# QUASI-STATIONARY MODE OF THE BEAM-PLASMA DISCHARGE

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Results of the beam-plasma discharge simulation are presented for the plane 2D model. Simulation was carried out using non-relativistic electrostatic package. Elastic collisions between electrons and neutral molecules, excitation and ionization of neutral molecules and radiative recombination were taken into account. Quasi-stationary stage of the discharge was achieved.

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## INTRODUCTION

Study of the beam-plasma discharge (BPD) is interesting for construction of the powerful sources of dense plasma that can be used for the films deposition [1]. It is also necessary for interpretation of experimental results of the electron beams' injection to the ionosphere plasma [2].

Exact analytic study of BPD in the real geometry is extremely complex [3], so computer simulation is often used, including PIC method [4]. On the other hand, simulation can demonstrate fast effects that can be hardly observer in the laboratory experiments [5-9].

In our previous works [10-12] simulation of the BPD initial stage was carried out. The aim of this work is the simulation of BPD in helium including its late stage, i.e. BPD quasi-stationary mode.

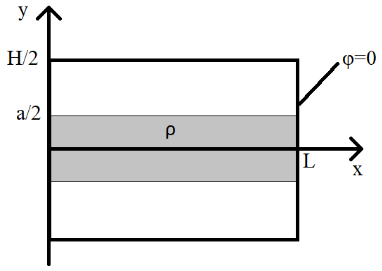


*Fig. 1. Geometry of the considered model*

## 1. SIMULATION METHOD AND MODEL PARAMETERS

All the results of this work are obtained using the original PLS package [12]. Electrostatic non-relativistic 2D model was used. Elementary interactions (elastic collisions between electrons and neutral molecules, excitation and ionization of neutral molecules and radiative recombination) were described using Monte Carlo method. The neutral gas was considered to be homogeneous and its density was constant in time. Stripped monoenergetic electron beam was injected along x-axis (Fig. 1). Simulation parameters are given in Table.

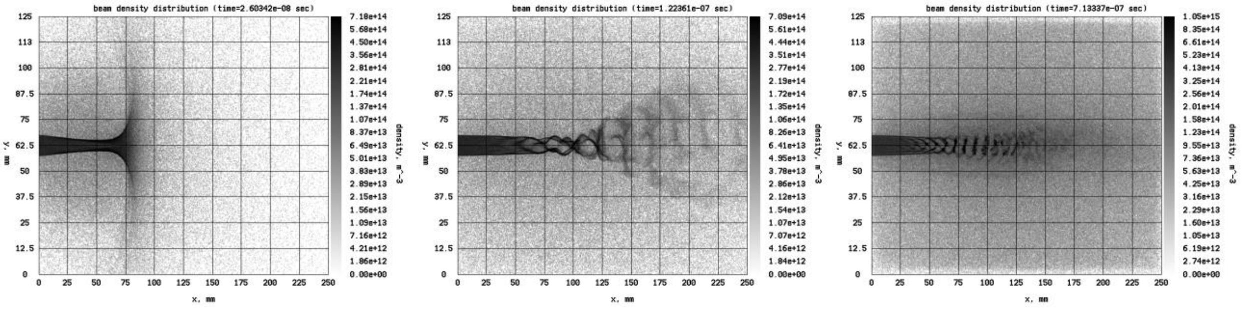
*Simulation parameters*

| **Parameters** | **Value** |
|---|---|
| Length, cm | 25 |
| Height, cm | 12.5 |
| Beam width, cm | 1 |
| Beam current density, kA/m$^2$ | 1 |
| Beam acceleration voltage, kV | 1 |
| Helium pressure, Torr | 0.1 |
| Initial Helium temperature, eV | 0.025 |
| Helium ionisation potential, eV | 24.6 |
| Helium excitation potential, eV | 19.7 |

## 2. SIMULATION RESULTS

### 2.1. ELECTRON BEAM DYNAMICS

Fig. 2 presents the spatial distributions of the beam electrons' density for different time points. The beam reflection from the negative space charge area was initially observed (see Fig. 2,a). It means that the initial beam current density exceeded its critical value for vacuum. The beam electrons' focusing due to the ions' space charge was observed during the initial time interval of the simulation. The beam electrons' oscillations caused by the beam-plasma instability had both longitudinal and parallel components (see Fig. 2,b), symmetry of the system was broken. At the end of the simulation time interval the spatial distribution of the beam electrons looked quasi-stationary (see Fig. 2,c).



