LOW-ENERGY HIGH-CURRENT ELECTRON BEAM GENERATION IN PLASMA SYSTEM AND BEAM-PLASMA INTERACTION

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The review of results of experimental investigations and computer simulations of low-energy high-current electron beam generation in a low-impedance system and dynamics of beam-plasma system are given. The system includes a long plasma-filled diode, an auxiliary thermionic cathode and an explosive emission cathode. The auxiliary cathode is used to generate a low-current, low-voltage electron beam to form long plasma anode by means of a residual gas ionisation in an external longitudinal magnetic field. The high-current low-energy electron beam is generated from the explosive emission cathode embedded in preliminary prepared plasma. Peculiarities of the system are due to: 1) the generation of electron beams with currents exceeding Alfven's limit; 2) the charge density of the beam close to the plasma density. These peculiarities complicate beam-plasma interaction significantly due to sharp non-uniform distribution of the beam current density, dominant transverse motion of the beam electrons and redistribution of ion-plasma density under the influence of fields. Computer simulation was performed using electromagnetic PIC code KARAT for different geometry's of the system.

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1. INTRODUCTION

Low-energy high-current electron beams are applied for surface modifications. Plasma-filled diodes with explosive emission cathodes have been proposed and shown its effectiveness to generate high-current low-energy electron beams of different duration [1 – 6]. In plasma-filled diode an electron beam is accelerated in a thin double-layer between a cathode and anode plasmas. This near-cathode layer is formed just after the beginning of an accelerating voltage pulse and the voltage applied is localised inside this layer making possible the beginning of the explosive emission from a cathode surface.

There are several different methods to form anode plasma. In our experiments to create a well-defined plasma channel we use ionisation of residual gas by additional pulsed low-energy (~300 eV), low-current (~1-3 A) electron beam guided by a 200-300 Gs magnetic field. The main advantages of this method are the high reproducibility and the flexibility of an operative control of the plasma.

2. GENERATION OF HIGH-CURRENT BEAMS IN THE DIODE WITH PLASMA ANODE

2.1. EXPERIMENTAL SETUP

The scheme of the experimental setup is shown in Fig.1. The voltage from IK50-3 capacitor bank (50 kV, 3 μF) charged to 10-40 kV is applied to the diode via coaxial transmission cables, connected to a cathode electrode supported by a high-voltage insulator. At the other end of this electrode a flat graphite cathode is installed. Plasma channel is formed by low-energy electron beam generated by a simple greed-less electron gun with filament-type thermocathode located between two sections of the drift chamber. A symmetrically propagating in a guiding magnetic field 2-way electron beam is produced using a pulse (250-350) V, negative biasing of the hot tungsten wire with respect of the grounded chamber.

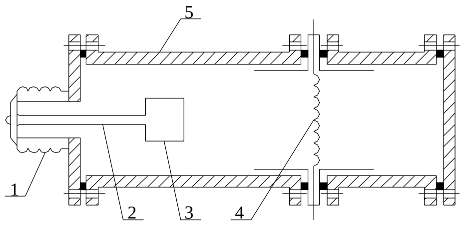

Fig.1. Schematic diagram of the experimental setup: 1 - input isolator of high-current diode; 2 – cathode stem; 3 – cathode of high-current diode; 4 – thermocathode of low-current beam; 5 – vacuum chamber with solenoid

The biasing voltage pulse (5-10 μs) is applied prior to turning on the pulsed power system of the main diode. A pulse powered (rise time is about 5 ms) one-layer solenoid is used to produce the uniform guide field, typically of 200-300 G.

2.2. GENERATION OF HIGH-CURRENT BEAMS IN THE DIODE WITH PLASMA ANODE

Measurements were performed under the next conditions. Plasma anode was created by 3 A (to both sides) 300 V auxiliary electron beam of 7 μs duration in the external magnetic field of 300 G. Capacitor bank was charged to the same voltage of 22 kV, the pressure of residual gas was about $(1 – 2)\times10^{-3}$ Torr.

Fig. 2 shows forms of the voltage and current pulses of auxiliary gun with and without the cathode heating. The peak voltage on the gun with emission is 250 V. It decreases rapidly to about 80 V due to shunting of the source by the resistance of created plasma. To verify it we simulated the influence of created plasma by external load commuted by a switch. Two upper traces in Fig. 3 show the same as in Fig. 2: the voltage with load of 5 Ω and without it. The third trace is shunt current and the forth – trigger pulse of the switch.

