CHARACTERISTICS OF DISCHARGE IN CROSSED ExH FIELDS NEAR BREAKDOWN CURVE IN ACCELERATION AND PLASMA REGIME

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In the present study the characteristics of discharge in crossed EH fields in acceleration and plasma regimes have been researched at low voltages near the breakdown curve. The new experimental data for current-voltage characteristic and their dependence on argon pressure and magnetic fields strength are presented. It is shown that initial stage of the current-voltage characteristic in acceleration and plasma regime are quite similar and correspond to regime with "oscillating" electrons. The theoretic model based on the energy balance of electrons in plasma regime is presented as well as the comparison of the theory with the experiment. The obtained results may be useful for further development of magnetron sputtering systems and plasma accelerators with closed electrons drift.

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INTRODUCTION

The ion source "Radical" has two different operating modes [1-3]. First of them usually name a "accelerating" mode (collimated-beam mode), or "a mode with an anode layer ", and the second - "magnetron", "plasma", or "diffusion-beam mode" [3, 4].

As show experiments [3] transition of a ion source in such modes depends on the working gas pressure. Transition from "magnetron" to "accelerating" mode is observed at reduction of pressure in the ion source less than $6 \cdot 10^{-4}$ Torr. The "accelerating" is characterized by discharge currents in the order of hundreds mA, and high values of current efficiency (70…80 %).

At work in "magnetron" mode the discharge expands from the accelerating channel of a source to the technological chamber volume. The discharge at this mode has greater currents in the order of even tens amperes [4], and small current efficiency (20…30 %). At such mode intensive sputtering of a cathode material is observed, that is typical for magnetron sputtering systems [5].

At the present moment is not enough the experimental materials necessary for a theoretical explanation of processes, taking place in the discharge at transition from one mode in another.

The aim of the present work is experimental research of transitive characteristics of the discharge in crossed **E** and **H** fields near to a threshold of ignition, and also development of the theoretical model of this phenomenon.

1. EXPERIMENTAL SETUP

The research was carried out on experimental installation with the ion source "Radical". The source is the type of ion source with the cold cathode and gas discharge in crossed **E** and **H** fields. In such sources the closed drift of electrons in crossed **E** and **H** fields in the interval anode – cathode is realized. The ionization of working gas is provided by high-energy electrons which are kept in specially organized electromagnetic trap.

The electron location in the interval anode - cathode is carried out by potential "well" and lenses configuration magnetic field. Ions, unlike electrons, practically is not influenced by magnetic field and accelerated in electric field. Therefore in space of transportation the tubular ion beam with an initial diameter about 100 mm is formed. The design of the ion source is presented on Fig. 1.

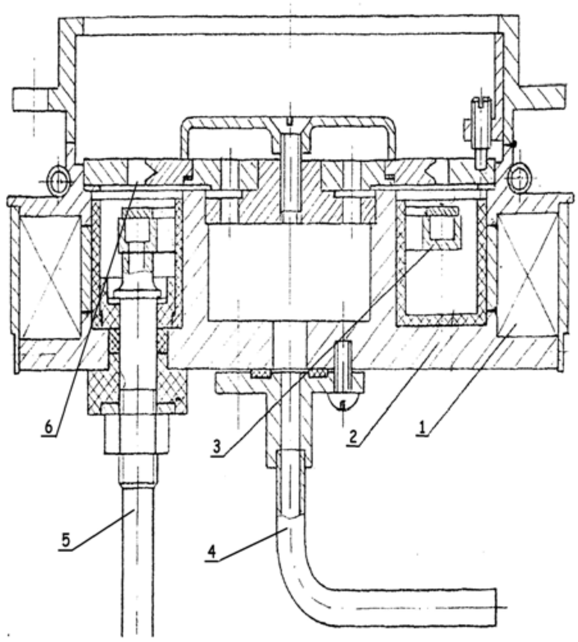

Fig. 1 Schematic layout of "Radical" ion source. 1 – solenoid; 2 – cathode; 3 – anode; 4 – gas inlet; 5 – cooling water inlet for anode ; 6 – anode layer of electrons

2. EXPERIMENTAL RESULTS

In an experimental part of work ignition curves have been measured depending on a current of the solenoid and working gas pressure, and also current-voltage characteristics in different modes of the discharge. On Fig. 2 the ignition curves of the discharge at various pressures are presented. As follows from figure, qualitative character of breakdown does not vary from pressure of working gas. There is a threshold of the solenoid current value (0.5…0.8 A) and above which the magnetic field doesn't effect on the breakdown voltage. This size of a magnetic field corresponds to the Hell's cut-off.

