Processes in subsonic expanding thermal argon plasmas

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This research deals with the coupling of charged particles with plasma flow properties as electron density and temperature. From the measurements, obtained using high quality Thomson-Rayleigh scattering diagnostic show that three-particle recombination mainly influences these flow properties in this subsonic expanding plasma. Besides, ambipolar diffusion plays an important role in the behavior of electron density and temperature. Although the calculated electron density shows good agreement with the measurements, the electron temperature demonstrates a deviation.

In the past decades, many investigations have been carried out that focus on the behavior of electrons and heavy particles in expanding plasmas. Particles in expanding plasmas are subject of interest in fundamental research like gase phase reactions, interactions with electron density and temperature and technical applications, e.g. plasma depositions [2].

Earlier investigations have shown that in the supersonic expansion the three-particle recombination mainly rules the electron density and temperature [2]. Otherwise, in the subsonic expansion, research has been demonstrated that mainly diffusion governs the behavior of the plasma electron density [3].

In this investigation will be shown that both three-particle recombination and ambipolar diffusion are the main processes affecting the electron density and temperature in the subsonic area with background pressure p_0 = 40 Pa. So the needed equations are the stationary electron mass and energy balance including three-particle recombination and diffusion (1). Here, $C_{rec,3}$ represents the three-body recombination rate, $E_{rec,3}$, the mean recombination energy released in the reaction **e+e+A⁺→e+A**$_{\mathbf{p}}$ w_e: electron flow velocity, β = -9⁄2 [2], and σ the three-body recombination cross section:

$$\vec{\nabla}\cdot\left(D_a\vec{\nabla}n_e\right)+\dot{n}_e=0 \qquad D_a=2D_+=2\lambda\bar{v} \quad \lambda=\left(\mathrm{n_e}\sigma\right)^{-1} \quad \bar{\mathrm{v}}=\sqrt{kT/m_i}$$
$$\vec{\nabla}\cdot\left(\frac{3}{2}n_ekT_ew_e\right)+n\ kT_e\cdot\nabla w_e=E_{rec,3}C_{rec,3}T_e^{\beta}n_e^3$$
$$\vec{\nabla}\cdot\left(n_ew_e\right)=0 \tag{1}$$

In this expanding plasma, the overal temperature equals the electron temperature, axial diffusion and ionization have been neglected, the radial and axial electron drift are comparable, and quasi-neutrality. When (1) has been written out in axial symmetric coordinates, the radial electron mass and energy balance with boundary conditions and analytic solutions are (2):

$$\frac{3}{r}\frac{d}{dr}\left(r\frac{dn_e^{1/3}}{dr}\right)=\frac{\sigma}{2}\sqrt{\frac{k}{m_i}}C_{rec,3}n_e^3 \qquad n_e(r)=n_0\left[\left(\left(\frac{n_w}{n_0}\right)^{1/3}-1\right)\left(\frac{r}{R}\right)^2+1\right]^3$$
$$n_e(r=0)=n_0 \qquad n_e(r=R)=n_w$$
$$w_{er}k_B\left(\frac{3}{2}T_e\frac{dn_e}{dr}-n_e\frac{dT_e}{dr}\right)=0 \qquad T_e(r)\propto n_e^{2/3}(r) \tag{2}$$

The axial temperature has been calculated with an ‘ansatz’ for the axial electron density n_e(z) [3]:

$$n_e=n_0\exp(-az) \tag{3}$$

and has been substituted into (4) to obtain the axial temperature decay along the main axis z of the reactor:

$$\frac{3}{2}n_e k w_{ez}\frac{dT_e}{dz} - k w_{ez} T_e \frac{dn_e}{dz} = C_{rec,3}E_{rec,3}n_e^3 T_e^{\beta} \qquad T_e(z) = T_e(0)\exp\left(-\frac{15az}{33}\right) \qquad (4)$$
$$T_e(z=0) = T_e(0)$$

The 2D contour plots, given in Fig. 1. represent the results obtained from (2) and (3), using the initial conditions a = 3, $T_e(0)$ = 3000 K, width R = 0.25 m, length L = 0.4 m, n_0 = 3.5 10^{19} m^{-3}, n_w = 10^{19} m^{-3}.

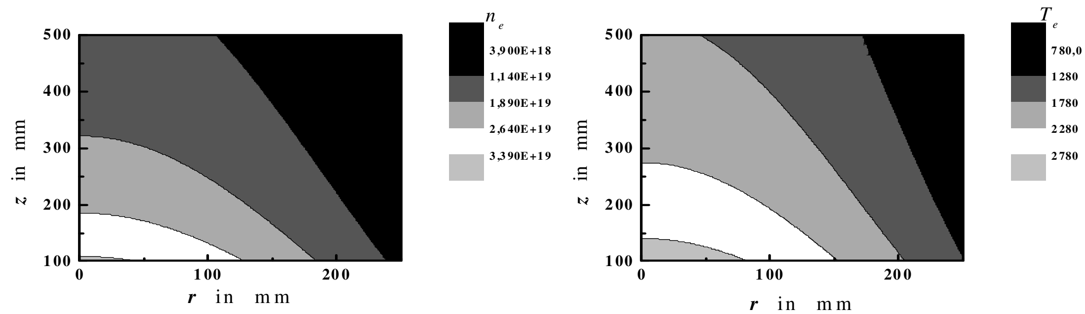

Fig. 1 Two-dimensional contour plots of n_e (left picture) and T_e (right picture) versus axial and radial coordinates

In the contour plots, the electron density follows a similar shape as the electron temperature. However, the electron density radially decays steeper than the electron density. Of course, this can be seen from (2).Fig. 2 is a cross section from Fig.1 at r = 0, along the expansion axis z. These results are compared with the high quality Thomson-Reighlay scattering diagnostic measurements [1] as sketched in Fig. 2:

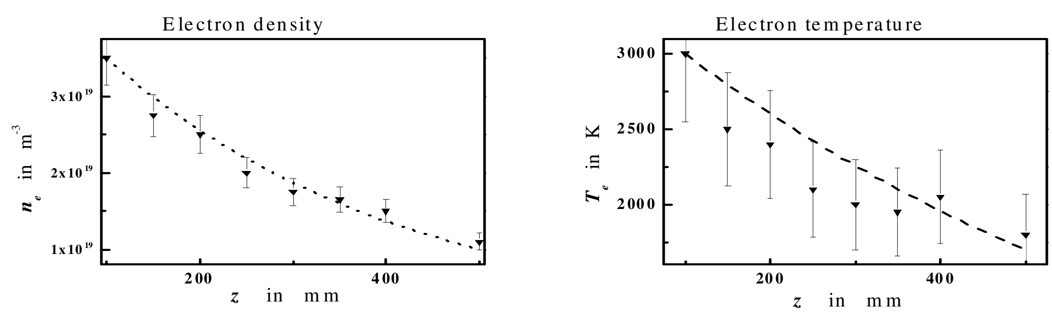

Fig.2: Cross sections of electron density n_e (left picture) and electron temperature T_e (right picture) at r = 0

Although the electron density in Fig.2, left picture, fits excellent with the measurements, the electron temperature shows a significant deviation, as shown in the right picture in Fig. 2. When the energy sources as heat conduction, ohmic dissipation and three-particle recombination have been compared with the transport term, the contribution of the ohmic dissipation and heat conduction will become more important. Therefore those latter two terms cannot be neglected, so they should be taken into account

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