NEUTRAL DYNAMICS IN SPT CHANNEL

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Dynamics of neutrals, which appear in SPT channel after neutralizing of primary ions on the walls, is investigated. It is shown, that, when the electric field focuses ions, these neutrals appear mainly near the inlet of the channel and partially deplete to the outlet.

New design of SPT, which is investigated in MIREA, compares favourably with previous model. It has for-volume with gas distributor. The anode is a pair of narrow metal rings, ancored on inner and outer insulatops at the inlet of the channel. Such design allows to have practically fully ionized working gas (Xe) at the inlet. However, one cannot prevent ions to reach the walls of the channel, even with focusing electric field. Ion, which reaches the wall, becomes neutral, moves into the channel, where it is ionized again, and secondary ion leaves the channel. It is interesting to estimate, even semi-quantitatively, this phenomenon. In stationary mode, the sum of ion and neutral fluxes along the channel is constant. The discharge current, the sum of ion and electron longitudinal currents, is also constant. Hence, if we know the pattern of neutral flux along the channel, we may judge synonimously about the pattern of electron current. Ih view of it, we tried to analyse ion and neutral dynamics in plane geometry of SPT channel. Let flow of ions with known distribution, maxwellian in transversal velocity, enter the channel with finite length ($0 < x \leq L$) and parallel identical insulating walls $|y| = h/2$, where h L. Although electric field focuses ions, part of them reaches the walls and becomes neutralized. These neutrals fly isotropically from the wall and have maxwellian distribution with wall temperature T. Partially they deplete in the channel, partially - reflect from the opposite wall with the same maxwellian distribution Basing on two-dimensional stationary kinetic equations, one may obtain with known ion flux density $j_{tr}(x)$ on the wall and frequency of ionization $\nu(x,y)$ (even on "y"), the linear integral equation for the amplitude a(x) of the neutral maxwellian function on the wall, and restore neutral distribution in the channel, thus obtain longitudinal neutral flux density in the channel:

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$$a(x) = \frac{2\sqrt{\pi}}{v_T} j_{tr}(x) + \frac{2h^2}{\pi} \int_0^L \frac{a(\mu)\,d\mu}{[h^2+(x-\mu)^2]^{3/2}} \int_0^\infty \frac{d\tilde{v}}{(1+\tilde{v}^2)^2} \times \tag{1a}$$

$$\times \int_0^\infty u \exp\left[-u - \frac{\sqrt{h^2+(x-\mu)^2(1+\tilde{v}^2)}}{v_T\sqrt{u}} \int_{-1/2}^{1/2} \nu(\mu+(x-\mu)(\xi+1/2), h\xi)\,d\xi\right] du$$

$$f_0 = \frac{1}{\pi v_T^2} a(x) \exp\left(-v^2/v_T^2\right) \tag{1b}$$

$$j_{x_0} = \frac{v_T}{\pi^{3/2}} \left(\int_0^x - \int_x^L \right) \sum_{i=1}^{2} \frac{\left(\frac{h}{2}+c_i\right) a(\mu)|x-\mu|\,d\mu}{\left[\left(\frac{h}{2}+c_i\right)^2+(x-\mu)^2\right]^{3/2}} \int_0^\infty \frac{d\tilde{v}}{(1+\tilde{v}^2)^2} \times \tag{1c}$$

$$\times \int_0^\infty u \exp\left[-u - \frac{\sqrt{\left(\frac{h}{2}+c_i\right)^2+(x-\mu)^2(1+\tilde{v}^2)}}{v_T\sqrt{u}} \int_0^1 \nu(\xi x+\mu(1-\xi), \left(\tfrac{h}{2}+c_i\right)\xi)\,d\xi\right] du$$

where $v_T = \sqrt{2T/M}$, $c_{1,2} = \pm y$. The second term in the right part of (1a) describes neutrals, which are reflected from the opposite wall and partially deplete in the channel. If $\nu = 0$, then:

