The simulation of electron drift in gas discharge

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An electron drift in a monatomic gas was studied for a spatially uniform electric field. Functions of the electron energy distribution are found by solving the Boltzmann equation in the two-term approximation and applying the Monte Carlo method. Integral characteristics of the electron drift in the gas were calculated, allowing analyzing the drift of electrons on a qualitative level.

INTRODUCTION

Diffusion and drift of electrons in gases have been well studied both theoretically and experimentally [1, 2]. But in recent years there has been a great interest in simulation of kinetics of electrons in low-temperature plasma, due to numerous technological applications. It is the numerical simulation that gives accurate and complete information about the characteristics of gas-discharge plasma, which is necessary for understanding and interpreting the properties of dust structures in plasma.

In many papers on the study of dusty plasma in the gas dc discharge at low gas pressure it is assumed that the plasma electrons have a Maxwellian distribution with a temperature which is determined from probe measurements [3]. Druyvesteyn distribution is sometimes used as an alternative model which does not lead to a significant difference in the characteristics of dusty plasmas [4]. But it is well known that Maxwell and Druyvesteyn distributions are significantly different from the actual distributions of the electron energy in the gas discharge, because in a self-discharge, a decisive contribution to the electron velocity distribution is made by the ionization and recombination processes.

MONTE CARLO MODEL

Let’s consider the problem of modeling at the independent gas discharge. It should include consideration of the motion of electrons in an electric field, elastic collisions of electrons with atoms, non-elastic collisions and loss of electrons. For the gas discharge tube DC at reduced pressure it is necessary to record the impact ionization, energy consumption for the excitation of atoms and the recombination of electrons on the walls of the tube.

The processes of excitation, ionization and recombination in real experimental conditions often cannot be taken into account in the spatially homogeneous (zerodimensional) model, since the electrons appear in the tube and die on its surface. Therefore, the distribution of electrons and ions in the coordinates, even in the steady state is inhomogeneous. However, you can take a model of spatially homogeneous drift and take into account loss of electrons on the tube walls by introducing a characteristic time of the withdrawal of electrons on the wall (the lifetime of electrons). The introduction of the lifetime, which is the same for electrons with different energies, was not very well done in many papers. Because of the electron with low energy cannot overcome the potential barrier of the wall and stays inside the hole as long as its energy is sufficiently large to overcome the potential barrier. If the electron has sufficient energy to overcome the potential barrier, it almost immediately goes to the wall and dies (recombines) on it.

Therefore, in this paper a different approach [5-7] was used to account for the birth and loss of electrons. For the process of electron drift in the positive column one can assume that total number of births and deaths of electrons are equal. Then the death of electrons on the walls can be taken into account by introducing into the algorithm a rule that for each act of ionization one electron is removed from the whole ensemble. The most logical for the problem of electron drift in the positive column is assumption that only a most energetic electron, which appears in an act of ionization, can leave the ensemble. The average energy of electrons that leave the system, can provide a good estimation of the potential of the wall. Thus, the wall potential is determined from the condition that the number of ionization events is equal to that of particles' escapes from the system.

MODEL OF THE BOLTZMANN EQUATION

In an electric field *E* one-particle distribution function of the electron velocity *F (r,v,t)* is determined by solving the Boltzmann equation [1, 2, 5]. Since the solution of Boltzmann equation is a very difficult task, for describing the kinetics of electrons in a gas discharge binomial approximation is often used. The Boltzmann equation in the binomial approximation in a uniform and constant electric field is as follows:

$$-\frac{eE_z \mathrm{v}}{3\varepsilon}\frac{\partial(\varepsilon f_1)}{\partial\varepsilon} = S^{el}(f_0) + \sum_j S_j^{in}(f_0) + S_{ion}(f_0) + S_w(f_0),$$
$$-eE_z\frac{\partial f_0(\varepsilon)}{\partial\varepsilon} = -\left(N_g\sigma_m(\varepsilon)\right)f_1(\varepsilon) \qquad , \qquad (2)$$

where, $S_{el}(f_0)$, $S_j^{in}(f_0)$, $S_{ion}(f_0)$ are integrals of elastic, non-elastic and ionization collisions of electrons with atoms, $S_w(f_0)$ is a term describing the process of electron loss to the walls of the discharge tube [8]. In this paper, the system of equations (2) was solved by iteration method

[5, 6]. Then obtained distribution functions were used to calculate various characteristics of the electron drift.

RESULTS OF CALCULATIONS AND DISCUSSION

In Table 1 for these three typical cases integral characteristics of the electron drift in a uniform external electric field are shown the drift velocity, average energy, and the rate of input energy for ionization and excitation of argon atoms. The results of calculations by Monte Carlo method and the two-term approximation of the Boltzmann equation give slightly good agreement.

