2D SIMULATION OF THE INITIAL STAGE OF THE BEAM-PLASMA DISCHARGE

D.I. Dadyka, I.O. Anisimov

Taras Shevchenko National University of Kyiv, Ukraine

2D electrostatic PIC code for simulation of the initial stage of the beam-plasma discharge in the rectangular geometry is developed. Simulation results for discharge in helium are presented. It is shown that the area of the most intensive plasma heating eventually moves further from the injector. In this area the intensive ionization takes place.

PACS: 52.35Fp, 52.40Mj, 52.50Gj, 52.65Rr, 52.80Tn

INTRODUCTION

Study of the beam-plasma discharge (BPD) is interesting for the formation of dense plasmas for technological applications [1], interpretation of artificial beam-plasma experiments in the ionosphere etc. Considering complexity of the processes accompanying BPD in the real geometry, it is impossible to provide the exact analytical description. Consequently computer simulation can be used [2, 3]. The aim of this work is simulation of the initial stage of the BPD in 2D geometry.

1. SIMULATION PACKAGE

The electrostatic PIC code with the rectangular geometry was used [4, 5]. Stripped electron beam was injected into the rectangular volume filled with the weakly ionized plasma. Electrons and ions were absorbed on the borders. The neutral component was considered as a continuous medium. The density of neutral atoms was assumed to be constant during the simulation. These assumptions are valid only for the initial BPD stage until ionization level is low. The code considered such elementary processes as elastic collisions, electron impact excitation and ionization of atoms (last two processes were taken into account qualitatively). Dependence of the cross sections of elementary processes on the electrons' energy that was used in the simulation is illustrated by Fig. 1, corresponding parameters are given in Table. 1. Processes of recombination were not taken into account.

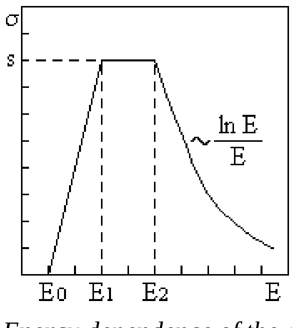

Fig. 1. Energy dependence of the elementary processes' cross-sections

Equations of motion for the charged particles were resolved by the finite differences' method, Poisson's equation – by the Fourier transform method. Linear weighting of the charge density was used to calculate the spatial distribution of potential. Components of the electric field in the grid were calculated by the potential differentiation. To calculate the electric field for points located between the grid nodes the linear weighing of values in the grid nodes was used. For suppression of the shortwave field components calculated inaccurately the window filter was used [5].

To speed up the calculation parallel computing was used. Typical calculation took several days.

Table 1. Parameters of elementary processes

Type of process	s (10^{-20}m^2)	E_0 (eV)	E_1 (eV)	E_2 (eV)
Elastic collision	4	0	3	30
Excitation	0.043	19.7	20.5	21.5
Ionization	0.2	24.6	59	400

Table 2. Simulation parameters

Gas type	Helium
Gas pressure	p=1 Torr
Gas temperature	T=0.025 eV
Camera length	L=1 m
Camera height	L=0.5 m
Initial plasma density	$n_{e0}=10^{10}$ cm^{-3}
Plasma temperature	T_{e0}=1 eV
Debye length	r_D=0.01 cm
Langmuir oscillations period	$T_{pe}=1\cdot10^{-9}$ s
Beam current density	j_b=1000 A/m^2
Beam acceleration voltage	U_a=5000 V
Number of cells along the length	16384
Number of cells along the width	8192
Simulation time step	$1\cdot10^{-12}$ s
Beam electron's transit time	$2.4\cdot10^{-8}$ s
Simulation time	10^{-7} s

2. SIMULATION PARAMETERS

Initially the gas was partially ionized. The ionization level was $n_{e0}=10^{10}$ cm^{-3}. Debye length for such plasma is $r_D=10^{-2}$ cm. The interval of 1 m between electrodes is divided into 16384 cells. Cell size is equal to Δx=0.006 cm and is less than half Debye length.

The Langmuir oscillations period of this plasma is $T_{pe}=1\cdot10^{-9}$ s. Considering that particles should not move more than 1 cell at one step, the simulation step was taken to be $\Delta t \approx \Delta x/V_b \approx 10^{-12}$ s.