a b c

*Fig. 2. Spatial distributions of the beam electrons' density for t=26 ns (a), t=122 ns (b), t=713 ns (c)*

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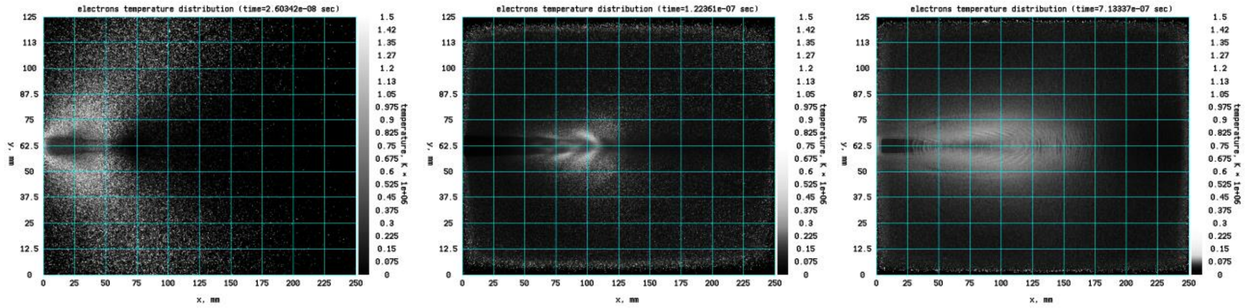
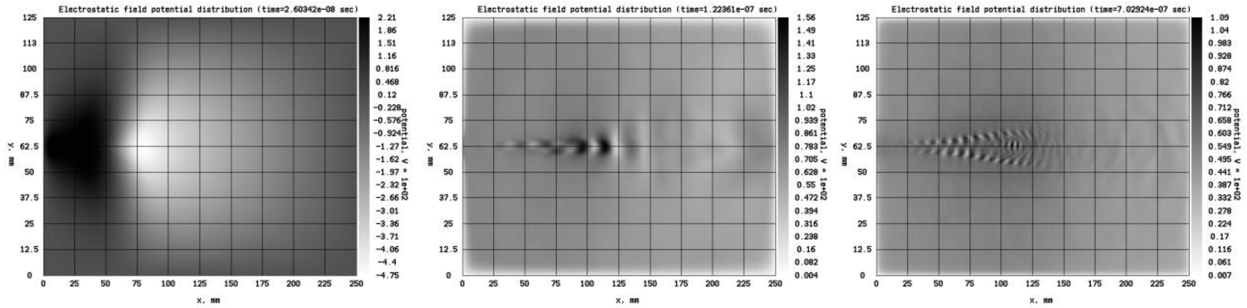


a b c

*Fig. 3. Spatial distributions of the plasma electrons' temperature for t=26 ns (a), t=122 ns (b), t=713 ns (c)*



*a* b c

*Fig. 4. Spatial distributions of the electrostatic potential for t=26 ns (a), t=122 ns (b), t=703 ns (c)*

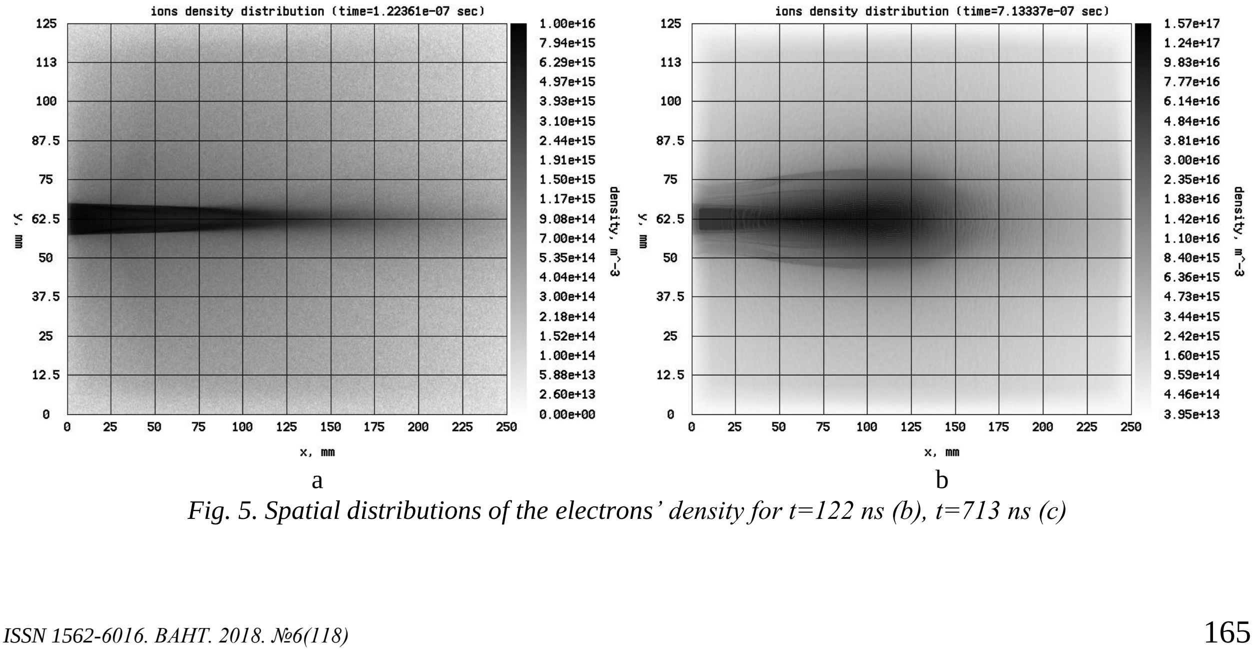
## 2.2. GAS IONIZATION AND PLASMA HEATING

