DISSIPATIVE STRUCTURE IN THE GLOW DISCHARGE

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Possibility description of the current cathode spot as dissipative structure caused by distributive feedback is proposed. Two stationary steady states can be associated with normal current density in glow regime and failure of current. Non-steady stationary state can be associated with dark discharge. Numerical computer model of non-stationary discharge is presented.
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1. INTRODUCTION

Interpretation of the normal current density effect in the glow discharge [1] attracts attention in the gas discharge physics for the long time. In the normal mode of the glow discharge in some range of currents the discharge voltage remains constant, and current growth occurs due to the increase of the cathode spot area, while the current density remains invariable. In spite of the fact that interpretation of this effect was already proposed [2-4], discussion of its details is still relevant [5-6]. In this work we try to discuss this effect in terms of synergetics: the cathode spot in the normal regime is treated as the dissipative structure caused by distributed feedback. The simulation algorithm of the non-steady state of the discharge burning in hydrodynamic approach is proposed for checkout of this idea.

2. CATHODE SPOT IN NORMAL MODE AS A DISSIPATIVE STRUCTURE

The above effect looks similar to the dissipative structures caused by the distributed feedback that are well known in synergetics (barretter, heat source in a mesh with intermixing and others) [7].

Really, the cathode spot area is stable against the small fluctuations, as well as the high-resistance area length in a barretter and the heat source area, thus its shape can vary. The distributed feedback can be caused by the series resistor connected with a discharge gap to the voltage source. In fact, the current density variations in any point of the cathode spot move to the total current change and accordingly the discharge voltage change. If the analogy with barretter is correct, that establishing of the discharge spot takes place via propagation of the running front type auto-wave. Velocity of this wave goes to zero when the spot area comes to its equilibrium value.

Nonlinearity and non-locality of the discharge makes its analytical description too complicate. So it looks reasonable to use computer simulation for its study. The first step is to create 1D non-steady code allowing to study processes of the glow discharge establishment. The next step needs 2D code.

3. THE BASIC EQUATIONS AND COMPUTATION PROCEDURE

In frameworks of the diffusion-drift approach the state of discharge plasma is featured by the continuity equations for electrons and ions densities

$$\frac{\partial n^\alpha}{\partial t} = -div\left(\vec{j^\alpha}\right) + S;$$

$$j^\alpha = n^\alpha v^\alpha - D^\alpha \nabla n^\alpha;$$

$$v^\alpha = a\mu^\alpha \nabla\varphi, \quad \alpha = e \rightarrow a = 1, \alpha = i \rightarrow a = -1;$$

$$S = Ape^{-\frac{Bp}{|\nabla\varphi|}} n^e \left|\vec{v^e}\right| - \beta n^e n^i,$$

(n^α are the charged particles densities, α=e for electrons, and α=i for ions, v^α, μ^α and D^α are velocities, mobilities and diffusion coefficients, respectively, S is the ionization – recombination source, A and B are constants from the Townsend ionization source, and β is the recombination rate), and the Poisson equation

$$\Delta\varphi = -\frac{e(n^i - n^e)}{\varepsilon_0},$$

where φ is the electric field potential and ε_0 is the vacuum dielectric constant.

Boundary conditions have a form

$$j^e = \gamma j^i, \qquad \varphi = 0$$

and

$$j^i = 0, \qquad \varphi = V$$

on the cathode and on anode, respectively.

Finite difference scheme was gained by the integral-interpolation method [8] on the uniform chess grid.

The upstream scheme was used [9] taking into account the considerable contribution of convective terms. Accumulation of charged particles (mainly electrons) on electrodes was considered because of the parameters non-stationarity;

$$\partial n^\alpha / \partial t = -div\left(j^\alpha\right).$$

The discharge voltage was found from the Ohm's law for a full chain. The cathode spot area was taken constant. Parameters for calculation were used from [4].

4. STEADY STATE OF GLOW DISCHARGE

Numerical simulation of glow discharge was carried out in many articles (see, e.g., [4, 10-12]). Majority of them is devoted to the stationary state of discharge, and they can't be used for study the discharge establishing. Non-stationary problem was studied only in several works (see, e.g.,[4, 12]). We also developed the non-stationary code. The first stage of its testing was to obtain the stationary picture of discharge.

Fig.1 shows electron and ion density profiles and the potential spatial distribution in the stationary mode of glow discharge. These results are similar to previous simulation and experimental data.

Note that hydrodynamic approach in invalid for small gas pressures and large current densities [13].

