BREAK-DOWN OF THE MAGNETICALLY INSULATED DIODE

I.A. Zagrebelnyy, A.V. Zykov[1], M.V. Glaznev[1]

NSC "Khakov Institute of Physics and Technology",
Akademicheskaya Str. 1, 61108 Kharkov, Ukraine;

[1]V.N. Karasin Kharkov National University,
Kurchatov av. 31, 61108 Kharkov, Ukraine, e-mail: kft@pht.univer.kharkov.ua

In the present work the comparative analysis of computer simulation results and experimental data for "Radical" ion source is carried out. The break-down curves are presented for different boundary conditions, such as: cathode-sheath-anode, plasma-sheath-anode, ion-beam plasma-sheath-anode. The influence of thermo-electron emission on the discharge characteristic was also investigated.

PACS: 52.77.-j

INTRODUCTION

Last decades there is the considerable interest to experimental and theoretical research of accelerators with the closed drift of electrons in crossed EH fields [1]. It is caused by the wide application of such type ion sources as charged particle accelerators, space thrusters and in ion-plasma technologies [2]. At the same time, despite extensive researches, development of numerical and analytical models of such systems allowing to carry out engineering calculations is an actual problem.

In the previous work [3] the 2D Fluid Model of accelerators with closed electron drift in crossed EH fields [4] had been advanced. The model is based on analytical solution of self-consistent equation system of motion, particle and energy balance for ions and electrons in the case of planar magnetically insulated diode. The introduction of new parameters of normalization and boundary conditions has allowed considerably to expand the parameters range of model application and to summarize the results of break-down, stationary states of EH electron layer and the Hull cutoff in the magnetically insulated diode.

The task of the present work is the comparative analysis of the computer simulation results and experimental data for "Radical" ion source [5].

EXPERIMENTAL SETUP

The schematic layout of the "Radical" ion source and magnetic force lines configurations are shown on Fig.1 Grounded cathode 1 with the 100 mm diameter ring slot was made from the soft magnetic material. Radial magnetic field with the value up to the 0.15 T was excited by the solenoid 3. Anode 2 was cooled by water.

The working pressure range of the ion source was 10^{-4} - 10^{-3} Torr, but the break-down of the discharge in crossed EH fields takes place down to the pressure 10^{-5} Torr (the base pressure of the pumping system).

The electrodes geometry of "Radical" ion source (Fig.1) approximately corresponds to the 1D model of the magnetically insulated diode described below.

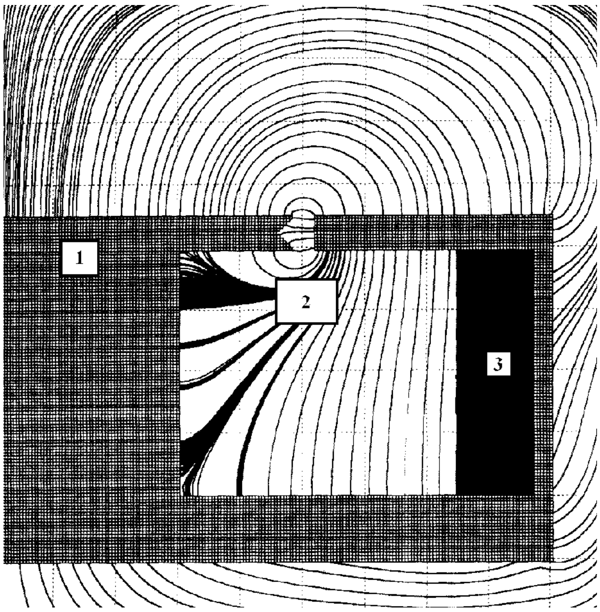


Fig.1. Schematic layout of "Radical" ion source: 1 - cathode, 2 - anode, 3 - solenoid

THEORETICAL MODEL

The 1D-steady state of electrons in crossed EH fields is described by the following system of equations [4].

$$j_x = b_\perp n_e \frac{\partial \phi}{\partial x} \quad (1)$$

$$\frac{dj_x}{dx} = \nu_i n_e \quad (2)$$

$$\frac{dE}{dx} = -4\pi e n_e \qquad (\mathrm{E} = -\nabla \varphi) \quad (3)$$

Where j_x -electron current density; n_e -electron density, $b_\perp$ -cross-field mobility, ν_i - electron ionization collision frequency.

