HIGH-CURRENT ELECTRON BEAM GUIDING BY THE CREATION OF PROFILED PLASMA CHANNEL

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Earlier performed experiments showed effectiveness of proposed approach for a high-current non-relativistic electron beam generation in a plasma-filled diode with a plasma anode and an explosive emission cathode. Our approach is based on the application of an additional low-current electron beam. This beam is used for the plasma anode and the transportation channel generation with predictable parameters of plasmas by the residual or prefilled gas ionization.. Measurements of plasma channel parameters in a wide region of experimental conditions confirm that this approach possesses to create radial profiled plasmas channels of desired plasmas density distribution for generation and transport of high-current beams.

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1. INTRODUCTION

Low-energy (10…40 keV) high-current (1…20 kA) electron beams are of great interest of researches on material treatment, in particular, surface modification. Earlier studies on surface modification were concentrated on the application of high-power ion beams. The situation was significantly changed with a successful development of 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 [1,2]. In the 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. Typically a set of arc-type plasma guns installed at an anode ring-shape electrode is used as a plasma source to fill the diode region and a beam drift chamber [1-4,6]. The erosion sources have a number disadvantages: parameters of plasmas are not well reproducible, a powerful system for high-current arcs ignition is needed, a plasma cloud is non-uniform and fills a limited part of a drift chamber, etc. One known solution of the problem is based on the anode and drift chamber plasmas generation by a pulse reflective (Penning) gas-discharge. It was developed and successfully tested by authors of [3,5]. We are developing another new approach to solve the problems mentioned. It is based on the using of an additional pulsed low-energy (~300 eV), low-current (~1 A) electron beam guided by a 200…300 G magnetic field to create a well defined plasma channel inside a drift chamber and in a diode region by a residual or pre-filled gas ionization. The main advantages of this method are the high reproducibility and the flexibility of an operative control of plasma parameters. The other one is the generation of a well-limited in radial direction plasma column with a well-defined position.

2. EXPERIMENTAL SETUP

A test stand was designed and constructed for initial experimental studies of performances of a new plasma-filled diode and effects of the beam propagation. A simplified diagram of the experimental setup is shown in Fig.1.

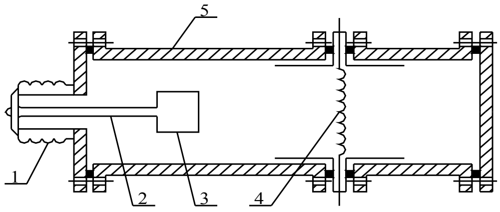

Fig.1: Schematic diagram of the experimental setup: 1 – input isolator of high-current diode; 2 – cathode stem; 3 – cathode of high-current diode; 4 – thermo-cathode of low-current beam; 5 – vacuum chamber with solenoid

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 ring-shape anode electrode (grounded diaphragm) of 30-mm aperture is placed 1 - 4-cm downstream from the cathode (not shown in Fig.1). A plasma channel is formed by low-energy electron beam generated by a simple greed-less 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 of the grounded chamber. The biasing voltage pulse (5…10 μ s) is applied prior to turning on the pulsed power system of the main diode. The wire heating current is AC and is provided by a simple split transformer. A pulse powered (rise time is about 5 ms) one-layer solenoid with additional compensating coils near the e-gun flanges is used to produce the uniform guide field, typically of 200…300 G.

The form of the thermocathode is shown in Fig.2. Fig.3 shows calculated magnetic field distribution along axis of the system (above) and the area occupied by electrons of low-current beam (below).

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.