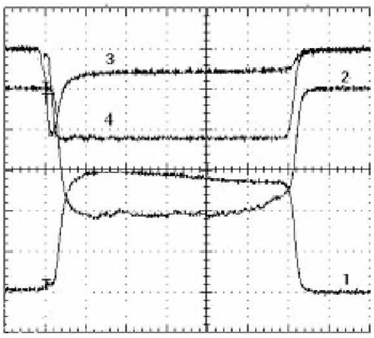

Fig. 2. Voltage and current pulses of the auxiliary gun: 1- total (6 A) emission current; 2 - current measured by the collector (3 A); 3 - voltage under emission of current; 4 - voltage without emission of the current (250 V); the division is 1 μs

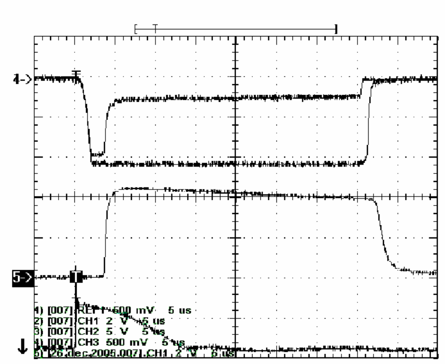

Fig. 3. Voltage pulses of the auxiliary gun with fixed external load

Fig. 4 describes low-impedance plasma system on the whole beginning since firing of high-voltage pulsed supply.

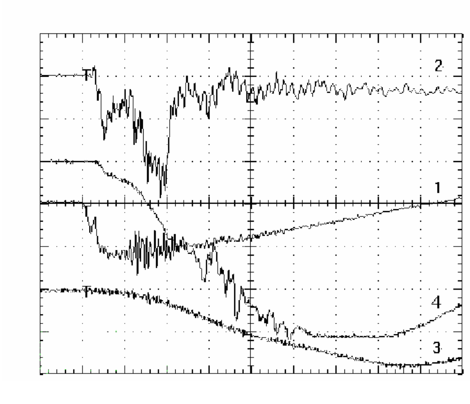

Fig. 4. Accelerating voltage (trace 1) with amplitude 22 kV, beam current measured by the collector with amplitude 11.5 kA (trace 2), integrated signal of azimuths magnetic field sender (trace 4), total current measured Rogowsky coil (trace 3) at the input of high-current diode; the division is 200 ns

Maximum amplitude of high-current beam measured by the collector reaches 12 kA under the voltage as higher as 18 kV. Integrated signal of azimuths magnetic field sender is observed simultaneously with collector signal. The total duration of the current pulse is 1.6 μs and full duration at half maximum is about 400 ns. The time delay of the collector current relative the beginning of the accelerating voltage reaches 80 ns and corresponds to 16 – 18 kV level of the accelerating voltage.

3. COMPUTER SIMULATION

Generation of high-current beam was investigated on smaller model of the setup. We considered the half of the setup between high-current and low-current cathodes. Diameter of explosive emission cathode was chosen equals to 1 cm. At initial time the plasma column has the same diameter and fills completely space in longitudinal direction between explosive emission cathode and anode placed instead of auxiliary gun. The voltage has the given form. It rose up to 20 kV for different time (from 1 to 10 ns) and was constant further. Output of electrons was permitted from cathode and anode surface surfaces into plasma if accelerating field has exceeded a given value. Calculations were performed for hydrogen, nitrogen and xenon plasmas for different values of external longitudinal magnetic field and for two different length of the plasma diode (2 and 10 cm). Results below are presented only for xenon plasmas with density $7\times10^{13}\,\text{cm}^{-3}$. Fig. 5 shows forms of current pulses for external magnetic fields 500 Gs and 5 kGs.

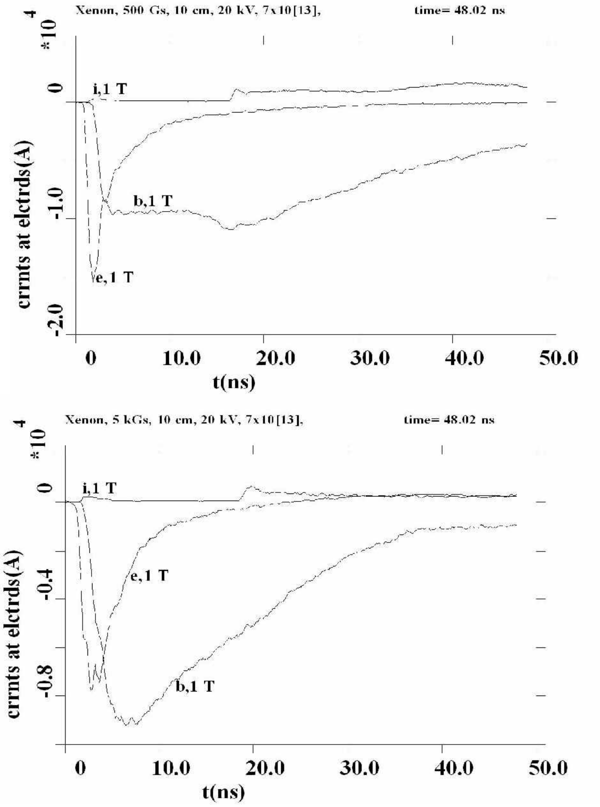

Fig. 5. Forms of beam (b), plasma electrons (e) and ion (i) currents on the anode

