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LANGMUIR PROBE DIAGNOSTIC OF NEGATIVE IONS IN PLASMA

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Plasma containing negative ions has been studied in positive columns hydrogen and iodine–helium low pressure discharges. In order to obtain the densities of negative ions, a simple model of the discharge plasma was used.These densities were measured with plane and cylindrical electrostatic probes. The method using the saturation–current of a probe is applicable if a proper calibration with a negative ion free case is made. The calculation and the measured values of densities of negative ions are in good agreement.

1. Introduction

Plasmas containing negative ions find numerous applications in various equipment. The plasmas under review have found its broadest application in plasma chemistry. Hydrogen plasma is used for peeling metal surfaces and creation of the negative ion flows [1]. The iodine–helium mixture forms the amplifying medium for laser action on several transitions in the near infrared between states of neutral atomic iodine [2]. Probe method is simple and suited for measuring negative ions.

2. Calculation

The H^-– and I^-–densities were obtained from the continuity equations, taking into account the various known production and destruction processes.

In hydrogen non-isothermal low pressure plasma the major charged particles are: electrons, negative H^-–ions and positive hydrogen molecule H_2^+–ions [3]. Demikhannov et al [4] suggested that formulation of H^- ions by dissociative recombination:

$$e + H_2^+ \to H^- + H^+$$

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could be essential in a plasma. The scross-section for this reaction has been calculated theoretically by Dubrovski et al [5]. The H^-–density was obtained from the continuity equation

$$K_1 \cdot n_{H_2} \cdot n_e + K_2 \cdot n_{H_2^+} \cdot n_e - K_3 \cdot n_e \cdot n_{H^-} - K_4 \cdot n_{H_2^+} \cdot n_{H^-} - \frac{n_{H^-}}{\tau} = 0, \quad (1)$$

where K_1, K_2, K_3 and K_4 are rate coefficients of dissociative electron attachment, dissociative recombination, electron detachment and mutual neutralization, respectively; n_{H_2}, $n_{H_2^+}$, n_{H^-}, n_e –densities of H_2–molecules, H_2^+– and H^-–ions and electrons, respectively; τ – the diffusion loss time. The numerical values of the rate coefficients K_1, K_2, K_3, K_4 with our measured electron energy distributions are (in cm^3s^{-1}): 3.04×10^{-14}, 2.39×10^{-12}, 2.07×10^{-9}, and 1.0×10^{-7}, respectively.

In iodine–helium mixture discharge the dominant reactions assumed to be dissociative attachment, mutual neutralization and wall processes. In caculating the negative ion electron densities ratio in iodine discharges, the effect of rare gas additives need only be considered in so far as they affect the electron temperature and wall processes. The continuity equation is

$$K_1 \cdot n_{I_2} \cdot n_e - K_4 \cdot n_{I_2^+} \cdot n_{I^-} - \frac{n_{I^-}}{\tau} = 0 \quad (2)$$

where K_1, K_4, n_{I_2}, n_e, $n_{I_2^+}$, n_{I^-} and τ present analogical quantities as in equation (1).

Assuming the Bessel distribution of negative ions along the radius [6], in case of cylindrical geometry, according to [7], the diffusion loss time was found as

$$\tau = \frac{1}{D^-_{eff}} \frac{R^2}{(2,4)^2}, \quad (3)$$

D^-_{eff} being the effective coefficient of diffusion of negative ions [8] and R – radius of a tube. The basic difficulty with solving the equations (1) and (2) for n_-, using still result from plasma neutrality $n_+ = n_e + n_-$, lies in the fact that the diffusion loss time is explicitly dependent on the unknown quantity n_-. So, the equations (1) and (2) were solved by an iterative method.

3. Experiments and method

The experiments were done in a discharge tubes, with a diameter of 4 cm and a length of 30 cm, with glowing oxide cathode for hydrogen plasma and with hollow cathode in the middle and two plane anodes located on both ends of the tube for iodine–helium mixture plasma.

