ELECTRON BEAM GENERATION IN A LOW-IMPEDANCE SYSTEM

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Results of computer simulation of low-energy high-current electron beam generation in a low-impedance system consisting of plasma-filled diode with a long plasma anode, an auxiliary thermionic cathode, and an explosive emission cathode are given. The auxiliary cathode is used to form the long plasma anode by means of residual gas ionization by a low-current low-voltage electron beam (currents of amperes, voltage of hundred volts) in an external longitudinal magnetic field. The high-current low-energy electron beam (currents of tens kA, voltage of tens kV) is generated from the explosive emission cathode embedded in prepared plasma. The long plasma anode presents simultaneously a transport channel providing charge neutralization of high-current beam. Computer simulation is performed using PIC code KARAT for different geometry and position of auxiliary cathode. Computer results are compared with experimental data. Work supported by RFBR under grant 05-02-16442.

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1. INTRODUCTION

Plasma-filled diodes with explosive cathodes have been proposed and shown its effectiveness to generate high-current low-energy electron beams of microsecond duration are of importance for surface modification [1-6]. However, theoretical analysis of a complicated beam-plasma system under condition of low voltage and high current of the beam is difficult. Existed idea is based on an origin of thin double-layer between cathode and anode plasma just after the beginning of accelerating voltage pulse. The full voltage applied is localized in this layer making possible the beginning of the explosive emission from the cathode surface. The length of accelerating gap is about plasma skin depth and exceeds considerably the Debay length at initial time until electron plasma temperature considerably increases. Plasma serves as a “liquid” anode preventing the system from collapses of impedance on the one hand and as a channel to guide a high-current beam on the other hand providing a charge and/or current neutralization of the beam and its transport to a target. A location of the gap at the next moment is uncertain because of the motion of cathode explosive plasma that has a considerable density gradient and changes its ionization degree under influence of the generated beam.

The system as a whole can be characterized as a multi-component system with alternating number of particles and cannot be described by regular theoretical methods. The main difficulties of its theoretical description are due to multistage of processes (creation of a plasma column by one of the various methods and then utilization of plasma as an anode) and comparable plasma and generated electron beam densities. The latter does not allow considering a beam influence on plasma due to small perturbations. Therefore, computer simulation was used to describe the physical processes.

In our experiments to create a well-defined plasma channel we use a residual gas ionization by an additional pulsed low-energy (~300 eV), low-current (~1…3 A) electron beam guided by a 200…300 G magnetic field. The beam with maximum current of 11.5 kA was generated under voltage 20 kV in system schematically shown in Fig.1 [7–10].

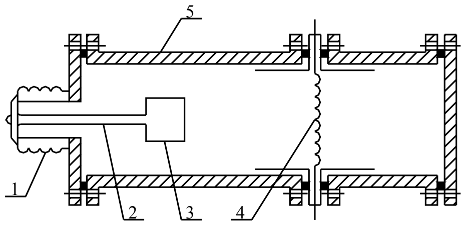

Fig.1. Schematic diagram of the experimental setup: 1 - input isolator of high-current diode; 2 – cathode stem; 3 – cathode of high-current diode; 4 - thermocathode of low-current beam; 5 – vacuum chamber with solenoid

2. COMPUTER SIMULATION OF HIGH-CURRENT BEAM GENERATON IN PLASMA FILLED DIODE

Formation of the plasma anode in residual gas by an auxiliary electron beam was calculated as the first step in comparison of numerical and experimental data including plasma density distribution and behavior of the auxiliary beam current reaching the collector. Calculated and measured shapes of the current pulse and plasma parameters have shown a well agreement. These results are omitted here.

Generation of high-current beam was investigated on a smaller model of the setup. We considered the half of the setup located between high-current and low-current cathodes. Diameter of explosive emission cathode was chosen to be 1 cm (2 times lesser). At initial time the plasma column had the same diameter and completely filled the space in longitudinal direction between the explosive emission cathode and anode placed instead of an auxiliary gun. The plasma density was homogeneously distributed along longitudinal *z* and radial *r* coordinates. Presented below are the results for plasma density 3.5×10^{13} cm^{-3}. Initial temperature of plasma varied from several to tens electronvolts. The voltage had the given shape. It rose up to 20 kV during 10 ns and then remained constant. If the accelerating field exceeds some given value, electrons could be emitted from the cathode and anode surface into the plasma. Calculations were performed for hydrogen, nitrogen, and xenon plasmas at different values of the external longitudinal magnetic field and two different lengths of the plasma diode (2 and 10 cm). Fig.2 shows the geometry under consideration with plasma column at initial time.