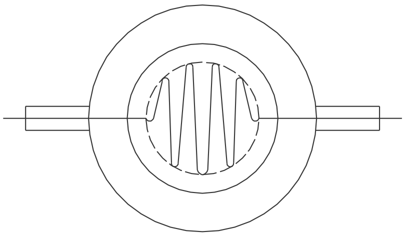

Fig.2. Schematic diagram of the thermocathode with zigzag W-filament in chamber cross-section

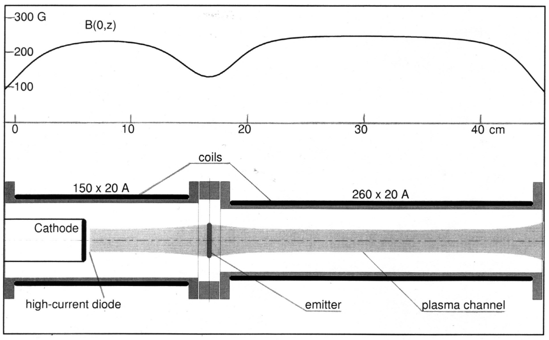

Fig.3. Magnetic field distribution and envelope of low-current electron beam

3. EXPERIMENTAL RESULTS AND METHODOLOGY

At the first stage of the experiments parameters of the plasma column generated by the low-voltage beam were measured in a wide range of the experimental conditions (residual gas pressure, biasing voltage, tungsten thermocathode geometry, etc.) to find out the optimal regimes for all components.

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 wide area of parameters show that the beam current changed during the pulse.

The typical pulses of the thermocathode biasing voltage U, emitted e-beam current I_e and e-beam measured by the end located collector I_c for the pressure of residual gas of $5 \cdot 10^{-5}$ Torr are presented in Fig.4. As can see, the emitted by thermionic cathode current I_e is rising by many times during the 10 μs constant biasing voltage pulse. At initial time it is closed to calculated value under condition spherical form of anode equipotential curves with radius equals radius of the chamber and did not exceed several mA. The beam current growth during the pulse up to the saturated current of thermoemission could be varied from 100 to 1000 mA. The propagated e-beam current measured by the collector I_c is rising almost proportional to the emitted current I_e.

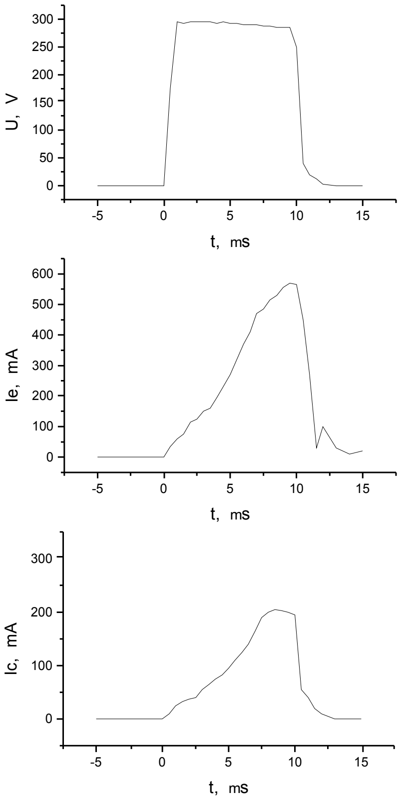

Fig.4. The typical pulses of biasing voltage U, emitted current I_e collector current I_c for the pressure of residual gas of $5x10^{-5}$ Torr

The form of rising parts of the current pulses is close to exponential one with constant depending on the pressure of the residual (filling) gas. Fig.5 shows the collector current waveforms for several values of the gas pressure: 1 for $p=4 \cdot 10^{-5}$ Torr, 2 - $p=10^{-4}$, 3 - $2 \cdot 10^{-4}$ and 4 - for $p=5 \cdot 10^{-4}$ Torr.

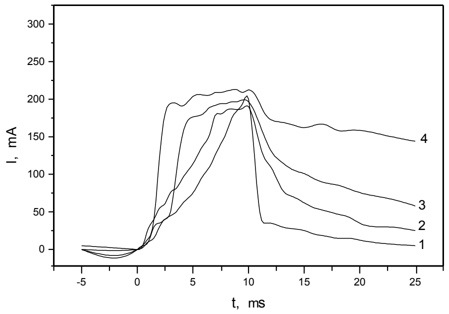

Fig.5. Collector current waveforms for different values of the gas pressure (see the text above)

Measured value of saturated current was used for estimation of effective cathode-anode gap between the cathode and plasma channel. These data correspond to the plasma channels exited by the e-gun with 7-segment zigzag-like tungsten wire of 0.2-mm diameter with full length 20 cm. The internal diameter of supporting diaphragm shown in Fig.2 equals 20 mm. Under these conditions the saturated thermoemission current equals approximately 0.6…1 A.