Fig. 3 and Figs. 5, 6 present the spatial distributions of the plasma electrons temperature ions' density of the background plasma, and integral density of the radiated energy, respectively, for the different time points. Fig. 7 shows the time dependency of the average ion density.

Spatial distributions of the background plasma electrons' and ions' densities were similar. Initially the background gas ionization was caused by the beam electrons impact (see Fig. 5,a), at the late stage of simulation – by heating of the background plasma electrons (see Fig. 5,b).

Initially the temperature of the background plasma electrons exceeded 100 eV, at the late stage of simulation it was of the order of ionization potential for helium (see Fig. 3). These results were obtained for the model without initial ionization of the background gas (it can be typical for the laboratory experiment). For the case of partially ionized gas (e.g., in the ionosphere) heating of the plasma electrons by the beam-plasma instability takes place [2].

Increase of the average ions' density at the end of the simulation interval demonstrated that stabilization of the discharge was not yet achieved at that moment (see Fig. 7). Nevertheless the spatial distribution of the integral density of the radiated energy (see Fig. 6,b) is qualitatively similar to the experimental results [7].



a b

*Fig. 5. Spatial distributions of the electrons' density for t=122 ns (b), t=713 ns (c)*

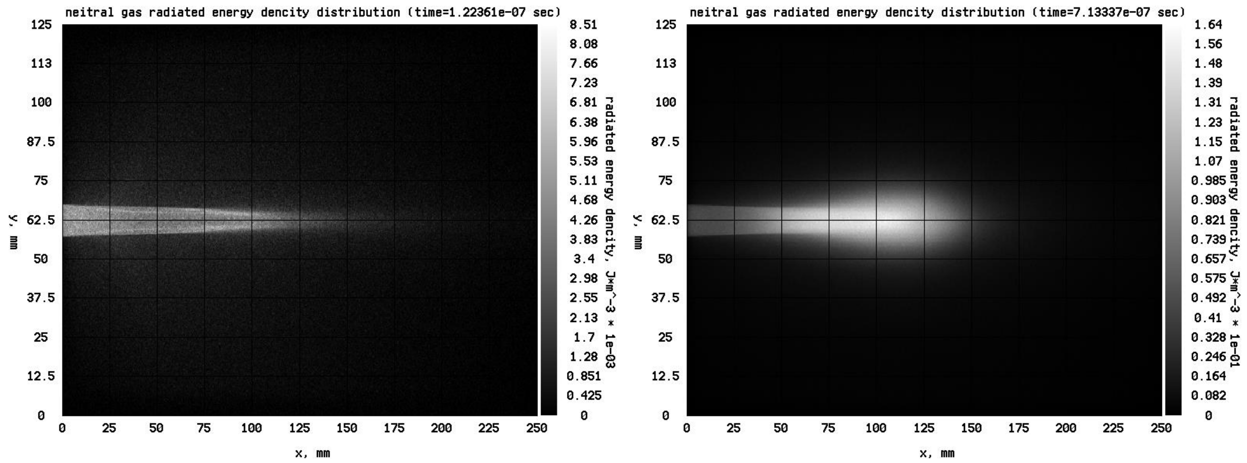


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*Fig. 6. Spatial distributions of the integral density of the radiated energy for t=122 ns (b), t=713 ns (c)*

