ELECTRON KINETICS IN BEAM DISCHARGE PLASMA AND COMPARISON OF PLASMA-BEAM AND GLOW DISCHARGE REACTORS

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ABSTRACT

This paper is devoted to the theoretical study of the electron kinetics in the beam discharge plasma and the comparison between the main properties of the beam and glow discharge plasmas.The calculations are carried out for molecular hydrogen and nitrogen.

1. INTRODUCTION

In paper /1/ it was proposed to use a stationary beam discharge plasma in plasmachemistry to obtain high nonequilibrium degree of plasma and to realize a big power input with respect to the other types of discharges.In the beam discharge plasma the main part of the electron beam energy is transfered to the Langmuir oscillations due to the beam-plasma instability and then those oscillations heat plasma electrons.The last ones interact with the heavy particles of the gas, exciting inner degrees of freedom, and making the molecules more reactionable. This paper is devoted to the electron kinetics in the beam discharge plasma in molecular nitrogen and hydrogen and to the comparison between the main macroscopic properties of the beam and glow discharge plasmas.

2. ELECTRON KINETICS IN BEAM DISCHARGE NITROGEN PLASMA

As have been shown in paper /2/ the kinetic equation for the electrons in beam discharge plasma can be written in the following form

$$\frac{\partial f}{\partial t} = \frac{2}{3}\frac{W}{n}\frac{1}{\sqrt{\varepsilon}}\frac{\partial}{\partial \varepsilon}\left(\nu_{\Sigma}\varepsilon^{3/2}\frac{\partial f}{\partial \varepsilon}\right) - St(f) \quad (1)$$

where f( ) - the isotropic part of the electron distribution function; n - electron density; ν_{Σ} - total frequency for the momentum transfer; W - energy density of Langmuir oscillations; St(f) - collisional integral of the Coulomb and electron-neutral interactions. Equation (I) was numerically solved for the total turbulence energies per one electron $\tilde{U} = \tilde{W}/n$ and degrees of ionization $\alpha = (n/N)$ as a given parameters by the method developed in /3/. For calculations we used the cross sections for momentum transfer (*el*), for vibrational (VE) and electronic (EE) excitation and direct ionization (I) and dissociation (DI) from /4/. Fig.I shows the distribution functions f(U) for different values of $\tilde{U}$ (in V) for the selected ionization degree $\alpha = 10^{-2}$. For low U a nearly Maxwellian form of distribution is to be found, so we observe greater deviations in the range of higher U values. Fig.2 shows the distribution functions for the selected value $\tilde{U} = 5 \cdot 10^{-3}$ V and for different degrees of ionization. Note that for $\alpha \gtrsim 10^{-4}$ the distribution function in beam discharge plasma in nitrogen has a nearly Maxwellian form. The dependence of the electron energy loss channels on the degree of ionization and remarkable change of them with respect to their dominant role can be seen from the relative energy losses (U^M/U^T), which are represented in Fig.3 and 4 for the two values $\tilde{U} = 5 \cdot 10^{-2}$ V and $5 \cdot 10^{-3}$ V.

3. ELECTRON KINETICS IN BEAM DISCHARGE HYDROGEN PLASMA WITH FINITE LIFETIME OF CHARGED PARTICLES

Earlier the degree of ionization α was supposed to be some fixed parameter, yet, it can be calculated as a function of parameters W/Po and P0·L (Po - pressure of the gas, L - the length of the device) when bearing in mind that in steady state the balance of electrons holds and that parameter $\tilde{U} = W/n$, determening the rate of heating, depends on α (provided that lifetime of electrons is limited by ambipolar diffusion). Then degree of ionisation $\alpha = (n/N)$ is easy to calculate by means of the additional iterative process, based on the electron balance equation. The calculations were carried out for molecular hydrogen. Fig. 5 shows the distribution function calculated for different values W/Po (J/cm³ Torr) and Po L (in cm·Torr). It's seen that the function f(U) depends on the parameter W/n T weakly for fixed Po·L.

