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# Investigations of Collisional Plasma Sheath in the Vicinity of Planar Probe

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## Abstract

The self-consistent model of processes in argon plasma sheath is presented in our study. The scattering processes are simulated stochastically by means of Monte Carlo method. The motion of charged particles in a non-uniform electric field is solved by the Verlet algorithm. The developed model includes only two important processes, i.e. elastic scattering of electrons on argon neutrals and the resonance charge transfer for positive argon ions. Our results obtained by the computer modelling for two various pressures in DC discharge in an argon gas are compared.

## 1 Introduction

The low-temperature plasma is widely used in many applications. This plasma is used e.g. in plasmachemical technologies as oxidation, etching, sputtering, in fabric production and actually in medical applications; shortly, there are many possibilities of using of low-temperature plasma in various branches. Therefore the theoretical description and understanding of the various physical and chemical mechanisms is very important.

For this purpose the computer modelling, sometimes called computer experiment, seems to be very useful tool [1], [2]. In low-temperature plasma there are two possible ways of solution of problems by means of computer modelling.

The first approach is so-called self-consistent modelling and the second one is a nonself-consistent modelling. In the first case the distribution of electric field in the vicinity of the probe immersed into plasma is derived from the space charge in the working area by solving the Poisson equation. The number of particles which must be treated simultaneously is large and calculations are extremely time consuming. On the other hand these calculations are more precise than those obtained by the second approach. In the second approach the nonself-consistent modelling is used. In this case the assumption is given that we know the distribution of electric potential in the vicinity of probe. As a consequence the trajectories of particles can be calculated separately. In this approach we can model the movement of smaller

number of particles and this approach is faster than the previous one, but unfortunately the obtained results strongly depend on the assumption about the distribution of electric potential near the probe.

## 2 Model

In our laboratory we have developed two self-consistent particle models for a DC discharge in an inert gas. In the first model we have considered only two types of interactions: elastic scattering between electrons and argon atoms and charge transfer for positive argon ions. The second model which includes more interactions [3], e.g. ionization, excitation, etc., is described in detail in [4]. This model works for various probe biases, but contains no pressure dependences. The first mentioned model with two basic interactions and for various pressures in an argon plasma is presented in this paper.

For the solution of our problem, we have chosen the first mentioned approach – the self-consistent modelling. Our computer model was one-dimensional in space and two-dimensional in velocities. In geometrical arrangement in our model the  $x$ -axis is perpendicular to the planar probe. The movement of particles is possible in all directions, but we observe the movement only in  $x$ -axis. Charged particles have  $x$ -component of velocity  $v_x$  and component of velocity  $v_r$ , that is perpendicular to the velocity  $v_x$ . The beginning of  $x$ -axis is located on the surface of planar probe and the source of particles is placed in undisturbed plasma on the right side from the planar probe. As a simulation technique the combination of molecular dynamics and Monte Carlo method was used.

Calculations were performed for Maxwell distributions of particles with different temperatures of both types of particles. The temperature of electrons was  $T_e = 2 \text{ eV} \approx 23,200 \text{ K}$  and temperature of argon atoms and ions was  $T_i = 300 \text{ K}$ .

For the computations of positions and velocities of particles the Newton equations of motion were solved

$$m_i \ddot{\vec{r}}_i = \vec{F}_i, \quad i = 1, 2, \dots, n.$$

The scattering of particles was treated stochastically using Monte Carlo method and the formula

$$\xi = -\lambda \ln \gamma$$

was used, where  $\xi$  is a random free path,  $\gamma$  is an uniformly distributed random number,  $\gamma \in (0, 1)$  and  $\lambda$  is a mean free path.

The total number of charged particles was set to  $2 \times 10^6$ , i.e.  $1 \times 10^6$  of electrons and the same number of argon ions was used. The time steps for electrons  $\Delta t_e = 1 \times 10^{-11} \text{ s}$  and  $\Delta t_i = 1 \times 10^{-8} \text{ s}$  for ions were used. The total time of our calculation was chosen to  $100 \mu\text{s}$ , which means 10,000 time steps in our model. The length of working area was  $0.01 \text{ m}$ .

### 3 Results

The results of our calculations are depicted in the following figures. In Fig. 1 and Fig. 2 the distributions of electric potential, in Fig. 3 and Fig. 4 the concentrations of electrons and ions and in Fig. 5 and Fig. 6 the total space charge distributions for two various pressures are shown.