$$a(x) \approx \frac{2\sqrt{\pi}}{v_T} j_{tr}(x) + \frac{h^2}{2} \int_0^L \frac{a(\mu)\,d\mu}{[h^2+(x-\mu)^2]^{3/2}}$$

$$J_{x_0} = \frac{v_T}{4\sqrt{\pi}} \left(\int_0^x - \int_x^L \right) |x-\mu|\, a(\mu) \sum_{i=1}^{2} \frac{h/2+c_i}{\left[\left(h/2+c_i\right)^2+(x-\mu)^2\right]^{3/2}} d\mu \tag{2}$$

and: $J_x = \int_{-h/2}^{h/2} j_{x_0}\,dy = \frac{v_T}{4\sqrt{\pi}} \left[\int_0^x a(\mu)\left[1 - \frac{x-\mu}{\sqrt{h^2+(x-\mu)^2}}\right] d\mu - \right.$

$$\left. - \int_x^L a(\mu)\left[1 - \frac{\mu-x}{\sqrt{h^2+(x-\mu)^2}}\right] d\mu \right]$$

and so:

$$\frac{dJ_x}{dx} = \frac{v_T}{\sqrt{\pi}} \left[a(x) - \frac{h^2}{2} \int_0^L \frac{a(\mu)\,d\mu}{[h^2+(x-\mu)^2]^{3/2}} \right] = 2 j_{tr}(x)$$

This expression coincides with (2) and shows, that, for totally neutral flux, the change of longitudinal flux is equal to the losses of the primary flux on the walls. The case $\nu = 0$ is the test one, it shows, that the eqs. (1) are right. It is necessary to know $j_{tr}(x)$. Let us set, for convenience, ion distribution f_i at the inlet of the channel and electric potential φ, which accelerates ions and focuses them, in form:

$$f_i\big|_{x=0} = n_{i_0} \left(\sqrt{\pi} v_T\right)^{-1} \delta(v_x - v_0) \exp\left(-v_y^2/v_T^2\right) \left[\theta\left(\frac{2y}{h}+1\right) - \theta\left(\frac{2y}{h}-1\right)\right] \tag{3}$$

$$\varphi(x,y) = \Phi(x) + 4 U_0 y^2/h^2;\ \Phi(0) = U_0,\ \frac{d\Phi}{dx} < 0$$

where $\theta(s)=\begin{cases}1 & s>0\\ 0 & s<0\end{cases}$ is unit function. Using two-dimensional collisionless kinetic equation for <u>unmagnetized</u> ions:

$$v_x\frac{\partial f}{\partial x}+v_y\frac{\partial f}{\partial y}-\frac{e}{M}\frac{d\Phi}{dx}\frac{\partial f}{\partial v_x}-\omega^2 y\frac{\partial f}{\partial v_y}=0,\quad \omega^2=\frac{8eU_{tr}}{Mh^2}$$

we obtain

$$f_i=n_{i0}(\sqrt{\pi}v_T)^{-1}\delta(v_{x_0}-v_0)\exp(-v_{y_0}^2/v_T^2)\left[\theta\left(\frac{2y_0}{h}+1\right)-\theta\left(\frac{2y_0}{h}-1\right)\right]$$

$$v_{x_0}^2+\frac{2e}{M}U=v_x^2+\frac{2e}{M}\Phi;\quad v_{y_0}=v_y\cos\varphi+\omega y\sin\varphi,\quad y_0=y\cos\varphi-(v_y/\omega)\sin\varphi$$

$$p(x)=\omega\int_0^x\frac{d\xi}{\sqrt{v_{x_0}^2+\frac{2e}{M}[U-\Phi(\xi)]}}=\omega\int_0^x\frac{d\xi}{\sqrt{v_0^2+\frac{2e}{M}[U-\Phi(\xi)]}}\qquad(4)$$