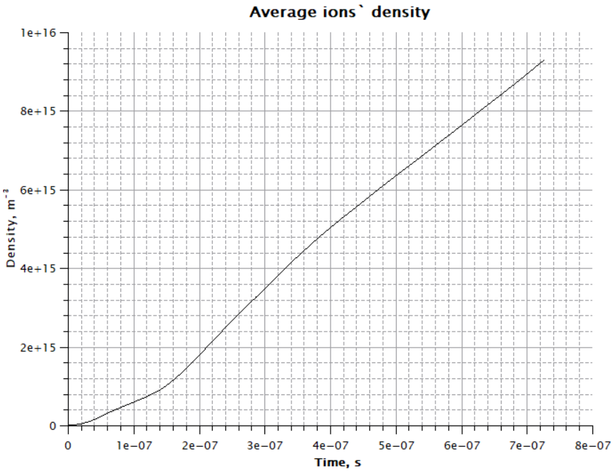

*Fig. 7. Time dependency of the average ion density*

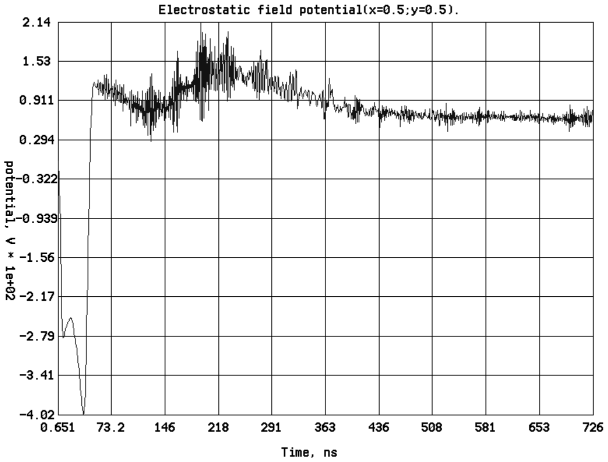

*Fig. 8. Time dependence of the electrostatic potential at the point y=0, x=12.5 cm*

### 2.3. QUASI-STATIC AND HF ELECTRIC FIELDS

Figs. 8,4 demonstrate time dependence of the electrostatic potential at some point of the simulation space and spatial distributions of this potential for some time points.

After start of the beam injection the space potential became negative (see Fig. 8). Later its sign changed due to the ions' appearance and partial displacement of the plasma electrons from the beam area. The range of the potential variation at the symmetry plane of the system decreases with the distance from injector. Position of the potential minimum moves from injector with the mean velocity $6 \cdot 10^6$ m/s (approximately 0.3 of the initial beam velocity).

After the excitation of the beam-plasma instability only one mode was observed (see Fig. 4,b). After the formation of the dense plasma area the excitation of several plasma modes took place (see Fig. 4,c). This effect is caused by the formation of inhomogeneous plasma at this stage of BPD development.

## CONCLUSIONS

1. Quasi-stationary stage of the beam-plasma discharge was achieved in the simulation.
2. The shape of the dense plasma area was similar to the experimental results.
3. The electron temperature of the background plasma decreased from about 100 eV to the value of the order of the ionization potential of the background gas.
4. Formation of the dense plasma area moved to the multimodal regime of the beam-plasma instability.

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## КВАЗИСТАЦИОНАРНЫЙ РЕЖИМ ПЛАЗМЕННО-ПУЧКОВОГО РАЗРЯДА

***Д.И. Дадыка, И.А. Анисимов***

Представлены результаты моделирования плазменно-пучкового разряда для планарной двухмерной модели. Моделирование проведено при помощи нерелятивистского электростатического кода. Учтены упругие столкновения электронов и нейтральных молекул, возбуждение, ионизация и излучательная рекомбинация. Достигнута квазистационарная стадия разряда.

## КВАЗІСТАЦІОНАРНИЙ РЕЖИМ ПЛАЗМОВО-ПУЧКОВОГО РОЗРЯДУ

***Д.І. Дадика, І.О. Анісімов***

Представлено результати моделювання плазмово-пучкового розряду для планарної двовимірної моделі. Моделювання виконано за допомогою нерелятивістського електростатичного коду. Враховано пружні зіткнення електронів з нейтральними молекулами, збудження, іонізація та випромінювальна рекомбінація. Досягнута квазістаціонарна стадія горіння розряду.