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

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Results of experimental investigations of low-energy high-current electron beam generation in a plasma-filled diode with a long plasma anode and an explosive emission cathode are given. An additional low-current electron beam was used to form the long plasma anode by means of the residual or prefilled gas ionization. The long anode is used simultaneously as the transportation channel with predictable parameters of plasmas. Low-current additional beam is emitted from the thermionic cathode, which can have different geometric form. The solution developed provides to create radial profiled plasmas channels of desired plasmas density distribution with a high reproducibility. Work supported by RFBR under grant 05-02-16442.

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INTRODUCTION

Low-energy (of tens keV) high-current (of tens kA) electron beams are applied for surface modification. For these purposes plasma-filled diodes with explosive cathodes capable to generate high-current low-energy electron beams of microsecond duration with energy densities up to 10…40 J/cm^2 were developed [1-12]. In a plasma pre-filled diode an electron beam is generated 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 localized in this layer making possible the beginning of the explosive emission from a cathode surface.

To create a well defined plasma channel we use a residual gas ionization by additional pulsed low-energy (~300 eV), low-current (~(1…3) A) electron beam guided by a (200…300) G magnetic field. The main advantages of this method are the high reproducibility and the flexibility of an operative control of the plasma.

EXPERIMENTAL SETUP

A simplified diagram of the experimental setup is shown in Fig.1.

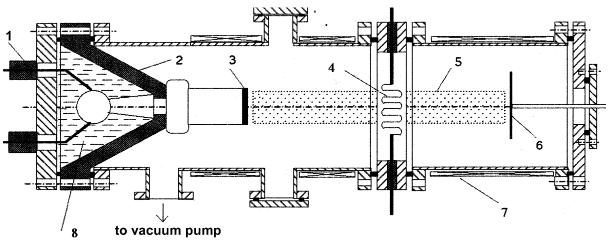

Fig.1. Scheme of the setup: 1 – HV input cables; 2 - isolator; 3 – cathode of high-current diode; 4 - thermocathode of low-current beam; 5 – plasma channel; 6 – collector; 7 – vacuum chamber

The high accelerating 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. A plasma channel is formed by a low-energy electron beam generated by a simple greedless electron gun (e-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 to the grounded chamber. The biasing voltage pulse of 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.

Under 20 kV diode voltage the peak currents of 0.6 up to several kA with duration from 0.2 μs up to 0.8 μs of the electron beam downstream of e-gun was recorded in preliminary experiments [11,12].

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

Plasma channel dynamics was observed using by experimental measured dynamics of the impedance of low-current thermocathode gun during the pulse of accelerating voltage. The changing of the impedance under condition of constant biasing voltage shows the changing of effective cathode-anode gap and gives the information about dynamics gas ionization for different pressure. The measurements performed in a wide area of parameters show that the beam current has changed during the pulse.

The shape of the density profile of the plasma channel depends on the geometry of the e-gun tungsten wire and may be adjusted to the desired one by the shaping of the thermocathode wire. During the experiments the plasma column profile was measured for different shapes of tungsten wires. For the high-current beam generation experiments it has been chosen a zigzag-like flat thermocathode with a working area of about 3 cm in diameter consisting of 7 zigzags or 0.5 mm diameter tungsten wire. As it was seen from data obtained it created the plasma channel with a “flat top” and rather sharp edges density profile.

Measurements were performed under the next conditions. Plasma anode was created by 3-A (in 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)×10^{-3} Torr.

Fig.2 shows forms of the voltage and current pulses of auxiliary gun with and without the cathode heating. The division is 1 μs.

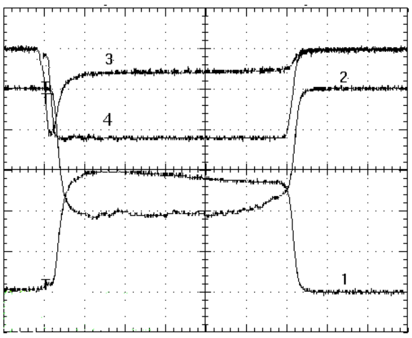

Fig.2. Voltages and currents pulses of the auxiliary gun: 1 - total (6 A) emission current; 2 – current measured by the collector (3 A); 3 - voltage with 2×3 A emission currents; 4 - voltage without emission of a current (250 V)

The peak voltage on the gun with emission is 250 V and rapidly decreases to about 80 V in saturated regime due to internal resistance of the supply and resistance of created plasma.

Fig.3 illustrates form of the pulses under condition of turned off auxiliary gun. The division is 1 μs.

