THE FORMATION OF NEAR ANODE DOUBLE LAYER IN HIGH-CURRENT PLASMA DIODE OF LOW PRESSURE

A.F. Tseluyko, D.V. Zinov'ev, V.N. Borisko, V.A. Tseluyko, A.A. Drobishevskaya

Kharkov National University, 61108, 31 Kurchatov Av., Kharkov, Ukraine,
E-mail: Borisko@pht.univer.kharkov.ua

A plasma electron source on the basis of a pulse plasma diode of low pressure with an extended interelectrode gap has been experimentally investigated. The basis of a plasma electron source serves a gas discharge of a new type - self-maintained beam-plasma discharge, which distinctive feature is the forming of a double electrical layer of a space charge in a discharge gap and generation of an intensive electron beam. The exterior parameters were determined, at which formation of a double layer and the acceleration of an electron beam in such discharge occurs immediately at working area of the anode.

The plasma electron source is calculated on generation of an electron beam with the energy $10^4 \ldots 10^5$ *eV* at the current 2…3 *kA*, current density 200…300 A/cm^2, pulse length 1…10 μs and efficiency of conversion of an exterior electric field energy into an electron beam energy up to 80%.

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INTRODUCTION

Formation of the double layer in a high-current arc discharge of low pressure, which is accompanied by sharp increase of discharge voltage, is not simple change of discharge parameters but transition to new kind of a self-maintained discharge in gas - independent beam-plasma discharge (IBPD) [1]. Such discharge is following after arc (according to Fransis scale [2]) new kind of an independent gas discharge. In IBPD electrons are emitted from the cathode similar to arc discharge by the cathode spots, and the carry of a current is performed by an electron beam similar to beam-plasma discharge with external injection of an electron beam.

Two types of independent beam-plasma discharge exist: K - discharge and M - discharge, which differ by a place of double layer localization and dynamics of processes [3]. In case of K - discharge the double layer is at the front of the dense plasma of cathode spots [4], which "wrings out" rather rare plasma of an interelectrode interspace from the cathode. The localization of the double layer in an interelectrode interspace in the region of the least current conductivity of a plasma column is the property of M - discharge [5].

At creation of a plasma electron source on the basis of an extended plasma diode of low pressure for lowering power losses of an electron beam in plasma it is necessary to form the double layer directly near the surface of the anode. In this case the electrons, accelerated in the double layer, at once fall on the anode. Thus, the greatest conversion coefficient of electrical field energy in an electron beam energy is reached, as the energy losses on interaction of the beam with plasma of the discharge gap are completely eliminated. In other words, in the plasma electron source the M - discharge should be excited with near anode voltage drop.

For excitation of such discharge in a plasma diode it is necessary to execute a number of conditions. At first, the general condition of IBPD excitation should be executed, which coincides with the condition of double layer formation. It is realized when the discharge current reaches the greatest possible value of the critical current I_c. It is determined by the peak current, which can be transferred by plasma due to thermal motion in conditions of low pressure:

$$I_c = \int_S \frac{1}{4} e n_p(\vec{r}) \sqrt{8kT_e/\pi m_e}\, d\vec{s}\,, \qquad (1)$$

here e, m_e and T_e are the charge, mass and temperature of the plasma electrons accordingly, $n_p(r)$ is the plasma density in the selected point, S is the current-carrying cross-section of the plasma column. At identical current-carrying cross-section of the plasma column the minimum critical value of the current I_c exists in the region of a minimum plasma density, where the double layer is formed.

From here second condition follows. For the double layer formation near the anode the plasma density should be minimum here. The gradient of the plasma density can be created by a pressure gradient of neutral gas, as, in conditions of intensive pulse discharges the neutral gas is ionized during time much shorter than time of plasma diffusion [6].

Also additional condition, improving system effectiveness, exists. For direct formation of M - discharge with exception of intermediate stage of K - discharge the primary plasma column should take all cross-section of the discharge tube [3].