$$|y_0|\le\frac{h}{2};\quad |y|\le\frac{h}{2}$$

One may see, that the length L of SPT channel is additionally limited by inequality $p(L)\le\pi$ ($p=\pi$ corresponds to the situation, when ion, starting from y=h/2, reaches the wall y=-h/2 and vice versa. When calculating j_{tr} with f_i, given by (4(), one must take into account, that ions, which reach the wall, become out of primary ion distribution, and we obtain, for example:

$$j_{tr}(0)=\frac{n_{i0}v_T}{2\sqrt{\pi}};\quad j_{tr}\Big|_{p=\pi/2}=j_{tr}(0)\frac{v_0}{\sqrt{v_0^2+\frac{2e}{M}[U-\Phi(X_{\pi/2})]}}\cdot\frac{\omega^2h^2}{4v_T^2}\exp\left(-\frac{\omega^2h^2}{4v_T^2}\right)\qquad(5)$$

$$j_{tr}\Big|_{p=\pi}=0$$

We see, that, since $\omega h/v_T\gg1$ (see below), j_{tr} decreases rapidly, when x (or p) increases. If we estimate $J_{tr}=\int_0^L j_{tr}(x)dx$, we obtain:

$$J_{tr}\le\frac{n_{i0}v_0v_T^2}{2\sqrt{\pi}\omega^2h}\qquad(6)$$

Then we may approximate $j_{tr}(x)$ as:

$$j_{tr}(x)=\begin{cases}j_{tr}(0) & 0\le x\le x_{max}\\ 0 & x>x_{max}\end{cases}\qquad(7)$$

where $j_{tr}(0)x_{max}=J_{tr}$, that is:

$$x_{max}\sim\frac{v_0v_T}{\omega^2h}\sim h\frac{T}{eU_{tr}}\ll h<L\qquad(8)$$

since $v_0\sim v_T$ and in SPT $T\simeq700^\circ K$; this value is much less, than eU_{tr} (at least, several eV). Estimating the second term in right

part of eq.(1a), we see, that it is $\sim x_{max}/h$ part of the first term, and so:

$$q(x) = \frac{2\sqrt{\pi}}{v_T} j_{t1}(x) = \frac{2\sqrt{\pi}}{v_T} j_{t1}(0) f\left(\frac{x_{max}}{x} - 1\right) \qquad (9)$$

Numerical simulation shows, that neutralized ions, which are reflected towards the inlet, leave the channel without being ionized, and it is sufficient to considder particles, which are reflected towards the outlet. Then, if we set $\mathcal{V}$ =const, for estimation, and $(\mathcal{V}/v)\sqrt{x^2 + (h/2 \pm y)^2} \gtrsim 1$, one may obtain from (1) for neutral flux density:

$$j_{x_0} = \frac{n_{i_0} v_T}{\pi\sqrt{\pi}} \sum_{i=1}^{2} \frac{\left(\frac{h}{2} + c_i\right) x\, x_{max}}{\left[\left(\frac{h}{2} + c_i\right)^2 + x^2\right]^{3/2}} \left\{\frac{\pi}{4}\left(1 + \gamma_i^2\right) \exp\left(-\gamma_i^2\right) + \sqrt{\frac{2\pi}{3}} \left(\frac{\gamma_i}{2}\right)^{\pi/6} \exp\left[-3\left(\frac{\gamma_i}{2}\right)^{2/3}\right]\right\} \qquad (10)$$

where $\gamma_i = \frac{\mathcal{V}}{v_T}\sqrt{x^2 + \left(\frac{h}{2} + c_i\right)^2} \gtrsim 1$; $c_{1,2} = \pm y_i x_{max} \sim h\frac{I}{eU_i} \ll h < L$. When $\mathcal{V} = 0$, eq.(10) are also correct. It is necessary to obtain from experiment $j_{tr}(x)$ and $\mathcal{V}$ in real electric field for more presise estimation.