The channel plasma density was measured using Langmuir probes with 0.5-cm and 1-cm long and 0,5-mm and 1-mm diameter tungsten wire. During the measurements the probe wires were oriented parallel or normal to the applied magnetic field. Measurements were done at two positions of the probes – near the diode region and 10-cm upstream from the end of the drift chamber. The same data obtained for both sets of probes showed that the plasma column has approximately the same parameters from both sides of e-gun. The peak ion densities derived from the ion saturation current were about $10^{11}…10^{12}$ cm^{-3} for a probe bias of – 200 V and the pressure of a residual gas of 0,1…1 mTorr. These data correspond to the plasma channels exited by the e-gun with a zigzag-like tungsten filament biased to – 300 V with respect to the grounded wall of the vacuum chamber and for the total emission current (measured in the filament biasing circuit) approximately 1A. For given experimental conditions the data of the measurements were well reproducible – the variations from pulse to pulse were well less than uncertainties of measurements.

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 first 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 of 0,3 or 0,5-mm diameter tungsten wire. As is seen from the data obtained it created the plasma channel with a “flat top” and rather sharp edges of a density profile. The optimal shape of the wire will be found using the experimental data on the high-current e-beam profile measurements.

Firings of the high-current diode were done at a 20 kV diode voltage. For an optimal time-delay between e-gun biasing voltage pulse and the beginning of the high-voltage pulse a peak current of 0.6 up to approximately 5 kA with duration from 0.2 µs up to 0.8 µs of the electron beam downstream of e-gun was recorded.

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УПРАВЛЕНИЕ ТРАНСПОРТИРОВКОЙ СЭП ПУТЕМ ФОРМИРОВАНИЯ ПРОФИЛИРОВАННОГО ПЛАЗМЕННОГО КАНАЛА

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

Проведенные ранее эксперименты по генерации плазменных каналов с контролируемым профилем плотности по радиусу для генерации низкоэнергетичного сильноточного электронного пучка в плазмонаполненном диоде с протяженным плазменным анодом показали эффективность предложенного подхода. В данной системе для генерации плазменного анода и канала транспортировки с заданными параметрами в результате ионизации остаточного или специально напущенного в систему газа использован вспомогательный слаботочный пучок электронов. Измерения параметров плазменного канала в широком диапазоне экспериментальных условий показывают, что такой метод позволяет создавать радиально ограниченные каналы с необходимой для получения сильноточных пучков плотностью с различным распределением ее по сечению.

КЕРУВАННЯ ТРАНСПОРТУВАННЯМ СЭП ШЛЯХОМ ФОРМУВАННЯ ПРОФІЛЬОВАНОГО ПЛАЗМЕННОГО КАНАЛУ

А.В. Агафонов, В.А. Богаченков, Є.Г. Крастельов

Проведені раніше експерименти по генерації плазмових каналів з контрольованим профілем густини по радіусі для генерації низькоенергетичного потужнострумового електронного пучка в плазмозаповненному діоді з протяжним плазмовим анодом показали ефективність запропонованого підходу. У даній системі для генерації плазмового анода і каналу транспортування з заданими параметрами в результаті іонізації залишкового або спеціально напущеного в систему газу використаний допоміжний слабкострумовий пучок електронів. Вимірювання параметрів плазмового каналу в широкому діапазоні експериментальних умов показують, що такий метод дозволяє створювати радіально обмежені канали з необхідної густиною для одержання потужнострумових пучків з різним розподілом густини по перерізу пучка.