In low magnetic fields pinched state of the beam-plasma system is formed. Beam electrons force plasma electrons out to electrodes in longitudinal direction, beam electrons are pinched to the axis of the system by self magnetic field exceeding significantly external one, and near axis ion pivot is formed. Such state of beam-plasma system exists for about 10 – 20 ns and further it goes to annular configuration of plasma ions and electron beam. These results differ from experimental ones. First of all, the calculated duration of beam current is significantly smaller. It can mean the dominated influence of longitudinal motion and density of explosive plasma on the beam pulse duration.

Energy spectrum and transverse distribution of beam current are of importance from the point of view of different applications. Calculation shows that energy spectra of beam electrons reaching the target is changed and become wide enough. Fig. 6 shows typical form of the spectra.

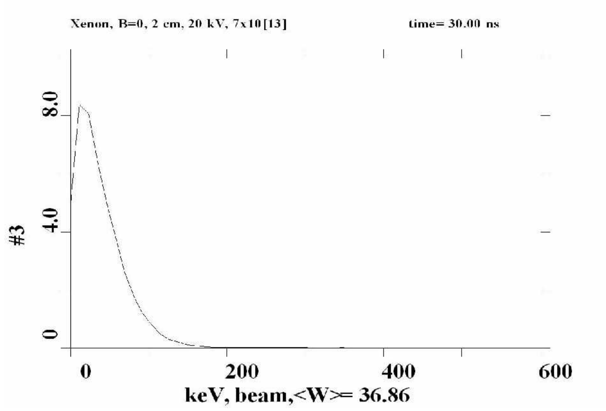

Fig.6. Form of the spectra

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ГЕНЕРАЦИЯ СИЛЬНОТОЧНЫХ НИЗКОЭНЕРГЕТИЧЕСКИХ ЭЛЕКТРОННЫХ ПУЧКОВ В ПЛАЗМЕННЫХ СИСТЕМАХ И ВЗАИМОДЕЙСТВИЕ ПУЧКОВ С ПЛАЗМОЙ

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Дан обзор результатов экспериментальных исследований и численного моделирования генерации низкоэнергетических (с энергией в десятки килоэлектронвольт) сильноточных (с токами в десятки килоампер) электронных пучков в плазмонаполненной системе с протяженным плазменным анодом и динамики всей системы в целом. Слаботочный низковольтный пучок от вспомогательного катода, находящегося во внешнем продольном магнитном поле, используется для создания протяженного плазменного анода в остаточном газе. Сильноточный электронный пучок формируется со взрывоэмиссионного катода, соприкасающегося со сформированной плазмой. Особенности системы связаны с формированием сильноточного пучка с плотностью частиц, сравнимой с плотностью плазмы, и током, превышающим предельный ток Альфвена, что резко усложняет характер пучково-плазменного взаимодействия в процессе транспортировки сильноточного пучка вдоль протяженного плазменного анода за счет резко выраженного поперечного движения и неоднородного распределения тока пучка.

ГЕНЕРАЦІЯ ПОТУЖНОСТРУМОВИХ НИЗЬКОЕНЕРГЕТИЧНИХ ЕЛЕКТРОННИХ ПУЧКІВ У ПЛАЗМОВИХ СИСТЕМАХ І ВЗАЄМОДІЯ ПУЧКІВ ІЗ ПЛАЗМОЮ

О.В. Агафонов, В.А. Богаченков, О.С. Сулейманов, В.П.Тараканов

Дано огляд результатів експериментальних досліджень і чисельного моделювання генерації низько-енергетичних (з енергією в десятки кілоелектронвольт) потужнострумових (зі струмами в десятки кілоампер) електронних пучків у наповненій плазмою системі з протяжним плазмовим анодом і динаміки всієї системи в цілому. Слабкострумовий низьковольтний пучок від допоміжного катода, що знаходиться у зовнішньому подовжньому магнітному полі, використовується для створення протяжного плазмового анода в залишковому газі. Потужнострумовий електронний пучок формується з вибухоемісійного катода, що стикається зі сформованою плазмою. Особливості системи зв'язані з формуванням потужнострумового пучка з щільністю часток, порівняної з густиною плазми, і струмом, який перевищує граничний струм Альфвена, що різко ускладнює характер пучково-плазмової взаємодії в процесі транспортування потужнострумового пучка уздовж протяжного плазмового анода за рахунок різко вираженого поперечного руху і неоднорідного розподілу струму пучка.