0^{3/4})} \frac{\partial}{\partial t} (f-2N_0^{3/4})(\kappa=1) \tag{13a}
\]

Substituting the value \( N_0 \), found from (13), in (6) and (7) we obtain values of ion current \( j_0 \) and electric field \( E_0 \) near cathode:

\[
V_0 = \frac{e_j}{2} \left( \frac{x_0}{2} \right); \quad E_0 = E(t - \frac{x_0}{\lambda}), \tag{14}
\]

Substituting (14) in (6) we obtain equation of the current-voltage characteristic of the cathode sheath.

The behaviour of the expression (17) depends greatly upon the value \( \delta \). By means of (6) and (7) it can be obtained that:

\[
\delta^2 = \frac{e_j}{\beta N_0^{3/4}} \frac{f}{N_0^{3/4} N_0^2} \tag{18}
\]

The value of parameter \( \delta \) is less or about 1 in electropositive gases at the pressures up to several atmospheres. Under this condition it can be neglected logarithmic term in expression (17). In electronegative gases, because of strong attachment of electrons, the parameter \( \delta \) can become much larger than 1. In this case it can't be neglected logarithmic term in (17). However, there are two limits, when (17) can be simplified independently of \( k \). The first limit takes place if:

\[
t_m \gg \max \left[ \frac{1}{k^2}; \delta^2 \right] \tag{19}
\]

The second limit takes place if:

\[
t_m \ll \max \left[ \frac{1}{k^2}; \delta^2 \right] \tag{20}
\]

From (17) and (14) we obtain for cathode drop \( V_0 \) and electric field \( E_0 \) near cathode:

\[
V_0 = \frac{e_j}{2} \left( \frac{x_0}{2} \right) ; \quad E_0 = E(t - \frac{x_0}{\lambda}), \tag{15}
\]

If the criterion (20) is carried out, then we have:

\[
V_0 = \frac{e_j}{2} \left( \frac{x_0}{2} \right) ; \quad E_0 = E(t - \frac{x_0}{\lambda}), \tag{22}
\]

4. Using (6), (15) and (16) we can obtain:

\[
J_d = \left( \frac{1}{f} - \frac{e_j}{2} \right) = e_j (x_0 + \gamma N'), \tag{23}
\]

\[
t_m = \gamma \frac{x_0}{\lambda} N' \tag{24}
\]

One can see from (23), that there are two characteristic lengths \( x_0 \) and \( \gamma N' \) of forming current in considered model. Under \( x_0 \gg \gamma N' \) the discharge current is formed mainly in the cathode sheath region, and under \( x_0 \ll \gamma N' \) the characteristic length of forming current is \( \gamma N' \). In the first case \( t_m \gg 1 \) and criterion (19) can be carried out; in the second case \( t_m \ll 1 \) and criterion (20) can be carried out. If criterion (19) takes place, then transition region with length \( x_0 \) and \( \gamma N' \) can be neglected and the sheath can be joined with plasma without consideration \( j_0 \) and \( E_0 \), that was made in /1/. If criterion (20) is carried out, ionization in the cathode sheath can be neglected in comparison with ionization on the length \( \gamma N' \), that was made in /2/. And general expression (17) must be used for determining \( V_0 \) in the intermediate case when the values \( x_0 \) and \( \gamma N' \) have the same order of magnitude.

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References
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