The boundary conditions for this system of equations are

$$x = 0,\ \mathrm{E} = \mathrm{E}_0, j = j_0\ \varphi = \varphi_0 .$$

If we introduce the dimensionless variables

$$E' = \frac{E}{E_0}, \quad j' = \frac{j}{-\nu_i E_0 / 4\pi e},$$

$$X = \frac{x}{-b_\perp E_0 / \nu_i}, \quad \Phi = \frac{\varphi}{b_\perp E_0^2 / \nu_i},$$

the system of equations is given by:

$$j' = -\frac{n_e}{n^*}\frac{d\Phi}{dX},$$

$$\frac{dj'}{dX} = \frac{n_e}{n^*},$$

$$\frac{dE'}{dX} = -\frac{n_e}{n^*},$$

where $n^* = \dfrac{\nu_i}{4\pi e b_\perp}$, $n_0 = -\dfrac{j_0}{b_\perp E_0}$, $N = \dfrac{n_0}{n^*}$.

The solution of the system in parametric form is:

$$j' = E' + (N-1)$$

$$X = E' - 1 - (N-1)\cdot \ln\left|\frac{E' + (N-1)}{N}\right|$$

$$\Phi = \Phi_0 + \frac{1}{2}\left[E'^2 - 1\right] - (N-1)\cdot X$$

The dependence of dimensionless density on electric field is:

$$\frac{n_e}{n^*} = 1 + \frac{N-1}{E'} .$$

The boundary condition for electron avalanches critical electric field was determined from the energy balance equation.

$$\frac{dWj_x}{dx} = -ej_x E - \varepsilon_i \nu_i n_e ,$$

W - average electron energy ; ε_i - energy loss per ion creation.

The criterion for starting of electron avalanches is:

$$\frac{d(W \cdot j_x)}{dx} \geq 0 .$$

So $$E_{kr} = \sqrt{\frac{\varepsilon_i \nu_i}{e b_\perp}} .$$

If we determine the boundary condition $E_0 = E_{kr}$ the solution of the equations system will depend on one parameter *N*.

The dependencies of dimensionless electron density n, potential Φ and current *j'* on the coordinate *X* for various values of boundary density *N* are presented at Figs. 2, 3.

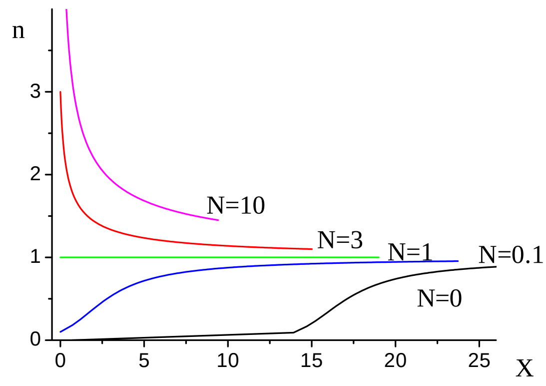


Fig.2. The dependencies of non-dimensional density on coordinate X for various values of boundary density N (different electron emission current from the cathode)

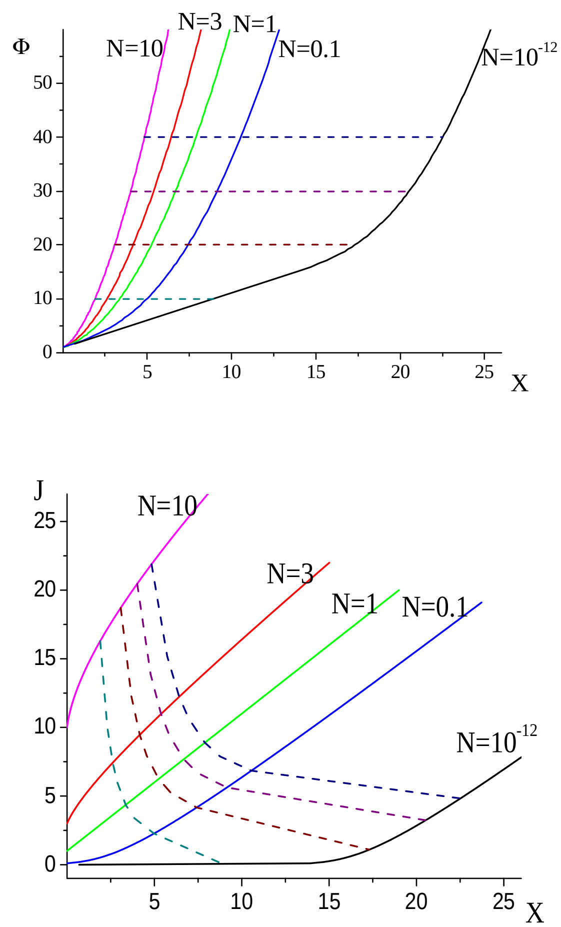
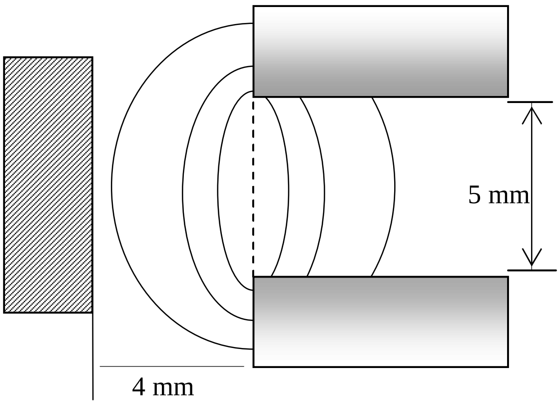