3. SIMULATION RESULTS

During the simulation the spatial distribution of such variables as potential, longitudinal and transversal (relatively to the beam velocity) electric field, the beam electron's density (logarithmic scale), the density of created ions (logarithmic scale), the energy density of the electric field, the beam electrons' temperature and the plasma electrons' temperature can be displayed and saved.

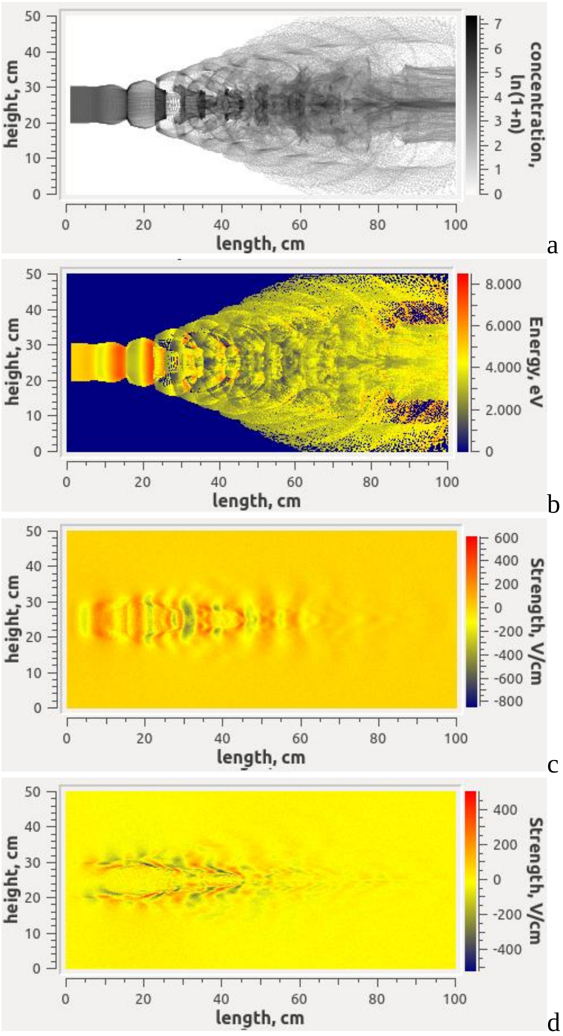

Fig. 2. The spatial distributions of the beam density (a); beam electrons' energy (b); longitudinal (c) and transversal (d) electric field

After the start of beam injection the periodic electric field appears in plasma due to the beam-plasma instability development (Figs. 2,c,d). The longitudinal component of the electric field forms the regions of beam electrons' acceleration and deceleration (Fig. 2,b). In the areas of acceleration the energy of the beam electrons substantially exceeds their initial energy. The transversal component of the electric field forms the regions of radial focusing and defocusing (Fig. 2,a).