An attempt of detecting negative ions was based on measuring of saturation current ratio of the electrostatic probe [9], for a Maxwell's energy distributions of all charged particles.

$$\frac{(i_{es}/i_+)}{(i_{es}/i_+)_{\alpha=0}} = (1-\alpha) + (mT_-/M_-Te)^{1/2}\alpha \quad (4)$$

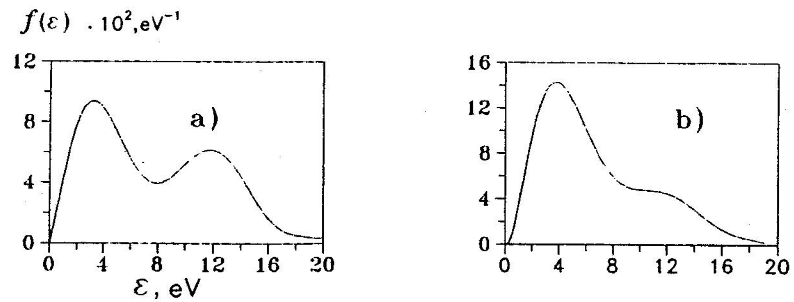

Fig. 1. The electron energy distribution along the striation: a) in the head of the striation, b) in its tail.

where (i_{es}/i_+), $(i_{es}/i_+)_{\alpha=0}$ are the saturation current ratios for a probe in the presence and absence of negative ions respectively; $\alpha = n_-/n_+$; m, M_- – masses of electrons and negative ions, respectively, and T_e, T_- – their temperatures. Because $m \ll M_-$, $T_- < Te$, for small α the equation (1) became

$$\frac{(i_{es}/i_+)}{(i_{es}/i_+)_{\alpha=0}} \approx (1-\alpha) \quad (5)$$

The measurement of n_- is based upon a deviation from the case of $\alpha = 0$.

4. Results and discussion

In hydrogen plasma a positive column was almost without striations ($P_{H_2} = 10^{-2}$ $torr$, $I_d = 50$ mA) or was constituted of several immovable striations ($P_{H_2} = 10^{-1}$ $torr$, $I_d = 200$ mA). In the first case the electron energy distributions were almost Maxwell type with $Te = 5$ eV and $n_e = 10^9$ cm^{-3}. Calculation of a $\alpha = n_-/n_+$ from the equation (1) gave $\alpha \approx 0,03$. When we increased hydrogen pressure and discharge current a positive column became stratified. The electron energy distribution was sharply non–equilibrium, and its shape was quite different in the "head" and "tail" of striation /see fig. 1/. The results of calculating the values of α for a measured electron energy distribution ($P_{H_2} = 4 \cdot 10^{-2}$ $torr$, $I_d = 150$ mA) were $\alpha = 0,2$ in the "head" and $\alpha = 4,5 \cdot 10^{-3}$ in the "tail" of the striation.

During the measuring of a saturation current ratio in helium and with the addition of hydrogen, the ratio varied within experimental error limits. So, only the upper limit of α, equal the experimental error, could be estimated. That limit turned out to be 0,2.

In helium–iodine mixture plasma ($P_{He} = 0,3$ $torr$, $P_{I_2} = 10^{-4} \div 10^{-3}$ $torr$, $I_d = 30$ mA) a positive column was sharply stratified. The electron energy distributions was quite different in the "head" and the "tail" of the striation. In the presence of superthermal electron group, as in the "head" of the striation, the theory of the saturation current at the positive probe bias must be changed. For more details one can find in [9].

Table 1.

P_{I_2} 10^{-4} Torr	Te eV	n_e 10^9 cm^{-3}	n_-/n_e calculated	n_-/n_e experiment
2.4	3.2	1.6	5.9	5.9
5.4	1.7	2.7	15.4	15.3
8.0	1.4	5.3	18.9	18.7
11.0	1.3	6.9	27.1	25.8

In the "tail" of the striation the electron distribution functions were almost the Maxwell type and we could compare the results of the calculation of the values n_-/n_e, assuming Maxwell's electron energy distribution and experimental measurements. The results are presented in the Table 1.

Strictly speaking, the right–hand side of the equation (4) must be multiplied by a factor $(M_{+eff}/M_+)^{1/2}$, where M_{+eff} is the effective mass of positive ions in mixture plasma and M_+ – positive ion mass in electropositive gas only. In the case of mixture plasma it may be assumed that $M_{+eff} = cM_{I_2^+} + (1-c)M_+$, where c and $M_{I_2^+}$ are the fraction and the mass of positive iodine ions, respectively. The values of c was determined by calculation.

5. Conclusion

As a method for determination of the negative ion density the saturation current ratio at positive and negative biases of the probe characteristics was considered. In hydrogen plasma the negative ion density was so small that it could not be detected exactly. In helium–iodine mixture plasma the calculation and the measured values of negative ion densities were in good agreement after multiplying the equation (4) by factor $\sqrt{M_{+eff}/M_+}$.

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