PT and SST Electron Energy Distribution and Transport Properties in Lucas-Saelee Model Gas

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Time resolved energy distribution and transport properties of electrons are compared with position resolved data. Obtained $\langle v_x \rangle(x)$ and $\langle \varepsilon \rangle(x)$ are a few % smaller than $\langle v_x \rangle(t)$and $\langle \varepsilon \rangle(t)$, respectively. This may be caused by the bilateral position dispersion under non-conservative condition against the one-way time dispersion in sequential flight of electrons.

Time resolved energy distribution and transport properties of electrons are calculated by newly developed the Pulsed Townsend-Flight Time Integral (PT-FTI) method[1] in comparison with position resolved data by the Steady State Townsend-FTI (SST-FTI) method[2] and stationary PT (SPT) data by the FTI method[3]. In the PT-FTI method, the n^{th} starting rate distribution $\Psi s_{(n)}(t_0, \varepsilon_0)$ for non-conserved electrons circulating the loop of a flight and a collision is used as the principal unknown function and as a tool to obtain the time resolved energy distribution. $\Psi s_{(n)}(t_0, \varepsilon_0)$ is given by iterative $(n-1)$ operations of non-conservative loop dispersion functions $L(t', \varepsilon'_0; t_0, \varepsilon_0)$[1] in two domains of time and energy to an initial starting rate distribution $\Psi \mathrm{sn}_{(1)}(t_0, \varepsilon_0)$ for a reduced electron as

$$\Psi s_{(n)}(t_0, \varepsilon_0) = L(t', \varepsilon'_0; t_0, \varepsilon_0)^{(n-1)} \otimes \Psi \mathrm{sn}_{(1)}(t_0, \varepsilon_0). \quad (t' \to t_0, \varepsilon'_0 \to \varepsilon_0) \quad [\mathrm{s}^{-1}\mathrm{eV}^{-1}] \tag{1}$$

The time dependent energy distribution in the n^{th} flight $Ff_{(n)}(t, \varepsilon, \theta)$ is obtained by an operation of dispersion functions in a flight $Hf_\ell(t, \varepsilon'; t_0, \varepsilon_0)$ in time and energy domains to $\Psi s_{(n)}(t_0, \varepsilon_0)$ as

$$\begin{aligned} Ff_{(n)}(t, \varepsilon, \theta) &= \sum_{\ell=0}^{\infty} P_\ell(\cos\theta) Hf_\ell(t, \varepsilon; t_0, \varepsilon_0) \otimes \Psi s_{(n)}(t_0, \varepsilon_0) \\ &= \sum_{\ell=0}^{\infty} P_\ell(\cos\theta) Ff_{\ell(n)}(t, \varepsilon). \qquad [\mathrm{eV}^{-1}] \end{aligned} \tag{2}$$

The time resolved energy distribution in flight accumulated until m^{th} is obtained as

$$Ff_{\mathrm{T}m}(t, \varepsilon, \theta) = \sum_{n=1}^{m} Ff_{(n)}(t, \varepsilon, \theta). \qquad [\mathrm{eV}^{-1}] \tag{3}$$

and the normalized distribution $F\mathrm{n}_{\mathrm{T}m}(t, \varepsilon, \theta)$ is obtained by

$$F\mathrm{n}_{\mathrm{T}m}(t, \varepsilon, \theta) = Ff_{\mathrm{T}m}(t, \varepsilon, \theta) / \int_0^\infty Ff_{\mathrm{T}m}(t, \varepsilon) \mathrm{d}\varepsilon. \qquad [\mathrm{eV}^{-1}] \tag{4}$$

In the SST-FTI method[4], the dispersion functions in two domains of position and energy $L(x', \varepsilon'_0; x_0, \varepsilon_0)$ are used with similar procedure.