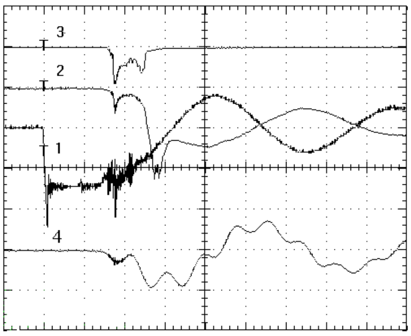

Fig.3. Accelerating voltage (curve 1) of 3.2 μs duration with amplitude 22 kV, 1.8 μs time delayed collector current with amplitude 90 A (curve 3) and signal of azimuths magnetic field (curve 2). Current measured Rogowsky coil (curve 4)

A beam collector is moveable and may be replaced by set of Langmuir probes to measure the plasma column parameters. Two resistive shunts and two Rogovsky coils are used for the beam current measurements at different positions – at high-voltage insulator upstream of the diode, at the low-voltage e-gun flange and at the end of the chamber. An outer resistive divider, connected to the high-voltage collector located in oil, measures the diode voltage. High-voltage pulse started just after the finishing of the pulse voltage of auxiliary gun. Azimuthal magnetic field of the high-current beam was measured additionally by screened solenoid coil placed inside the vacuum chamber near the collector.

Fig.4 describes low-impedance plasma system on the whole beginning since firing of high-voltage pulsed supply. The division is 200 ns.

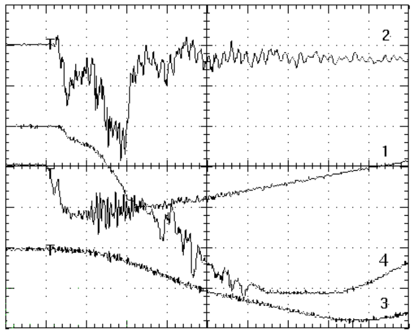

Fig.4. Accelerating voltage (curve 1) with amplitude 22 kV, beam current measured by the collector with amplitude 11.5 kA (curve 2), integrated signal of the azimuths magnetic field sender (curve 4), total current measured Rogowsky coil (curve 3) at the input of high-current diode

Maximum amplitude of high-current beam measured by the collector reaches 11.5 kA under the voltage as higher as 18 kV. An integrated signal of the azimuths magnetic field sender is observed simultaneously with a 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. It confirms the existence of a narrow accelerating gap near the cathode surface and the absence of impedance collapse due to the presence of rather dense plasma column. Maximum of current registered by Rogowsky coil corresponds to the minimum of accelerating voltage on the diode and equals to about 8 kA.

CONCLUSION

These experiments have shown the possibility of generation of high-current electron beams in low-impedance plasma system even at accelerating voltage as low as 20 kV. Peak current of 11.5 kA with duration about 0.4 μs was recorded. The result ought to consider as preliminary and it must be confirmed additionally by independent measurements and analyses. First of all it is necessary to observe bremsstrahlung signals simultaneously with beam current on collector to compare the duration of both. Moreover, an energy spectrum and transverse distribution of beam current are of importance from the point of view of different applications.

To increase energy density of the beam up to necessary values needed for surface modifications the accelerating voltage has to be increased up to 50…70 kV and the duration of beam current has to be increased to 1 μs. This task demands designing and construction a new experimental setup. Some more problems of generation of curved plasma channel and generation of high-current electron beam in a diode with curved anode must be taking into account in it.

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ГЕНЕРАЦИЯ СИЛЬНОТОЧНОГО НИЗКОЭНЕРГЕТИЧЕСКОГО ЭЛЕКТРОННОГО ПУЧКА В ПЛАЗМЕННОЙ СИСТЕМЕ

А.В. Агафонов, В.А. Богаченков, Е.Г. Крастелев

Приведены результаты экспериментов по генерации низкоэнергетического сильноточного электронного пучка в плазмонаполненном диоде с протяженным плазменным анодом. Для создания протяженного плазменного анода, одновременно представляющего собой и канал для транспортировки пучка, используется ионизация напущенного в систему газа вспомогательным слаботочным пучком электронов. Для генерации сильноточного пучка используются различные «взрывоэмиссионные» катоды. Создание плазмы вспомогательным электронным пучком, эмиттируемым с термокатода (энергия в сотни электронвольт при токе в единицы ампер), форма которого может варьироваться, позволяет формировать плазменные каналы с различным поперечным профилем с высокой воспроизводимостью. Работа выполнена при поддержке РФФИ по гранту 05-02-16442.

ГЕНЕРАЦІЯ ПОТУЖНОСТРУМОВОГО НИЗЬКОЕНЕРГЕТИЧНОГО ЕЛЕКТРОННОГО ПУЧКА В ПЛАЗМОВІЙ СИСТЕМІ

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Наведено результати експериментів по генерації низькоенергетичного потужнострумового електронного пучка в плазмозаповненому діоді із протяжним плазмовим анодом. Для створення протяжного плазмового анода, що одночасно є каналом для транспортування пучка, використається іонізація напущеного в систему газу допоміжним слабкострумовим пучком електронів. Для генерації потужнострумового пучка використаються різні "вибухоемісійні" катоди. Створення плазми допоміжним електронним пучком, що емітується з термокатода (енергія в сотні електронвольт при струмі в одиниці амперів), форма якого може варіюватися, дозволяє формувати плазмові канали з різним поперечним профілем з високою відтворюваністю. Робота виконана за підтримкою РФФД по гранту 05-02-16442.