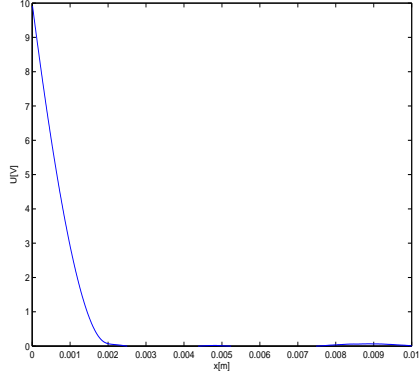


Figure 1: Distribution of electric potential, pressure 0.1 torr

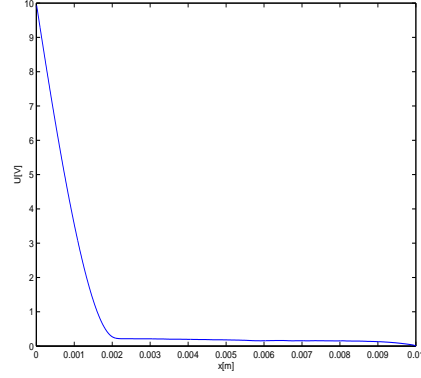


Figure 2: Distribution of electric potential, pressure 1.0 torr

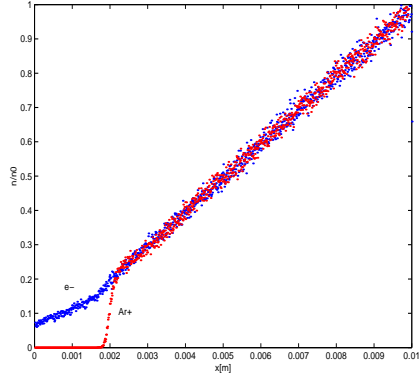


Figure 3: Concentrations of electrons and ions, pressure 0.1 torr

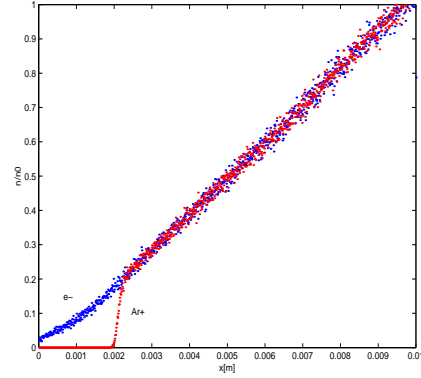


Figure 4: Concentrations of electrons and ions, pressure 1.0 torr

In figures 7 and 8, there are shown the distributions of the  $x$ -component of electron velocity for two various pressures in argon discharge. These results were obtained in relatively wide intervals near the planar probe. To obtain better results, the more narrow intervals and the higher number of particles must be used.

Further results, e.g. for variable length of working area or variable probe biases, can be found in [4], [5].

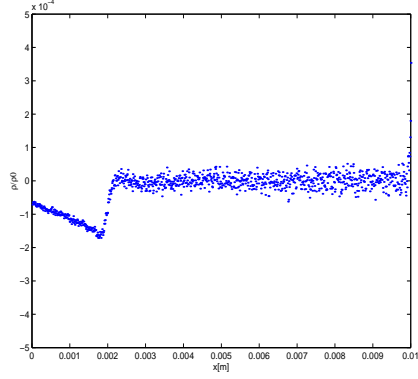


Figure 5: Total space charge distribution, pressure 0.1 torr

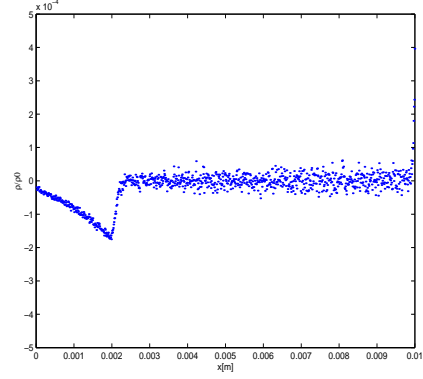


Figure 6: Total space charge distribution, pressure 1.0 torr

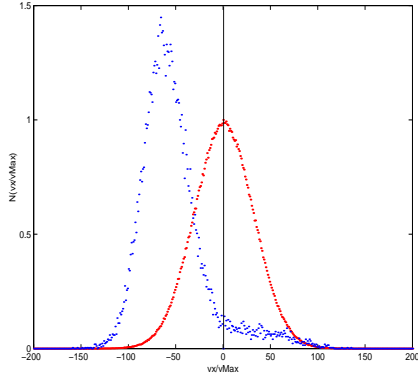


Figure 7: Electron  $v_x$  component distribution, pressure 0.1 torr, red line – theoretical Gauss distribution

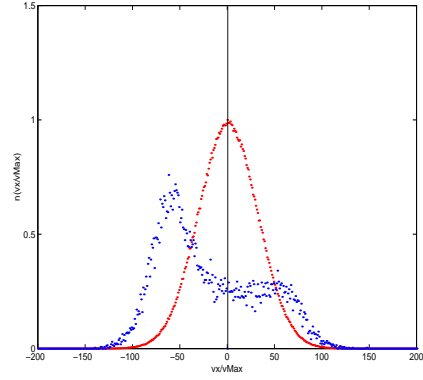


Figure 8: Electron  $v_x$  component distributions, pressure 1.0 torr, red line – theoretical Gauss distribution

## 4 Conclusions

It is known that computer modelling is a very useful tool for the study of plasma processes. Despite simplicity of our model we can conclude that it provides throughout expected results. Some results, as distribution of electric potential, concentrations, etc., were obtained in relative units, whereas e.g. electron velocity distribution, etc., are obtained in absolute units. More precise results would be obtained from the full three-dimensional model both in space and in velocities ( $3d3v$ ), which is in preparation.

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