Here, we examined the PT and SST behaviors of electrons in Lucas-Saelee model gas[5],

$$\sigma_{el}(\varepsilon) = 4\varepsilon^{-1/2} \quad [\text{Å}^2]$$

$$\sigma_{ex}(\varepsilon) = 0.1(1-F)(\varepsilon - 15.6) \quad [\text{Å}^2] \quad (\varepsilon \geqq 15.6\mathrm{eV}), \quad \sigma_{ex}(\varepsilon) = 0 \quad (\varepsilon < 15.6\mathrm{eV})$$

$$\sigma_i(\varepsilon) = 0.1F(\varepsilon - 15.6) \quad [\text{Å}^2] \quad (\varepsilon \geqq 15.6\mathrm{eV}), \quad \sigma_i(\varepsilon) = 0 \quad (\varepsilon < 15.6\mathrm{eV})$$

with the ionization index $F = 0.5$, equal energy sharing, the gas density $N = 10^{17}$ [cm^{-3}], the reduced electric field $E/N = 50$ [Td], the mass ratio $m/M = 1/1000$, a reduced electron released at $t = 0$ [s], $x = 1$ [cm].

In Fig. 1, accumulating distributions $F f_{\mathrm{T}m}(t) = \int_0^\infty F f_{\mathrm{T}m}(t,\varepsilon)d\varepsilon$ and $F f_{\mathrm{T}m}(x) = \int_0^\infty F f_{\mathrm{T}m}(x,\varepsilon)d\varepsilon$ are shown by every $m = 5$ up to 50. While $F f_{\mathrm{T}m}(t)$ smoothly increases giving $\langle\varepsilon\rangle(t)$ and $\langle v_x\rangle(t)$ constant, $F f_{\mathrm{T}m}(x)$ in semi-periodic form gives oscillatory $\langle\varepsilon\rangle(x)$ and $\langle v_x\rangle(x)$, as shown in Fig.2. This may be caused by $L(x',\varepsilon_0';x_0,\varepsilon_0)$ of bilateral energy dependent dispersion in position in contrast to $L(t',\varepsilon_0';t_0,\varepsilon_0)$ of one-way dispersion in time. While $\langle v_x\rangle(t)$ and $\langle\varepsilon\rangle(t)$ in Fig.2 agree respectively with $\langle v_x\rangle$ and $\langle\varepsilon\rangle$ in SPT obtained by FTI method, $\langle v_x\rangle(x)$ and $\langle\varepsilon\rangle(x)$ are about 10 % and 2 % smaller than $\langle v_x\rangle(t)$ and $\langle\varepsilon\rangle(t)$, respectively. Correspondingly, the energy distributions $Fn_{\mathrm{T}m}(t,\varepsilon)$ in equilibrium region has the same form as $F_{\mathrm{n}}(\varepsilon)$ obtained by FTI method but $Fn_{\mathrm{T}m}(x,\varepsilon)$ is different from $F_{\mathrm{n}}(\varepsilon)$ as seen in Fig. 3. This is considered to be caused by the bilateral dispersion in $L(x',\varepsilon_0';x_0,\varepsilon_0)$ under non-conservative condition adopted here. The increasing rate of $\Gamma(t)$ and $\Gamma(x)$ agree with the ionization frequency ν_i and ν_i/Wr' (virtual drift velocity in configuration space), respectively[5]. Good agreement of PT-FTI data with FTI data verify the validity of both. The PT-FTI and SST-FTI procedures may be extended for the Time Of Flight (TOF) analysis.

