EXCITATION OF SELF-SUSTAINED SECONDARY EMISSION BY GAS DISCHARGE AND HOLLOW BEAM GENERATION IN MAGNETRON INJECTION GUN

S.A. Cherenshchykov[1], V.D. Kotsubanov[2], I.K. Nikolskii[2]

[1]Institute of High Energy Physics and Nuclear Physics, NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine, E-mail: cherench@kipt.kharkov.ua;
[2]Institute of Plasma Physics, NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

The electron beam is frequently used for the energy input into the plasma. However, the strong transverse field hampers the charged-particle beam penetration into a closed magnetic trap. This problem can be solved by means of a new electron gun. It is an electron gun with a cold-cathode developed on the principle of self-sustained secondary electron emission. In experiments described below the gun ignition was for the first time observed at 2…6 kV direct voltage in the range of pressures ~ 10^{-2}…10^{-1} Pa. The gun produced the hollow electron beam with current exceeding 1 A and pulse duration up to 1 ms. After ignition the gun can principally operate at any higher vacuum.
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1. INTRODUCTION

For the electron beam generation one usually uses the electron guns with a heated cathode. The cathode heating to high temperatures involves some very complex problems in the plasma facility operation on the whole, particularly, if closed magnetic traps are used.
Let us consider the most complicated case including all its problems, as well as, the ways to solve them by conventional methods.
1. A cathode should be heated to the temperature close to the melting temperature, and, therefore, it should be protected from the direct plasma contact. It is necessary to prevent the cathode overheating and cathode material evaporation into the plasma what is undesirable for fusion plasma devices.
2. As the transversal magnetic field hampers the electron beam injection, the gun and the cathode should be placed in close proximity to the plasma in the strong magnetic field region.
3. To compensate the electrons escaping from the plasma the currents of high values should be used. Therefore it is necessary to increase the cathode area or the total area of cathodes, if more than one gun is used, or to increase the voltage and the temperature of the cathode. Thus, the hazard of plasma contamination with heavy elements increases.

In practice the use of plasma guns does not eliminate all difficulties. A charge from a solid (condensed) electrode should be injected into the gun plasma anyway. From the cold electrode the high current can be extracted only by forming a cathode spot on it. In other word, in this case the cathode sputtering will be significant too.

2. PROBLEM STATEMENT

In 1990, a multipurpose cold-cathode electron source was developed in NSC KIPT by one of the authors of this report, due to the support and participation of B.G. Safronov [1]. Its advantage is the possibility to obtain high electron currents during unlimited lifetime. Furthermore, the cathode may be made of a material resistant to the high-temperature plasma action. For the material be suitable a maximum value of its secondary-electron emission coefficient should be higher than unity. Most of materials and alloys possess this property.

The principle of operation of the source under consideration is based on the self-sustained secondary emission in the crossed fields. Electron bombardment at an energy corresponding to the maximum of secondary emission, i.e. to the value of about thousands of electron-volts depending on the material, does not change properties of metal surface. Therefore, with the source operating by this principle, the plasma is contaminated no more than the first wall of fusion reactor having the same area. At the same time, it is established experimentally, that such-type source is capable to generate currents higher than 1000 amperes at enough high voltages [2]. It is rather simple and has a robust construction, and, also, allows the operation of many guns simultaneously from single power source. The strong magnetic field is the «natural environment» of its operation.

3. DESIGN OF ELECTRON SOURCE AND DESCRIPTION OF EXPERIMENTAL FACILITY

The design of the source under consideration is rather simple [2, 3]. Two coaxial electrodes are placed parallel to the magnetic field direction. The negative high-voltage pulse supplies an internal electrode. Thus, the hollow (tubular) electron beam, propagating along the magnetic field, is formed.

The experiments were carried out at the facility "Rassvet" ("Sunrise") after it has been upgraded. The facility (Fig.1) comprises the following: solenoid, hollow anode (drift tube) with the internal diameter of 54 mm, cathode and collector. The gun cathode of 20 mm in diameter is connected directly to the storage capacitor via the protective resistor of 1 kΩ.

The beam trace on the collector was recorded by the luminescence of a phosphor deposited on the transparent plate covered by the fine-structure metal gauze for protection of charge accumulation. The collector circuit included the resistor of 5 Ω for current signal measurement.