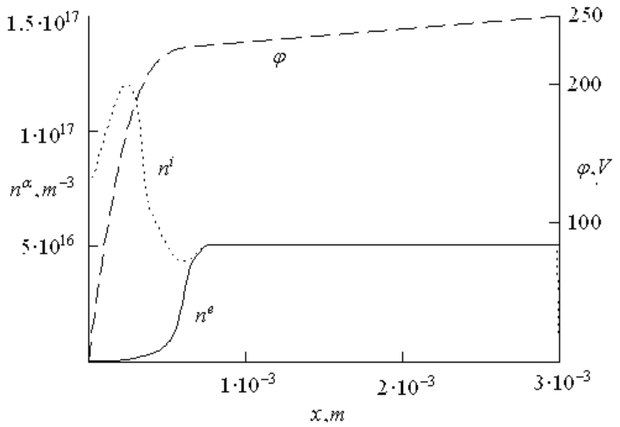


Fig. 1. Spatial distribution of potential and electron and ion densities for glow discharge in nitrogen (p=1995 Pa, T=300K, γ=0.33, E=250 V)

5. ESTABLISHING PROCESSES

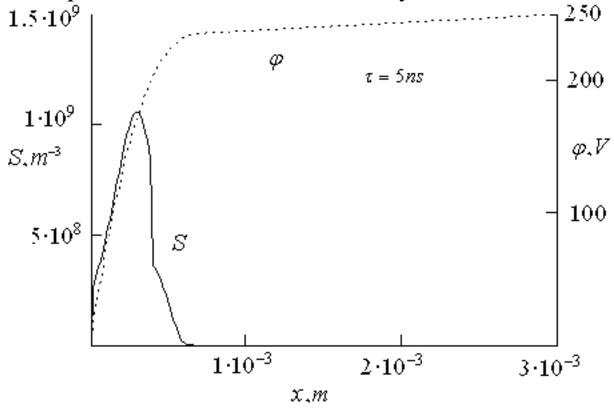
The discharge gap at low cathode temperatures has three stationary states for the given total voltage on the tube and resistor. The first one corresponds to the lack of current (without any external ionizing agents). It is formed due to the transversal diffusion of the charged particles. The second state corresponds to the glow discharge. The growth of the current is restricted due to the external resistor that moves to the decrease of the discharge voltage for large currents. Both states are stable against the small perturbations. The third state that is instable against the small perturbations can be associated with the dark discharge.

The developed 1D code gives the possibility to study the establishing of the glow discharge. Initial conditions corresponded to homogeneous distribution of electrons and ions (without initial velocity) in the discharge interval.

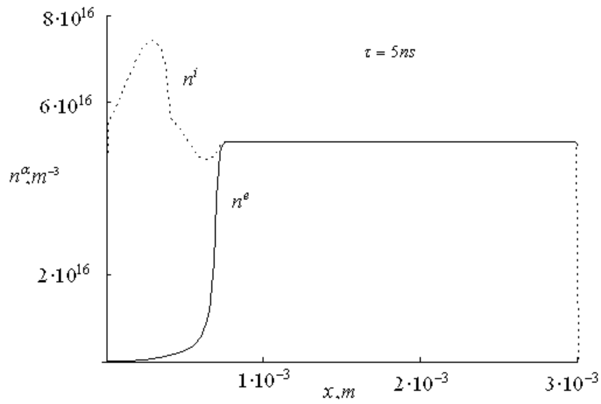
Fig.2 a shows the spatial distributions of potential and ionization-recombination source for the time point 1ns. Fig 2 b shows the spatial distributions of electron and ion densities for the same time point.

In the 1D model this phenomenon is reached by the following way. At small initial densities of charged particles electrons promptly transit in an external circuit and traversal diffusion of ions is reached by introduction of an additional addend proportional to an ion concentration into S function. For reception of the dark discharge initial densities from analytical model were set from [2].

Evolution of glow discharge depends from initial densities of charged particles. In case of the homogeneous and equal initial allocations the core parameters are given in Fig 4 and 5. One can see the initial stage of formation of the positive column and cathode layer.



a



b

Fig.2. a – spatial distribution of potential and ionization-recombination source; b – spatial distribution of electron and ion densities. t=5 ns, other parameters are the same as on Fig.1

6. CONCLUSIONS

1. Interpretation of the cathode spot in the normal mode of glow discharge as the dissipative structure caused by distributive feedback is proposed.
2. 1D non-stationary hydrodynamic code for simulation of gas discharge is described. Establishing of the stationary regime of the glow discharge is studied.

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ДИССИПАТИВНАЯ СТРУКТУРА В ТЛЕЮЩЕМ РАЗРЯДЕ

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Рассмотрена возможность описания катодного пятна тлеющего разряда в нормальном режиме как диссипативной структуры, обусловленной распределенной обратной связью. Два устойчивых стационарных состояния при этом можно связать с нормальной плотностью тока в режиме тлеющего разряда и с отсутствием тока. Неустойчивому стационарному состоянию при этом соответствует темный разряд. Предложен численный алгоритм для расчета нестационарного состояния разряда.

ДИСИПАТИВНА СТРУКТУРА В ЖЕВРІЮЧОМУ РОЗРЯДІ

О.П. Пономарьов, І.О. Анісімов

Розглянута можливість описати катодну пляму жевріючого розряду в нормальному режимі як дисипативну структуру обумовлену розподіленим зворотнім зв'язком. Два стійкі стаціонарні стани при цьому можна трактувати як випадок нормальної густини струму в режимі жевріючого розряду та випадок відсутності струму. Нестійкому стаціонарному стану при цьому відповідає темний розряд. Запропонована числова модель для розрахунку нестаціонарного стану розряду.