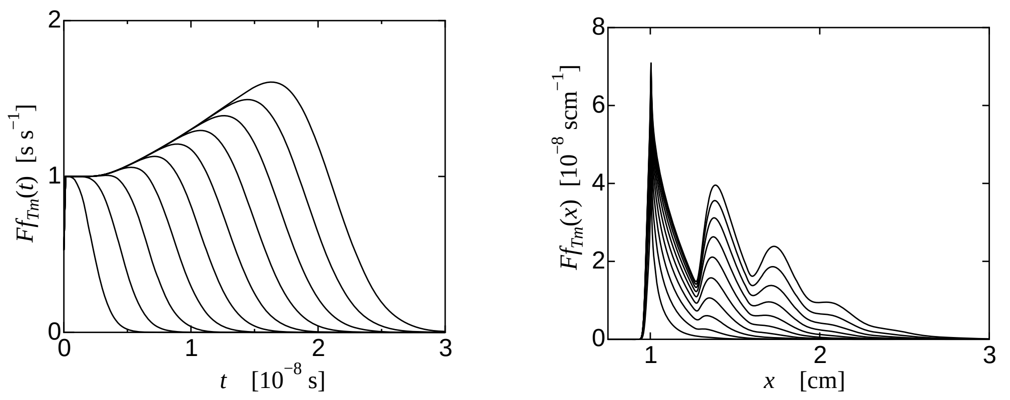

Fig. 1: $F f_{\mathrm{T}m}(t)$ and $F f_{\mathrm{T}m}(x)$ by every $m = 5$ up to 50.

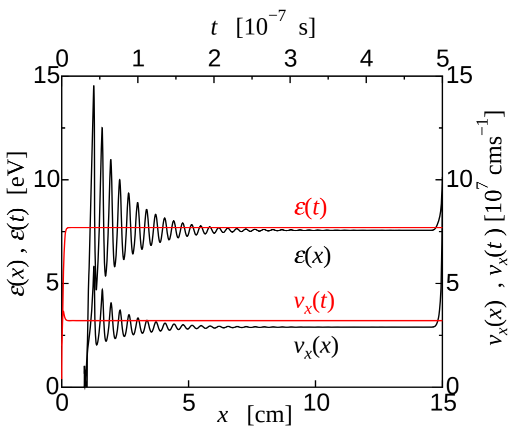

Fig. 2: Comparison of $\langle\varepsilon\rangle(t)$, $\langle v_x\rangle(t)$ and $\langle\varepsilon\rangle(x)$, $\langle v_x\rangle(x)$.

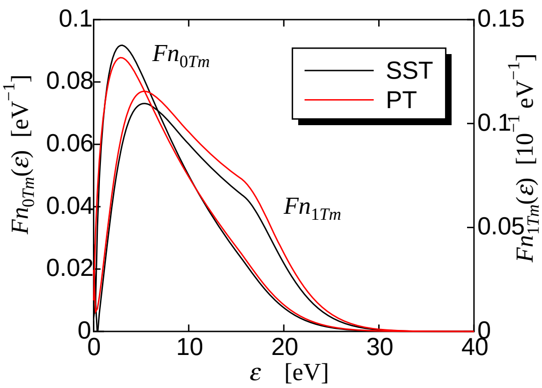

Fig. 3: Energy distributions $F_{\mathrm{n}0\mathrm{T}m}(t,\varepsilon)$, $F_{\mathrm{n}1\mathrm{T}m}(t,\varepsilon)$ and $F_{\mathrm{n}0\mathrm{T}m}(x,\varepsilon)$, $F_{\mathrm{n}\mathrm{T}m}(x,\varepsilon)$ in equilibrium region.

[1] A. Takeda, N. Ikuta, *Trans. IEE of Japan* **Vol.132 No.4** (2012) 1-6 (in Japanese).
[2] A. Takeda, N. Ikuta, *Trans. IEE of Japan* **113-A** (1993) 618-625 (in Japanese).
[3] N. Ikuta, S. Nakajima, *J. Phys. Soc. Jpn.* **64** (1995) 1148-1163.
[4] A. Takeda, N. Ikuta, *J. Phys. Soc. Jpn.* **70** (2001) 678-688.
[5] A. Takeda, N. Ikuta, *IEEJ Trans. FM* **126** (2006) 163-168 (in Japanese).