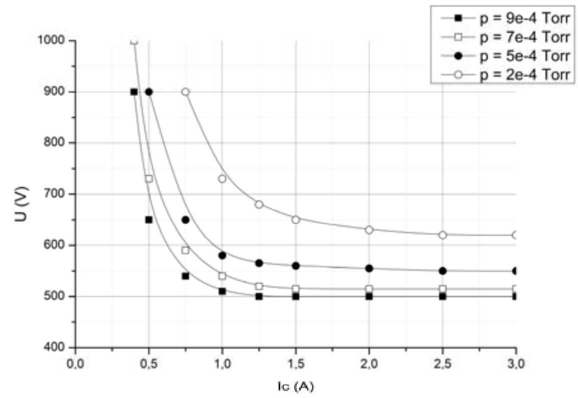

Fig. 2. The ignition curves of the discharge at various pressures

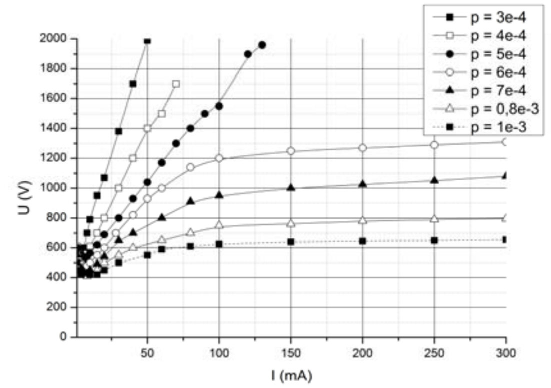

Fig. 3. The current-voltage characteristics of the ion source in linear scale of a current at various pressure of working gas

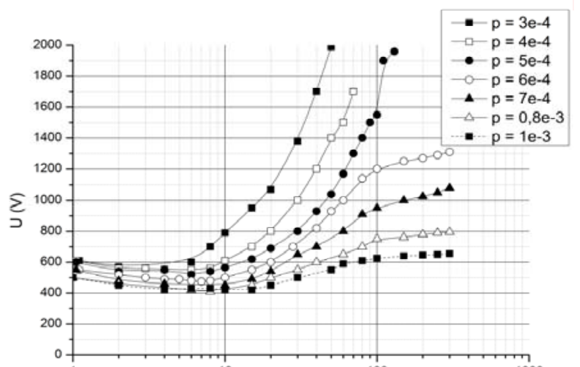

Fig. 4. The current-voltage characteristics of the ion source in logarithmic scale of a current at various pressure of working gas

The current-voltage characteristics of the ion source in linear scale of a current at various pressure of working gas are presented on Fig. 3. The pressure was measured in the working chamber and the pressure in the ion source exceeded pressure in the chamber in 7 times.

The investigation of current – voltage characteristics near the threshold of ignition, at rather small values of current and voltage, has been made by means of the digital voltmeter with high resolution. These characteristics are presented in half-logarithmic scale of current and voltage on Fig. 4.

As has shown on the Fig. 4 the starting part of current- voltage characteristics, corresponding to various operating modes of the ion source are similar, and at significant pressure reduction the discharge voltage grows slightly.

3. THEORETICAL MODEL

Theoretical model of a plasma mode is based on a electron power balance in discharge. The Theoretical model considers ionization in an electromagnetic trap by two groups of electrons: the primary high-energy γ - electrons emitted from the target as ion bombardment result and the secondary plasma electrons which were appeared in volume of plasma. Accordingly the energy loses per ion creation for primary electrons is I, and for plasma electrons-. ε. At a first approximation the power balance of system could be presented in the form:

$$U(I+\gamma I)= U\cdot I+ \varepsilon\cdot I_1+ \mathrm{I}\cdot I_2+T_e\cdot I_1+\gamma\cdot I\cdot T_e\,, \quad (1)$$

$$I=I_1+I_2 \text{ or } I_1=I-I_2. \quad (2)$$

Where I – a total current of ions on the cathode; I_1 – the current of the ions created by the plasma electron with temperature T_e; I_2 – the current of the ions created by γ-electrons; U – the discharge voltage.