Fig. 3. The dependencies of non-dimensional potential Φ and non-dimensional current j' on coordinate X for various values of emission electron current from the cathode, corresponding to different values of N



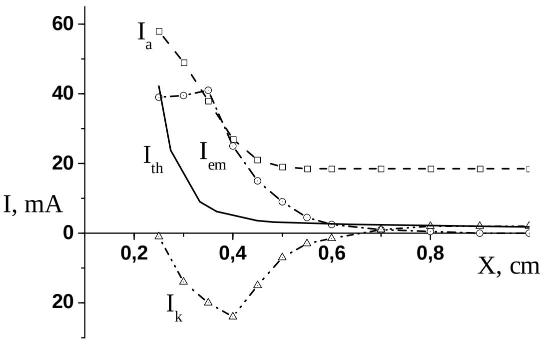


Fig.4. The experimental dependencies of "Radical" source anode current I_a, cathode current I_k and electron emission current I_{em} on coordinate X of thermo-cathode. The solid curve I_{th} is the emission current calculated from the theoretical model

EXPERIMENTAL RESULTS

The comparative analysis of computer simulation results and experimental data for "Radical" ion source was carried out.

The most interesting result is the influence of electron emission from moving thermo-cathode on discharge characteristics. The dependences of "Radical" anode current I_a, cathode current I_k and electron emission current I_{em} on coordinate X of thermo-cathode are presented at Fig.4. The solid curve I_{th}, calculated from the theoretical model, corresponds to the experimental current I_{em}.

Also the break-down curves for different boundary conditions, such as: cathode-sheath-anode, plasma-sheath-anode, ion-beam plasma-sheath-anode was measured. The comparison of theory and experimental data has shown a good correspondence.

CONCLUSIONS

New presented result is the electric field boundary condition for the starting of electron avalanches obtained from the electron energy balance equation. This condition has allowed to present a solution of a set of equations for *n, j', Φ* depending on single parameter N (electron density on exterior boundary of the layer). It is possible to determine 4 various regimes of the layer, which are observed in experiments:

1. N « 1 the case of the cold conductive cathode
2. N ≤ 1 the case of ion-beam plasma
3. N ≥ 1 the case of dense plasma
4. N » 1 a case of a hot cathode on exterior boundary.

Let's mark, that in paper [4] one solution relevant to a case N ≤ 1 is obtained only. At the same time quantitative disagreement of experimental data and theoretical calculations requires the further advancing of the model.

REFERENCES

1. *Ion injectors and plasma accelerators* // Edited by A.I. Morozov and N.N. Semashko. Moscow: "Energoatomizdat", 1990.
2. A.A. Goncharov et al. // *Problems of Atomic Science and Technology. Series "Plasma Physics"(6).* 2000, N 6.
3. I.A. Zagrebelnyy, A.V. Zykov. The advanced model of the magnetically insulated diode with ionization amplification // *Book of Abstracts. 10th International Conferences and School on Plasma Physics and Controlled Fusion.* Alushta, Ukraine, September 13-18, 2004, p.178.
4. Yu. V. Sanochkin, V.K. Kalashnicov. The theory of discharge with closed electron drift // *ZhTF.* 1974, v.44, N12, p.2501-2516.
5. S.V. Dudin, A.V. Zykov, A.V. Ushakov. The dinamics of electrons in EH electron layer // *Pisma v ZhTF.* 1995, v.21, p.25-30.

ПРОБОЙ МАГНИТОИЗОЛИРОВАННОГО ДИОДА

И.А. Загребельный, А.В. Зыков, М.В. Глазнев

Представлен сравнительный анализ численных расчетов и экспериментальных данных для ионного источника ионов "Радикал". Разрядные кривые представлены для различных типов граничных условий таких как: катод-слой-анод, плазма-слой-анод, ионно-пучковая плазма-слой-анод. Также исследовано влияние термоэлектронной эмиссии на разрядные характеристики

ПРОБІЙ МАГНІТОІЗОЛЬОВАНОГО ДІОДА

І.А. Загребельний, О.В. Зиков, М.В. Глазнєв

Представлено порівняльний аналіз чисельних розрахунків й експериментальних даних для іонного джерела іонів "Радикал". Розрядні криві представлені для різних типів граничних умов таких як: катод-шар-анод, плазма-шар-анод, іонно-пучкова плазма-шар-анод. Також досліджено вплив термоелектронної емісії на розрядні характеристики.