Investigation of the plasma electron source based on discharge in crossed electric and magnetic field in hollow configuration

N A Podguyko, M K Marahtanov and Yu A Khohlov

BMSTU, 105005, 5, 2-ya Baumanskaya, Moscow, Russia

E-mail: podguyko.nikolay@mail.ru

Abstract. This article presents a study of the plasma electron source based on discharge in crossed electric and magnetic fields in hollow configuration with a discharge current of up to 1 A. It was found that using a cathode screen with a central hole affects the operation of the device. The discharge voltage is reduced and the formation of an electron beam becomes possible without using for this purpose the extraction voltage. It is shown that the current strength of the electron beam in the absence of an extraction voltage depends on the flow rate of the plasma-forming gas.

1. Introduction

Source of electron is used in many areas of technology. For example, it is used in the processes of welding, cutting and dimensional processing of materials. In vacuum technology of producing thin films electron beam evaporates various materials. In ion-plasma technology and electric propulsion, an electron source is used as a neutralizer cathode. Most of the currently used electron sources use thermionic emission to create a stream of particles. They are either filaments, or more complex constructions with an external heated emission insert [1]. The disadvantage of such emitters is the many factors limiting their life time. The main ones are: high incandescent temperature, degradation of emission materials due to evaporation of alloying materials and the base material [2]. The life time of such electron sources is further reduced when they work in an environment of reactive gases [2, 3].

There are plasma electron sources with a cold cathode that are resistant to reactive gases [4, 5, 6]. Such sources most often uses glow discharge or Penning discharge. This paper presents study of a plasma electron source based on a discharge in crossed electric and magnetic fields in a hollow configuration. This configuration was already presented earlier in [6]. A feature of the investigated electron source is the presence of a cathode screen.

2. Construction and experiment

The plasma electron source based on a discharge in crossed electric and magnetic fields in a hollow configuration is investigated. The design of the device is an axial system with an overall size of 100 mm (Fig. 1). All details of the design - the body of rotation. A hollow cathode is a copper cylinder inside of which a discharge is burning, the anode is a cap insulated from the cathode cylinder with an orifice for extraction the electron beam. Permanent magnets are located around the cathode creating an axial magnetic field. The cathode and anode assembly was water cooled. The design provides the ability to add a cathode screen 3 – a disk with a central hole (see, Fig. 1).
Investigations were carried out in an experimental stand based on the “Bulat-6” vacuum station. A vacuum chamber with an installed plasma electron source and an electron current collector was pumped out to background pressure of $7 \cdot 10^{-3}$ Pa. The flow rate of the working gas (argon) was fed to the electron source using the gas inlet system “SNA-2”. A plasma power supply of 0 ... 600 V was used for the operation of the plasma electron source, and a voltage source of 0 ... 100 V was used for extraction voltage. The connection scheme is shown in Figure 1. The distance between the emission orifice and the electron current collector was 30 mm.

3. Discussion and results

In the absence of a cathode screen the device parameters are close to the analogue presented in [6]. The discharge voltage is 340 V with a discharge current of 1 A and a flow rate of working gas (argon) of 14 ml/min. The electron beam current of 1.1 A is extracted by applying a positive voltage of 0 ... 60 V to an electron current collector set at a distance of 30 mm from the emission orifice. The electron beam is not formed at zero voltage and its current to the collector (as in [6]) has a zero value.

In the second construction the cathode screen separates the cathode volume from the anode (see Fig. 1). Depending on the ratio of the diameters of the hole in the cathode screen and the anode orifice different results were obtained. The most interesting is the case when the diameters of the holes in the cathode screen and the anode were respectively equal to 3.5 mm and 2 mm. At the same flow rate of the working gas and the discharge current, the discharge voltage decreased by 6% to 320 V. It was also noted that the electron collector current exists at zero extraction voltage reaching a value equal to 10% of the discharge current.

The appearance of the electron current on the collector in the absence of an extraction voltage can be explained by the shape of the magnetic field in the device under study. Since the magnetic field inside the cathode is formed by permanent magnets arranged as shown in Figure 1, the leakage field affects the operation of the device. It can be seen that the magnetic flux abuts the anode and do not confine the movement of electrons in the absence of a cathode screen. All electrons of the discharge come to the anode. If a cathode screen is used, the movement of electrons to the anode becomes confined. They can reach the anode only through a hole in the screen. The magnetic flux directly at the anode orifice in this case confine the movement of electrons to the anode because they need to move across the magnetic flux (Fig. 2). Some of them come out of the device bypassing the anode. Due to this, an electron beam is formed even in the absence of an extraction voltage.

In the experiments with a cathode screen the dependence of the electron beam current in the absence of an extraction voltage on the flow rate of the working gas was also found. It was experimentally shown that with a working gas flow rate of 14 ml / min, the electron current to the collector in the absence of an extraction voltage was equal to 2% of the discharge current. Under

![Figure 1. Plasma electron source design and power supply connection scheme:](image)

- hollow cathode, 2 - anode with emission orifice, 3 - cathode screen with a central hole, 4 - permanent magnets, 5 - magnetic cores, 6 - insulator, 7 - electron current collector, 8 - laboratory power source for discharge, 9 - laboratory power source for extraction collector voltage.
similar conditions the electron current reached 10% of the discharge current with a working gas flow rate of 5 ml/min.

![Figure 2](image-url)

**Figure 2.** The result of a numerical calculation of the magnetic flux near the emission orifice: 1 — cathode, 2 — anode with emission orifice, 3 — cathode screen with a central hole.

4. Conclusion

Two variants of the construction of a plasma electron source are investigated. They are distinguished by the presence of a cathode screen. It is established that in the case of a cathode screen, it is possible to reduce the voltage of the main discharge and to form the primary electron beam without the use of a special extraction electrode. The current strength of the electron beam to the collector depends on the working gas flow rate. This design feature can be used to create efficient plasma electron sources, since the presence of a primary electron beam creates pre-ionization, which facilitates the formation of a plasma bridge between the cathode and the ion beam in the case of using an electronic source as a neutralizer cathode. In another application, this can simplify the design of an electron beam extraction system.

5. References

[1] Grishin S D 1973 *Osnovy teorii ionnyh dvigatelej* (Moscow: Moscow State University Press) p 140

[2] Kaufman H R, Cuomo J J and Harper J M E 1982 *Journal of Vacuum Science & Technology* 21 725

[3] Goebel D M and Katz I 2008 *Fundamentals of Electric Propulsion: Ion and Hall Thrusters* (John Wiley & Sons) p 486

[4] Oks E M 1992 *Plasma Sources Science and Technology* 1 249.

[5] Galansky V L, Gruzdev V A, Osipov I V and Rempe N G 1994 *Journal of Physics D: Applied Physics* 27 953

[6] Dostanko A P and Golosov D A 2009 *Technical Physics* 54 1454