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Simulation Technique for the Gas Discharges

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ABSTRACT

The electron swarm drift velocity for nitrogen gas is calculated in the range of 4 - 240 [Td] (1 Td = 10^{-17} V·cm²). The result is in good agreement with the data measured by the time-of-flight method in the previous study. Also, an accurate and efficient method for solving the electron swarm parameters in gases is described.

1. Introduction

The electron swarm parameters are necessary for the analysis and simulation of discharge plasma now applied in plasma processing, plasma displays, gas lasers, e-beam switches, HID lamps, gas insulation and other important areas of modern technology.

The theoretical simulation of electrical discharges and plasma in gases can provide useful data for inferring the electron collision cross sections and the electron energy distributions, several investigations have been reported recently for the theoretical analysis and simulation of electron swarm parameters by the Boltzmann equation method in gases.1]-5]

In this paper, the simulation technique is employed to discuss the validity of the experimental method and to calculate the transport parameters at moderately high values of 4 ≤ E/N ≤ 240 [Td]. Here E is the electric field and N is the gas number density.

2. Theoretical formulation

The Boltzmann equation for analysis of the electron swarm properties may be written as

$$\frac{\partial f}{\partial t}+v\cdot\frac{\partial f}{\partial r}+\frac{eE}{m}\cdot\frac{\partial f}{\partial v}=\left(\frac{\partial f}{\partial t}\right)_{coll} \qquad (1)$$

Here, $f=f(v,r,t)$ is the electron velocity distribution function, v is the electron velocity, r is the position, t is the time, e and m are respectively the electronic charge and mass, and E is the electric field.

In a spatially dependent steady state approximation, the Boltzmann equation takes the following intro-differential form:6]

$$\frac{E^2}{3N^2}\frac{u}{Q_m}\frac{df}{du}+\frac{2m}{M}u^2Q_m\left(f+\frac{kT}{e}\frac{df}{du}\right)+\frac{\alpha_i E}{3N^2}\frac{uf}{Q_m}$$
$$+\frac{\alpha_i E}{3N^2}\int_0^u\frac{u}{Q_m}\frac{df}{du}du+\frac{\alpha_i^2}{3N^2}\int_0^u\frac{uf}{Q_m}du$$
$$=\sum_{j\neq i}\int_u^{u+u_j}uQ_j(u)f(u)du-\int_0^u du\int_{u+u_i}^{2u+u_i}zq_i(z,z-u-u_i)f(z)dz$$
$$-\int_0^u du\int_{2u+u_i}^{\infty}zq_i(z,u)f(z)\,dz+\int_0^u uQ_i(u)f(u)\,du \qquad (2)$$

where M is the mass of the molecule, k is the Boltzmann constant and u=mv²/2e is the electron energy in volts, Q_m is the electron momentum-transfer cross section, Q_j is the inelastic cross section for the exitation of the jth level, $q_i(u,u')$ is the differential ionization cross section and f is the isotropic part of the electron distribution function.

Once the distribution function has been calculated for a given E/N, the electron swarm parameters are obtained through the following relations:

$$W = -\left(\frac{2e}{m}\right)^{1/2} \frac{E}{3N}\int_0^\infty \frac{u}{Q_m}\frac{df}{du}\,du \qquad (3)$$

$$D_r = \left(\frac{2e}{m}\right)^{1/2} \frac{1}{3N}\int_0^\infty \frac{u}{Q_m} f\,du \qquad (4)$$

where W is the electron drift velocity, D_r the radial diffusion coefficient. All the above relations stand with the following normalization of the electron distribution function:

$$\int_0^\infty u^{1/2} f(u)\,du = 1 \qquad (5)$$

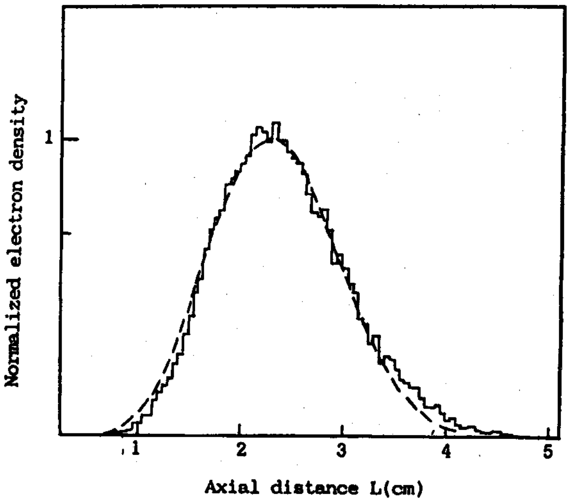

Figure 1. Simulated electron distribution. at E/N = 14 Td, t = 1 μs

3. Results and Discussion

The continuity equation governing the motion of electrons in an isolated travelling swarm, where there is only a slight degree of ionization, is given by