Substituted (2) to (1) it is easy to obtain:

$I_2(\varepsilon\text{-I})=(\eta- \gamma U)I_i$, where $\eta= \varepsilon+(1+\gamma)T_e$ the-energy losses per ion creation with kinetic losses. It is easy to obtained final expression in a dimensionless variables:

$$Y=1-(1-B)/X\,, \quad (3)$$

where $Y= \gamma U/ \eta$, $X=I/I_2$, $B=(I+ \gamma T_e) / \eta$.

The limiting case X → 1 is corresponded to an initial stage of the discharge, when plasma electrons don't take part in ionization and the discharge mode with «oscillation» electrons is realized (γ –electrons, located in the electromagnetic trap). Thus Y →B, i.e. the discharge voltage} is $U=I/\gamma$

At X>> 1 ionization is carried out basically by plasma electrons, and the discharge voltage is $U =\eta /\gamma$. The dependence (3) is presented on Fig. 5.

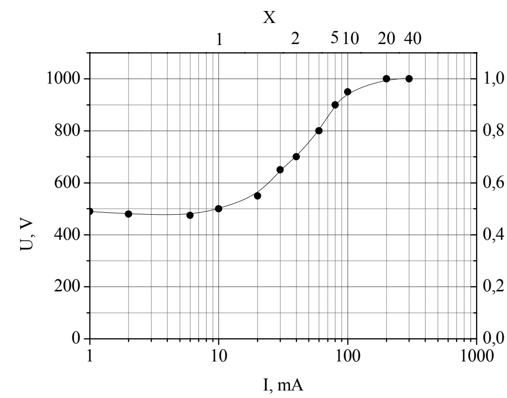

Fig. 5. The current-voltage characteristics of the ion source in plasma regime ($p=8\cdot 10^{-4}$) and the dimension less dependence (3). B=5

CONCLUSIONS

In the present work the basic characteristics of the discharge in crossed ExH fields – ignition curves and current-voltage characteristic depending on working gas pressure and intensity of a magnetic field were studied.

Characteristics of the discharge near to a threshold of ignition in accelerating and plasma (magnetron) modes were investigated in details and it was shown:

- Transition from accelerating to the plasma mode depending on pressure take place continuously.
- Breakdown on the bottom branch of a curve of ignition in accelerating and plasma modes are equivalent.
- The initial stage of discharge current-voltage characteristics in accelerating and plasma modes is identical and corresponds to regime with «oscillation» electrons.
- The theoretical model on the base of the energetic balance of electron was presented and demonstrated a good agreement with experimental results.

The received results are of interest for the further development of the theory of discharge in crossed **ExH** fields and for magnetron sputtering systems.

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ХАРАКТЕРИСТИКИ РАЗРЯДА В СКРЕЩЕННЫХ ExH ПОЛЯХ ВБЛИЗИ КРИВЫХ ЗАЖИГАНИЯ В УСКОРИТЕЛЬНОМ И ПЛАЗМЕННОМ РЕЖИМАХ

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Исследованы характеристики разряда в скрещенных ExH полях в ускорительном и плазменном режимах вблизи порога зажигания. Получены новые экспериментальные данные для вольт-амперных характеристик и их зависимости от давления и напряженности магнитного поля. Показано, что стартовые участки вольт-амперных характеристик в ускорительном и плазменном режимах идентичны и соответствуют режиму с «осциллирующими» электронами. Также представлена теоретическая модель на основе энергетического баланса электронов и проведено сравнение с экспериментом. Полученные результаты представляют интерес для дальнейшего развития магнетронных распылительных систем и плазменных ускорителей с замкнутым дрейфом электронов.

ХАРАКТЕРИСТИКИ РОЗРЯДУ В СХРЕЩЕНИХ ExH ПОЛЯХ ПОБЛИЗУ КРИВИХ ЗАПАЛЮВАННЯ В ПРИСКОРЮВАЛЬНОМУ ТА ПЛАЗМОВОМУ РЕЖИМАХ

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Досліджено характеристики розряду в схрещених ExH полях у прискорювальному та плазмовому режимах поблизу порогу запалювання. Отримано нові експериментальні дані для вольт-амперних характеристик та їх залежності від тиску та сили магнітного поля. Показано, що стартові участки вольт-амперних характеристик у прискорювальному та плазмовому режимах ідентичні і відповідають режиму з «осцилюючими» електронами. Також представлено теоретичну модель на базі енергетичного балансу електронів та проведено порівняння з експериментом. Отримані дані будуть корисні для подальшого розвитку магнетронних розпилювальних систем та плазмових прискорювачів з замкнутим дрейфом електронів.