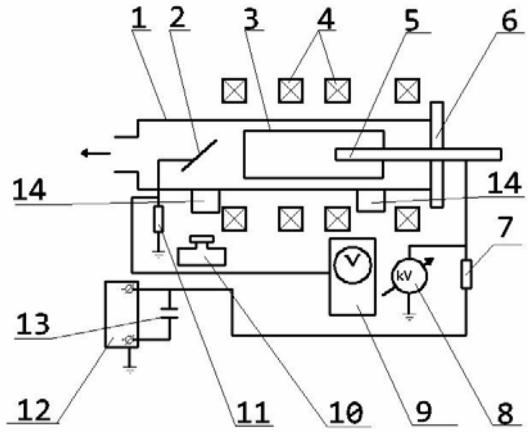

Fig.1. Facility "Rassvet" ("Sunrise")
1- cylindrical vacuum chamber (ceramic insulator); 2- collector with luminescence cover; 3 - tube anode (stainless steel); 4 - coils of pulse magnetic field; 5- cathode; 6- metal flange for cathode maintaining; 7- protective resistor; 8 - kilovoltmeter; 9 - oscilloscope with memory; 10 - digital camera; 11 - signal resistor; 12-high-v oltage source; 13 - storage capacitor; 14 -optical windows for observation.

4. DESCRIPTION OF EXPERIMENTS

The self-sustained secondary emission in the gun was excited by the residual gas ionization. The similar method of secondary emission excitation in the magnetron was used by Vaughan [4]. The gas throttling procedure was applied to increase the pressure to the secondary-emission excitation threshold. If the residual gas pressure is increased to several units of 10^{-2} Pa. the conditions for secondary-emission ignition becomes possible.

With magnetic field switched on, the electron beam pulse with a current of about 1 A and duration of about 1 ms was generated. The oscillograms of beam current pulses are shown in Fig. 2. One can see the current oscillations which are not resolved by the oscilloscope. This phenomenon was observed earlier by one of the authors [2, 5] and by other authors [6].

Sometimes, the electron beam generation was broken up by a low-voltage (arc) discharge formation.

The beam cross-section was registered by taking the photo of the collector luminescence. The corresponding pictures are shown on a Fig. 3. It is seen that the beam has a characteristic tubular structure.

After long series of pulses it has been observed that the gun cathode is covered by a brown deposit (snuff) that proves the presence of intense electron bombardment of the cathode. It is impossible to prevent the oil vapor penetration into the vacuum chamber because in the facility the oil fore pump is used. The oil film is polymerized under electron bombardment [8]. As a result, the brown layer of products of oil film polymerization is formed.

Another confirmation of intensive bombardment of the cathode is the bright blue luminescence from the cathode area arising due to the transition radiation of electrons bombarding the cathode [9].

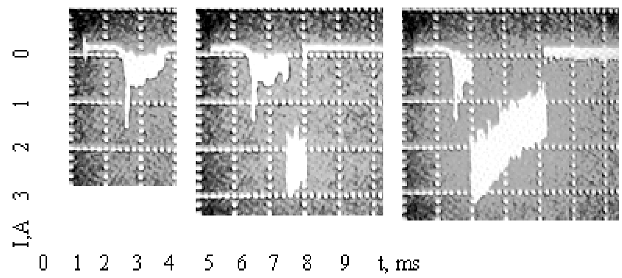

Fig.2. Oscillations of the beam current and arc breakdown at three shots of magnetic field are shown. Start voltage 4 kV; start pressure 0.01 Pa; storage capacitor 4 µF

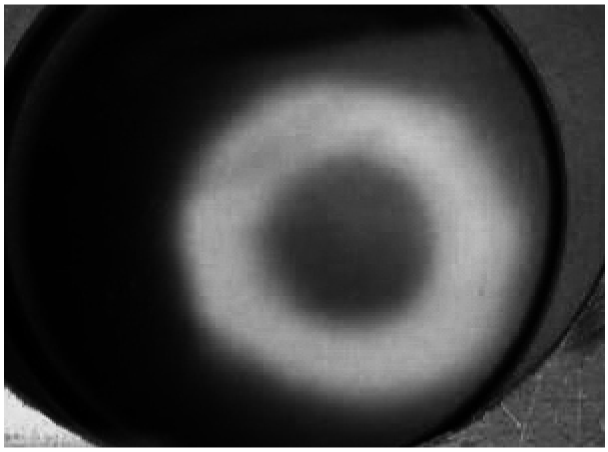

Fig.3. The beam trace as it is seen on the luminescent screen. Voltage 6 kV; pressure 0.1 Pa; storage capacitor 100 pF