$$-\frac{\partial n}{\partial t} + \nu_i n + D_T\left(\frac{\partial^2 n}{\partial r^2}\right) + D_L\left(\frac{\partial^2 n}{\partial z^2}\right) - W\frac{\partial n}{\partial z} = 0 \qquad (6)$$

where

$$r^2 = x^2 + y^2$$

The number density solution of equation (6) was derived by Huxley 7],8]

$$n(r,z,t) = \frac{n_0}{(4\pi D_L t)^{1/2}(4\pi D_T t)} \exp\left(-\frac{r^2}{4 D_T t}\right) \exp\left(-\frac{(z - Wt)^2}{4 D_L t}\right) \qquad (7)$$

The use of this solution implies that the electron swarm is produced from an isolated point source, well away from any boundary conditions and with negligible non-equilibrium regions. In this situation, the number density at a particular axial position z and time t, for all x and y is given by

$$n(z,t) = \frac{K}{(4\pi D_L t)^{1/2}} \exp\left(-\frac{(z - Wt)^2}{4 D_L t}\right) \qquad (8)$$

where K is a constant independent of z and t. This equation is used to obtain the experimental values and compared with the simulated electron distributions.

The theoretical distribution obtained using the drift velocity and longitudinal diffusion coefficientsresults found from the experiments using the time-of-flight method is shown in figure 1.

The arrival time spectrum at E/N = 14 [Td] is shown in figure 2 with the peak arrival times by open circles. In figure 2, the axial electron distributions are distinctly non-Gaussian in shape in the neighborhood of cathode, and it is expected that this is expected that this is due to the very large dens-

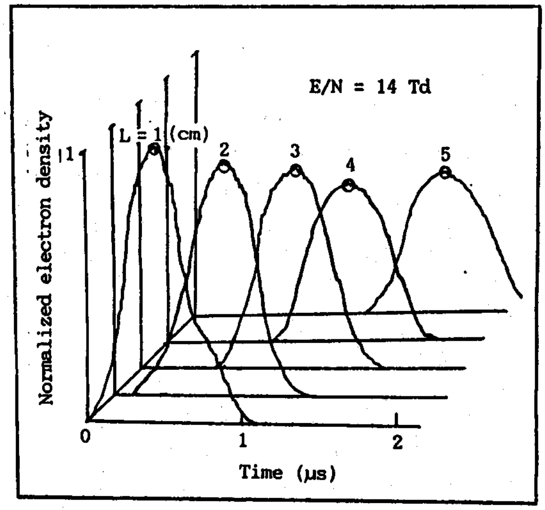

Figure 2. Arrival time spectrum.

ity and energy gradients operating in this region.

Also, the peak arrival times are plotted in figure 3. The electron swarm drift velocity is deduced as the reciprocal of the gradient of time t_p with respect to distance L.9] The simulated values are in good agreement with the measured values.

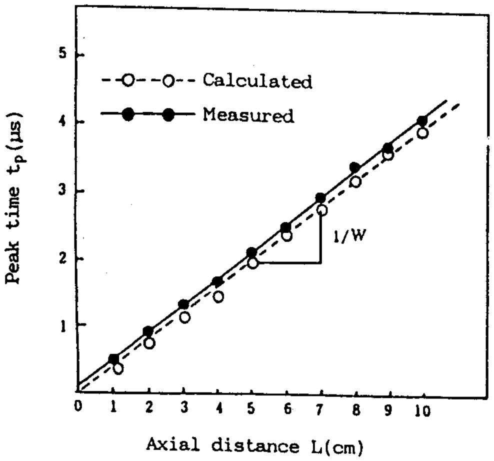

Figure 3. Peak arrival times t_p as a function of L at E/N = 14 Td.

4. Conclusion

A theoretical simulation has been performed for electron swarms in nitrogen gas. The electron swarm drift velocity and longitudinal diffusion coefficients determined in the previous study were used. The electron swarm arrival distributions obtained in the present study are in excellent agreement with those determined in the previous study.
A theoretical simulation shows that there in clear indication of good accuracy of time-of-flight method.

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