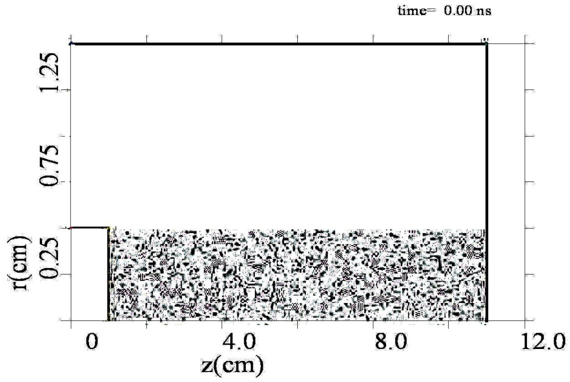

Fig.2. Configuration of the diode with plasma anode

2.1. SMALL-LENGTH DIODE

To estimate the scale of the current and the influence of external magnetic field and plasma composition we performed series calculation for a diode of smaller length (2 cm instead of 10 cm shown in Fig.2). Fig.3 (upper part) shows the behavior of the number of plasma ions (i) and electrons (e) and beam electrons (b) inside the diode for the case of hydrogen plasma and magnetic field of 500 G. Corresponding currents on the anode surface of 1 cm diameter are shown in bottom part.

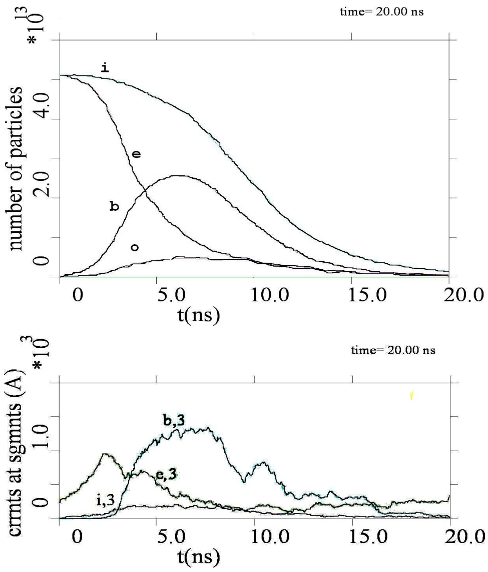

Fig.3. Dynamics of particles number and particle currents for the case of hydrogen plasma

Maximum beam current reaches about 1.5 kA and plasma electron current has about the same value, i.e. the total peak current equals to 3 kA. Energy spectra of both electron components are broad. Energy is distributed from small energy to energy exceeded an applied voltage by several times. Time duration of beam current is small because of fast departure of light ions to electrodes and decrease of the accelerating field within widening gap. Magnetic field increase up to 5 kG allows obtaining a slightly larger beam current of about the same duration because ion longitudinal motion starts to play a major role.

The choice of a heavier gas (e.g. Xe) considerably improves both the beam current duration and the current amplitude. Results for the case of Xe at the same magnetic field of 500 G are shown in Fig.4.

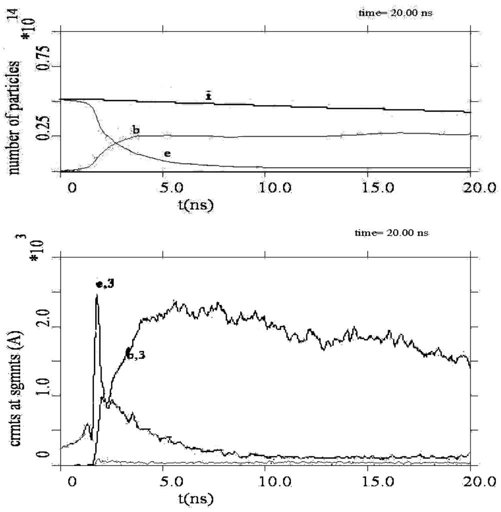

Fig.4. Dynamics of particles number and particle currents for the case of Xe plasma

2.2. FULL-LENGTH DIODE

A full-length diode (Fig.2) has the plasma anode length of 10 cm. Calculation results obtained for the case of hydrogen plasma at the magnetic field of 5 kG are shown in Figs.5,6.