5. DISCUSSION OF RESULTS AND PROSPECTS OF APPLICATION

The phenomenon of high-current hollow electron beam fragmentation is known in [7]. This is possible when the beam is propagating for a long distance with low gun voltage and at high enough current. This phenomenon is caused by the action of space-charge forces. It should be noted, that the beam fragments diffuse across the magnetic field due to the collective effects in the beam, as is seen on photos of the beam trace (not shown here) [7].

The time increasing magnetic field may be a favorable factor for the electron injection into the closed magnetic traps. The vortex field component can send electrons to the plasma center and increase its negative potential.

The self-modulation operating mode [2, 6], with the beam consisting of separated bunches, may be considered as some advantage of such-type gun. The bunch repetition rate observed in [2, 7] is within the limits of 10…200 MHz. This can provide the direct excitation of high-frequency oscillations in the plasma. Thus, in this case it is not necessarily for the beam to reach the plasma boundary. The excitation of oscillations is possible due to the plasma oscillation field penetration into vacuum.

In addition to the effective injection of the charge and energy, such an approach will provide the stable plasma ignition at the lowest pressure, even at a low power of the gun.

6. CONCLUSIONS

The described experiments have been carried out with a novel type of an electron source, with cold metal cathode. In earlier publications on this subject the gun has been excited by short pulse with voltage of tens kilovolts and higher [1, 2, 6].

The results presented above demonstrate that such an electron gun can be ignited with a rather low voltage (≥ 2 kV) in a not high vacuum ($10^{-2}…10^{-1}$ Pa) and show the prospect of its application in experimental fusion installations.

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ВОЗБУЖДЕНИЕ САМОПОДДЕРЖИВАЮЩЕЙСЯ ВТОРИЧНОЙ ЭЛЕКТРОННОЙ ЭМИССИИ ГАЗОВЫМ РАЗРЯДОМ И ГЕНЕРАЦИЯ ТРУБЧАТОГО ПУЧКА В МАГНЕТРОНОЙ ПУШКЕ

С.А. Черенщиков, В.Д. Коцубанов, И.К. Никольский

Ввод энергии в плазму зачастую можно произвести электронным пучком. Однако, сильное поперечное магнитное поле препятствует проникновению пучков заряженных частиц в замкнутую магнитную ловушку. Проблема может быть разрешена путем применения новой электронной пушки. Принцип действия новой электронной пушки с холодным катодом - самоподдерживающаяся вторичная электронная эмиссия. В описанных экспериментах зажигание пушки впервые наблюдалось при постоянном напряжении 2…6 кВ в диапазоне давлений $10^{-2}…10^{-1}$ Па. Пушка создавала полый электронный пучок с током выше 1 А и длительностью до 1 мс. После зажигания работа такой электронной пушки принципиально возможна и при более высоком вакууме.

ЗБУДЖЕННЯ ВТОРИННОЇ ЕЛЕКРОННОЇ ЕМІСІЇ, ЩО САМОПІДТРИМУЄТЬСЯ, ГАЗОВИМ РОЗРЯДОМ ТА ГЕНЕРАЦІЯ ТРУБЧАСТОГО ПУЧКА У МАГНЕТРОННІЙ ГАРМАТІ

С.О.Черенщиков, В.Д.Коцубанов, І.К.Нікольский

Введення енергії в плазму може бути зроблено за допомогою електронного пучка. Однак, сильне поперечне магнітне поле перешкоджає проникненню пучків заряджених часток в замкнуту магнітну пастку. Ця проблема може бути частково вирішена шляхом використання нової електронної гармати. Принцип дії такої гармати з холодним катодом – вторинна електронна емісія, що самопідтримується. В описаних експериментах уперше запалювання гармати спостерігалося при постійній напрузі 2...6 кВ у діапазоні тиску $10^{-2}...10^{-1}$ Па. Гармата утворювала електронний пучок зі струмом більшим ніж 1 А та тривалістю 1 мс. Після запалювання робота такої електронної гармати принципово можлива і при більш високому вакуумі.