Fig.6 shows the ionization degree α, mean energy $\bar{U}$ and parameter W/n T as a functions of W/Po. The dependence of the energy input $\hat{P}$ per one electron and pressure unit and the absolute energy losses of the electron $\bar{U}^M$/Po (in V/s · Torr) in different elementary processes on the parameter W/Po for $P_0 \cdot L$ = I cm.Torr is represented in Fig. 7. In Fig. 8,9 the relative energy losses (U^M/U^T) are represented as the functions of W/P_0 and $P_0 \cdot L$.

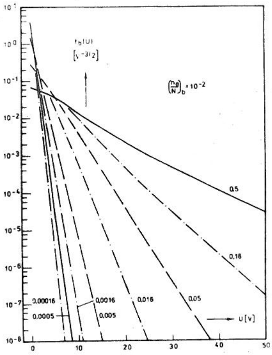

Fig.1

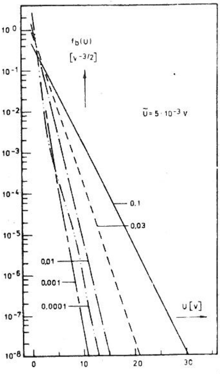

Fig.2

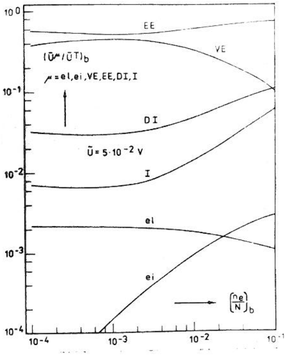

Fig.3

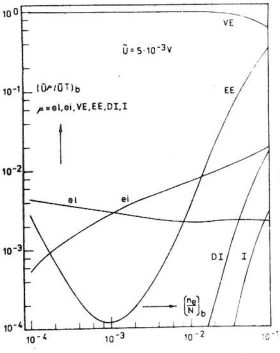

Fig.4

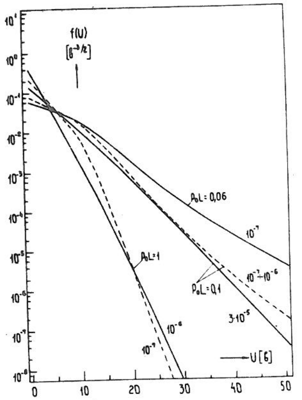

Fig.5

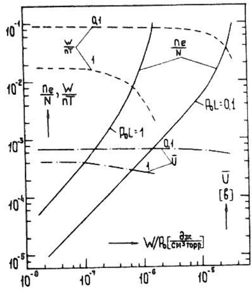

Fig.6

4. THE INFLUENCE OF THE SUPERELASTIC IMPACTS ON ELECTRON KINETICS IN BEAM DISCHARGE PLASMA

To study the influence of the population of the vibrational levels on the discharge parameters the electron distribution function was calculated with the superelastic impacts taken into account. The calculations were carried out for molecular hydrogen and $P_0 L = I$ cm Torr, $W/P_0 = IO^{-6}$ J/cm^3. Torr. The population was supposed to be Boltzman's with the temperature T_V in the range $0 \leq T_V \leq 0.8$ eV. It's also supposed that only single transitions between the vibrational levels occur with the cross sections being $Q_{V,V+1} = (V + 1) \times Q_{OI}$ (E) /5/; cross sections for ionization, dissociation and excitation of electron levels are accepted to be the following: $Q_V^K (E) = Q_0^K (E - \Delta E_{V,0})$; where $\Delta E_{V,0}$ - energy of the V-th vibrational level. Fig. IO shows the distribution functions for $T_V = 0$ and 0.8 eV. Apart from paper /6/ the dependence of f(U) on T_V is weak due to electron balance taken into account. Fig. II represents the dependences of α , $\bar{U}$, $W/n \cdot T$ on the temperature T_V. The energy input $\hat{P}$, and absolute energy losses of the electrons (U^M/P_0) in dependence on T_V are shown in Fig. I2. It's seen that the energy losses due to the virbational excitation appreciably decrease with the increase of T_V.