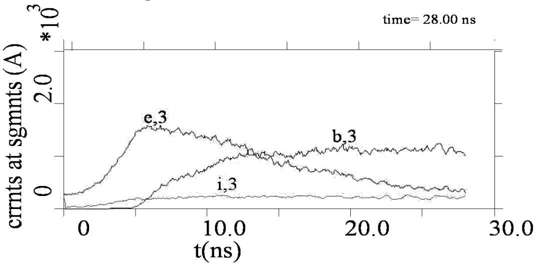

Fig.5. Dynamics of particle currents in full-length diode for the case of hydrogen plasma

The beam behavior in the full-length diode did not differ much if compared with the small length diode case. The only parameter that was changed significantly is the beam current duration. It increased by several times (up to 60 ns). However, the peak current of the beam remained at about the same level.

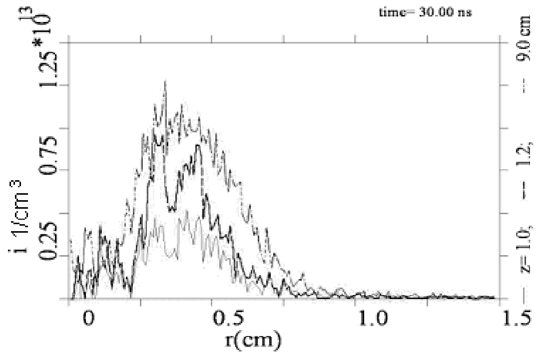

Fig.6. Transverse distribution of ion density

As noted above, the main reason is the small accelerating field in the gap filled by light ions. Moreover, transverse beam dynamics starts influence the beam propagation within the plasma channel as the beam current becomes comparable with the Alfven's limiting current. A half of the beam current reaches the anode outside the marked area of 1-cm diameter. Transverse distributions of the plasma ions and beam electrons are transformed from uniform to a hollow one (Fig.6). Energy spectra of electrons and ions are changed and become broad enough.

Calculations for the case of nitrogen or xenon plasma show more complicated pictures because of a significant accelerating field increase within a gap as well as beam current increase.

3. CONCLUSION

Results of computer simulation of low-energy high-current electron beam generation in a plasma-filled diode with a long plasma anode are presented for various plasma compositions and magnetic field values. Physical processes in such a system are discussed as for obtaining the given beam parameters for some applications.

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ГЕНЕРАЦИЯ ЭЛЕКТРОННОГО ПУЧКА В НИЗКОИМПЕДАНСНОЙ СИСТЕМЕ

А.В. Агафонов

Приведены результаты численных экспериментов по генерации низкоэнергетичного сильноточного электронного пучка в низкоимпедансной системе, включающей в себя плазмонаполненный диод с протяженным плазменным анодом, вспомогательный термокатод и взрывоэмиссионный катод. Слаботочный, низковольтный пучок от вспомогательного катода, находящийся во внешнем продольном магнитном поле, используется для создания протяженного плазменного анода, одновременно представляющего собой и канал для транспортировки пучка, посредством ионизации остаточного газа. Сильноточный электронный пучок (ток до десятка килоампер при напряжении в десятки киловольт) формируется с взрывоэмиссионного катода, погруженного в предварительно сформированную плазму. Численное моделирование проведено с помощью PIC-кода КАРАТ для различных геометрий и положений вспомогательного катода. Работа выполнена при поддержке РФФИ по гранту 05-02-16442.

ГЕНЕРАЦІЯ ЕЛЕКТРОННОГО ПУЧКА В НИЗКОІМПЕДАНСЬНІЙ СИСТЕМІ

А.В. Агафонов

Наведено результати чисельних експериментів по генерації низькоенергетичного потужнострумового електронного пучка в низькоімпедансьній системі, що включає в себе плазмозаповнений діод із протяжним плазмовим анодом, допоміжний термокатод і вибухоемісійний катод. Слабкострумовий, низьковольтний пучок від допоміжного катода, що перебуває в зовнішнім поздовжнім магнітному полі, використається для створення протяжного плазмового анода, що одночасно представляє собою і канал для транспортування пучка, за допомогою іонізації залишкового газу. Потужнострумовий електронний пучок (струм до десятка кілоампер при напрузі в десятки кіловольт) формується із вибухоемісійного катода, зануреного в попередньо сформовану плазму. Чисельне моделювання проведене за допомогою PIC-коду КАРАТ для різних геометрій і положень допоміжного катода. Робота виконана за підтримкою РФФІ по гранту 05-02-

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