For creation of the electron source on the basis of an extended plasma diode the experiments on formation of M - discharge in conditions of a pressure gradient with heightened density in near cathode region were performed.

EXPERIMENTAL SAMPLE OF THE PLASMA SOURCE OF THE ELECTRONS

Outgoing from offered idea, the design of the experimental sample of the pulse plasma source of the electron beam was developed. The design of the source is shown in Fig. 1.

The plasma source of the electrons consists from the discharge tube 1, the cathode unit 2 with the source of the preliminary plasma, the anode unit 3 and the divider of the voltage 4. Discharge tube from a glass has a minor diameter of 56 *mm* and length of 450 *mm* at wall thickness of 6 *mm*. The experimental sample is calculated for currents up to 30 *kA* and voltage up to 100 *kV*. In the

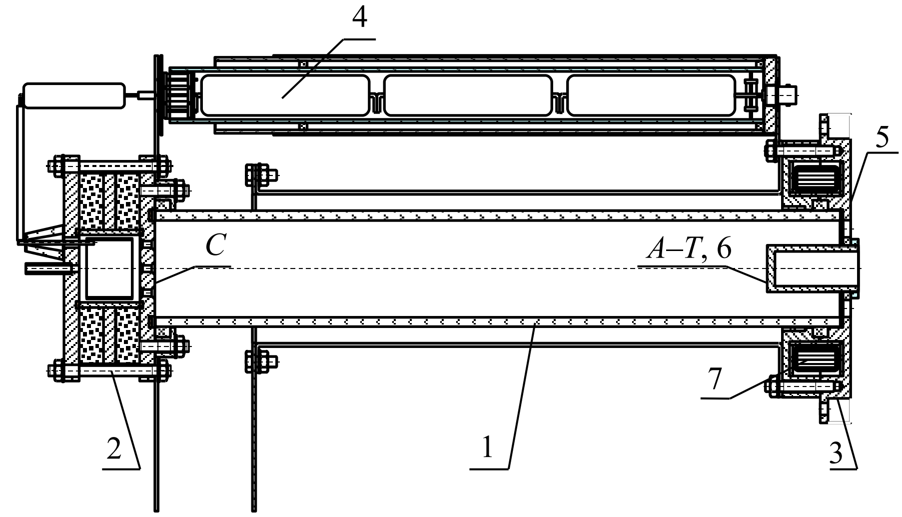

Fig.1. The general view of the experimental sample of the plasma source of the electrons

working order this device joins the vacuum installation with limit pressure not worse than 10^{-5} *Torr* and rate of pumping out of hydrogen not below 500 *l/s* at pressure 10^{-4} *Torr*.

The companion flange 5 in the assembly, anode 6 and Rogovsky belt 7 for measurement of the discharge current enters in an anode unit. For a passage of gas in a companion flange there are 12 pumping out holes of diameter 10 *mm*, and also central threated hole for attachment of the anode. The anode represents changeable hollow copper glassful with external diameter of 27 *mm*, which by means of a thread connection fastens to a companion flange.

For determination of the functionability of the experimental sample of the plasma source of the electrons the preliminary tests were performed. The experiments were performed at lowered voltage of the power up to 10 *kV* with usage of the capacitor C_o of capacity 2,5 μF. The oscillograms of the discharge current and voltage and also the signals from external capacitive probes are shown in Fig. 2.