5. COMPARISON BETWEEN THE MAIN MACROSCOPIC PROPERTIES OF THE BEAM AND GLOW DISCHARGE PLASMAS

Macroscopic quantities of electrons especially the distribution functions and the efficiency of energy dissipation into the molecular component were calculated by means of the solution of the adequate kinetic equation and compared under the condition of equal energy input from the electric fields to the electrons per volume unit of both plasmas in molecular hydrogen. The comparison between both plasmas was performed under typical conditions of their existence sich as $P_0^b = IO^{-2}$, $P_0^g = I$ Torr of the pressure. Furthemore we used a constant ionization degree for the glow discharge columm of $(n/N)_g = IO^{-6}$ and performed the comparison for the three typical ionization $(n/N)_b = IO^{-2}, IO^{-3}, IO^{-1}$ of the beam discharge plasma. Fig. I3 shows the correspondent distribution functions $f_b(U)$ in the beam discharge plasma and $f_g(U)$ in the glow discharge plasma for a constant turbulence energy $\hat{U} = 5 \cdot IO^{-2}$ V per one electron and for the different values of the ionization degree $(n/N)_b$. It's easy to see that $f_b(U)$ and $f_g(U)$ are very close for $(n/N)_b = IO^{-2}$. The case corresponds to the condition of equal energy input per one electron and pressure unit $\hat{P}_b = \hat{P}_g$, which can be considered to some extent as a similarity law for the different types of discharge plasmas. The remarkable difference in the dominance of the various energy loss channels in those two discharge plasmas can be seen from the relative energy losses (U^M/U^T), represented in Fig. I4 for the degree of ionization $(n/N)_b = IO^{-1}$.

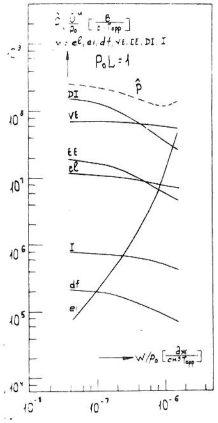

Fig.7

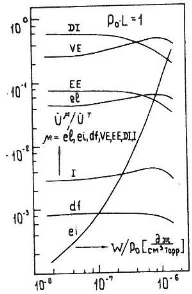

Fig.8

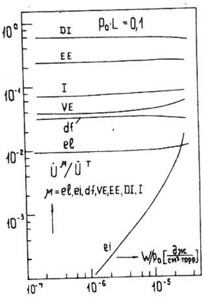

Fig.9

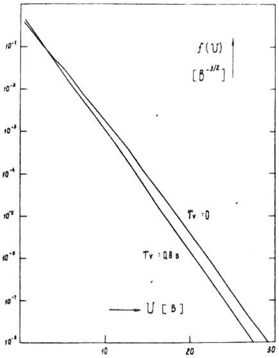

Fig.10

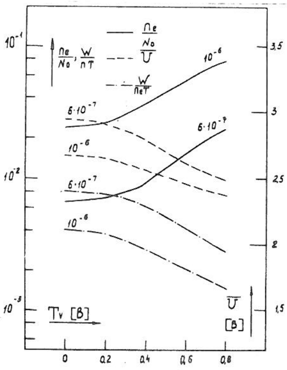

Fig.11

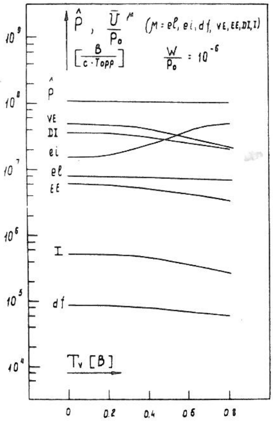

Fig.12

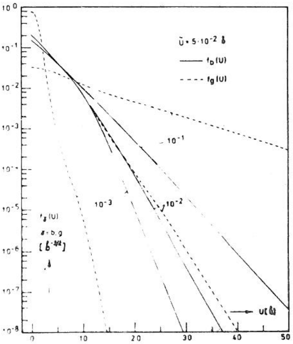

Fig. I3

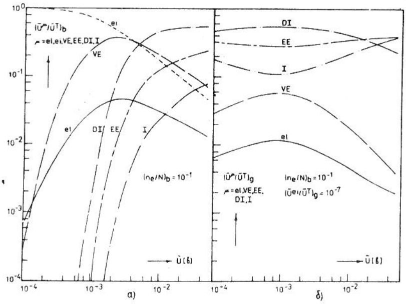

Fig. I4

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