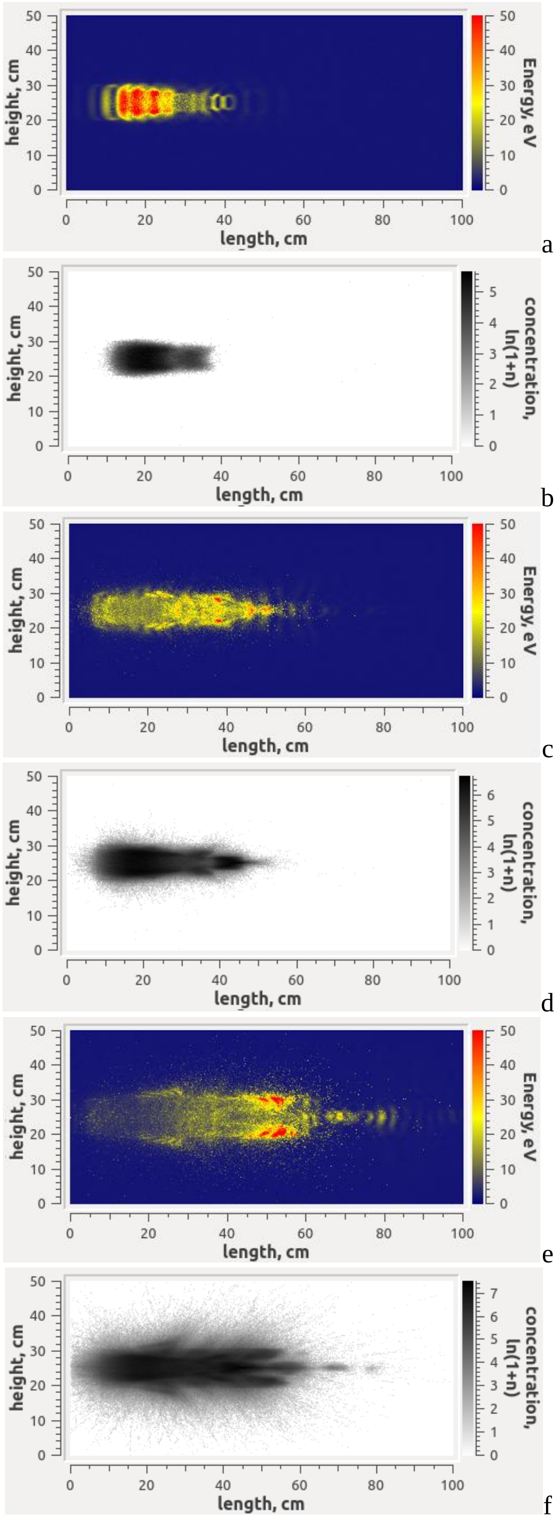

Fig. 3. The spatial distributions of the created ions' density (b, d, f) and plasma electrons energy (a, c, e) for the time points $t = 1.5{\cdot}10^{-8}$ c (a, b); $t = 3.5{\cdot}10^{-8}$ c (c, d) and $t = 7{\cdot}10^{-8}$ c (e, f)

Ionization of the neutral component is observed in the areas where the plasma electrons have maximal energy. This effect is illustrated by Fig. 3. Number of the appeared ions is increasing over time because recombination is not taken into account in the code. In the first approximation the spatial distribution of the created ions density appears as the time integral of the spatial distribution of the plasma electrons' energy.

CONCLUSIONS

1. Electrons are accelerated in the areas of the beam longitudinal and radial focusing due to the development of the beam-plasma instability. The energy of the accelerated electrons exceeds substantially their initial energy.

2. In the first approximation the spatial distribution of the charged particles produced in the discharge can be treated as the time integral of the spatial distribution of the energy of the background plasma electrons counted from the ionization level.

3. Mainly longitudinal waves are excited by the beam at the initial stage of simulation. Later the waves with substantial transversal component of the wave vector appear.

4. The background plasma becomes considerably inhomogeneous due to the neutrals' ionization. The area of the most intensive plasma heating eventually moves further from the injector. In this area the intensive ionization takes place.

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Article received 23.11.2014

ДВУХМЕРНОЕ МОДЕЛИРОВАНИЕ НАЧАЛЬНОЙ СТАДИИ ПЛАЗМЕННО-ПУЧКОВОГО РАЗРЯДА

Д.И. Дадыка, И.А. Анисимов

Рассматривается начальная стадия развития плазменно-пучкового разряда (ППР). Разработан программный код для двумерного электростатического моделирования с помощью метода крупных частиц в ячейках. Получены результаты моделирования начальной стадии ППР в гелии. Показано, что интенсивная ионизация нейтрального газа наблюдается в областях с сильным электрическим полем. Показано, что область максимального нагрева фоновой плазмы со временем смещается дальше от инжектора к коллектору.

ДВОВИМІРНЕ МОДЕЛЮВАННЯ ПОЧАТКОВОЇ СТАДІЇ ПЛАЗМОВО-ПУЧКОВОГО РОЗРЯДУ

Д.І. Дадика, І.О. Анісімов

Розглядається початкова стадія розвитку плазмово-пучкового розряду (ППР). Розроблено програмний код двовимірного електростатичного моделювання за допомогою методу крупних частинок у комірках. Наведено результати моделювання початкової стадії ППР у гелії. Показано, що інтенсивна іонізація нейтрального газу відбувається в тих областях, де присутнє високочастотне електричне поле. Показано, що область максимального розігріву фонової плазми з часом зсувається від інжектора до колектора.