The analysis of the oscillograms of the discharge current and voltage shows, that on an initial state of the discharge development during 12 μs the large resistance of the discharge is realized, that is the result of the formation of the electrical double layer. According to the oscillograms from the external capacitive probes the double layer originally is localized in the interelectrode region. Thus, the electron beam, which is formed in the double layer, some part of its energy transmits to plasma of the discharge interspace. The remaining energy is provided for the anode. After 6 μs after the discharge beginning the double layer moves in the near anode region on distance about 10 *cm* from the anode. It is shown by appearance of the negative voltage on the distant external capacitive probe (oscillogram V_1). After 3 μs the double layer moves to the surface of the anode (the signals on probes V_2, V_3, V_4 synchronously grow up.). Here it is located up to the end of the discharge phase with large resistance. The current of the electron beam during a pulse increases from several hundreds amperes up to 2,5 *kA*. Thus its energy decreases from 10 *keV* up to 4 *keV*. One can see the small difference between the maximum current value of M - discharge (I_m) and peak current of the inductive discharge (I_{of}): $I_m = 0.8\ I_{of}$ and also rather large duration of existence of M - discharge (about 12 μs) and high conversion coefficient of the energy, accumulated in the capacitor, in the energy of the electron beam (at a level 75 %). The mean power of the beam equals 107 *W* and mean power density on unit of the surface of the anode– $1.7 \cdot 10^6$ W/cm^2. The general energy, which is provided for the surface of the anode - target during one pulse, is about 100 *J*.

Thus, the preliminary experiments with the experimental sample of the plasma source of the electrons have shown the high efficiency of the selected type of the discharge and built device.

CONCLUSIONS

Perspective of use of an extended plasma diode of low pressure as an intensive source of an electron beam was shown on the basis of the carried out experimental examinations. The feature of operation of such diode is the excitation of the self-maintained beam-plasma discharge in it with forming of a double electrical layer of a space charge and generation of an intensive electron beam in a discharge gap.

It was determined that at use of such plasma electron source for magnification of a efficiency of conversion of an exterior electric field energy into the energy of an electron beam it is necessary to excite the self-maintained beam-plasma discharge of M-type with near anode double layer. In this case electrons, accelerated in a double layer, will get at once on an anode. Thus losses of electron beam energy on interaction with discharge gap plasma are practically eliminated.

For forming of the M-discharge with near anode double layer in a plasma electron source the execution of the following requirements is necessary:

- The plasma of a discharge gap should have a gradient of concentration with a minimum at the anode;
- The peak current of the power supply must in 5 … 10 times exceed a current, which can transfer a plasma filament in the field of a minimum of concentration;
- The primary plasma filament should occupy the whole section of a discharge tube;
- The diameter of a discharge tube should ensure flowing of a working current in view of 100 % of working gas ionization;
- In a dielectric discharge tube leaking of working gas should be carried out from the cathode side, and pumping-out - from the part of an anode.

Authors have designed and created the experimental model of a plasma electron source which is calculated on generation of an electron beam with energy $10^4 \ldots 10^5$ *eV* at a current 2…3 *kA*, current density 200…300 *A/cм*^{2}, pulse duration 1…10 *μsec* and efficiency of conversion of an exterior electric field energy into an electron beam energy up to 80 %.

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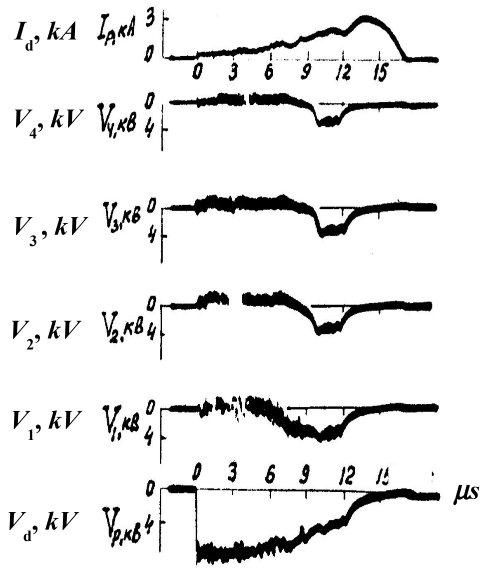

Fig. 2. Formation of M–discharge in the experimental sample of the plasma source of the electrons I_d is the discharge current, V_1, V_2, V_3, V_4 are the signals from the external capacitive probes, placed, accordingly, on 30, 35, 40 and 45 cm from the cathode; V_d is the voltage on the electrodes. $p = 10^{-4}$ Torr, $V = 10$ kV

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