HIGH-CURRENT NON-RELATIVISTIC ELECTRON BEAM GENERATION AND TRANSPORT

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INTRODUCTION

Low-energy (10-40 keV) high-current (1-20 kA) electron beams are of great interest for 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 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. 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 [1-3]. 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, 4]. We are developing another a 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.

EXPERIMENTAL SETUP AND FIRST RESULTS

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 schematic diagram of the experimental setup is shown in Fig.1.

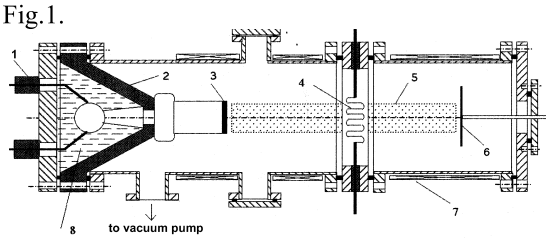

Fig.1. Schematic diagram of the experimental setup.

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 (1), connected to a cathode electrode supported by a high-voltage insulator (2). At the other end of this electrode a flat graphite cathode (3) is installed. A ring-shape anode electrode (grounded diaphragm) is placed 2-4-cm downstream from the cathode (not shown in Fig.1). A plasma channel (5) is formed by low-energy electron beam generated by a simple greed-less electron gun (e-gun) with filament-type thermocathode (4) 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 μs) 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 (7) with additional compensating coils near the e-gun flanges is used to produce the uniform guide field, typically of 200-300 G. Shown in Fig.1 a beam collector (6) 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 (8), measures the diode voltage.

Fig.2 shows the general view of the test stand after replacement of the plastic insulator shown in Fig.1 by a new ceramic one (visible at the left side).

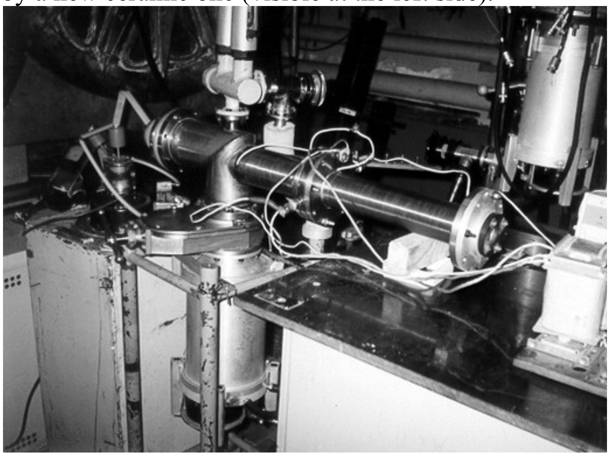

Fig.2. The test stand view.

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.

The channel plasma density was measured using Langmuir probes with 1-cm long and 0,5-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 –300V 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 it was seen from data obtained it created the plasma channel with a “flat top” and rather sharp edges density profile. The optimal shape of the wire will be found using the experimental data on the high-current e-beam profile measurements will have to be done during the next step of the experiments.

First firings of the high-current diode were done at 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 4,2 kA of the electron beam downstream of e-gun was recorded.

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