Table 1 - Characteristics of the electron drift in argon (E1 = 11,5 eV, I = 15,8 eV) T = 298 K at different values of gas pressure.

Surface potential of the tube - φ_{wall}, V
Drift velocity - W, km / s
Average Energy - $<\varepsilon>$, eV
The energy factor of Townsend - $eD_\perp / \mu$, eV
Reduced ionization coefficient of Townsend - α / N_a, 10^{-16} cm^2
The rate of energy input from electric field to the elastic losses in the gas, $(Q_{ea} / Q_{EW}) * 100\%$
Rate of energy inputs to the excitation, $(Q_{ex} / Q_{EW}) * 100\%$
Rate of energy inputs to the ionization, $(Q_{ion} / Q_{EW}) * 100\%$.

Pressure, torr	*0.32*	*0.22*	*0.12*
E/N, Td	*19.0*	*27.0*	*51.0*
φ_{wall} *V*	*16.0*	*17.0*	*18.0*
W, km/s, MC	*17.3*	*23.6*	*40.5*
W, km/s, Boltzmann	*22.8*	*32.4*	*58.0*
$eD_\perp / \mu$*, eV, MC*	*6.8*	*6.8*	*7.0*
$eD_\perp / \mu$*, eV, Boltzmann*	*9*	*8.9*	*8.8*
$<\varepsilon>$*, eV, MC*	*5.7*	*6.0*	*6.5*
$<\varepsilon>$*, eV, Boltzmann*	*5.4*	*5.6*	*6.0*
α / N_a, 10^{-16} cm^2	*0.00084*	*0.0046*	*0.034*
$(Q_{ea} / Q_{EW}) * 100\%$	*11.6*	*10.0*	*16.6*
$(Q_{ex} / Q_{EW}) * 100\%$	*87.7*	*87.3*	*73.0*
$(Q_{ion} / Q_{EW}) * 100\%$	*0.7*	*2.7*	*10.4*

Figure 1 presents the results of calculations of electron energy distribution functions for the drift in argon at *P = 0.12 Torr, E/N=51Td*. Monte Carlo simulation took into account the finiteness of wall potential and the loss of electrons on it; when solving the two-term approximation of the Boltzmann equation we used the model of ambipolar diffusion of electrons on the wall. For comparison, the distributions of Maxwell and Druyvesteyn are also shown. The figures prove that results of EEDF calculations with the Boltzmann equation have a good agreement with calculations by Monte Carlo method.

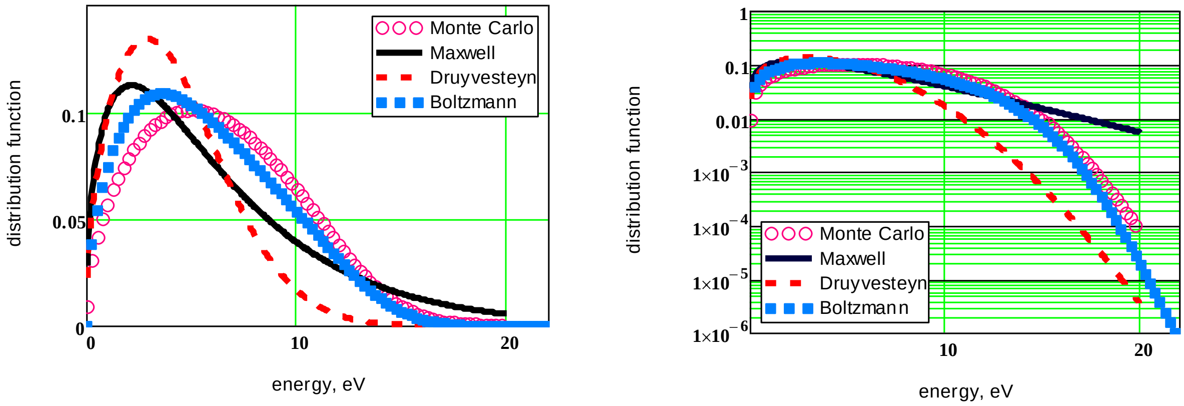

Figure 1 - The function of the electron energy distribution in argon for the drift, *P = 0.12 Torr, E/N=51Td* - the results of calculations by various models

CONCLUSIONS

In conclusion, we formulate the main:

1) The model of electron drift in a uniform static electric field was constructed taking into account non-elastic processes and loss of electrons on the walls of the tube.

2) Characteristics of the electron drift in the gas were calculated, allowing analyzing the drift of electrons on a qualitative level.

3) A comparison of results by Monte Carlo simulation with the solutions of the Boltzmann equation in a two-term approximation was made.

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