UDC 533.922

PLASMA SOURCE FOR THE FORMATION OF LARGE CROSS SECTION CHARGED PARTICLES BEAMS

EVGENY HOMICHENOK, DMITRY ANTONOVICH
Polotsk State Universitys, Belarus

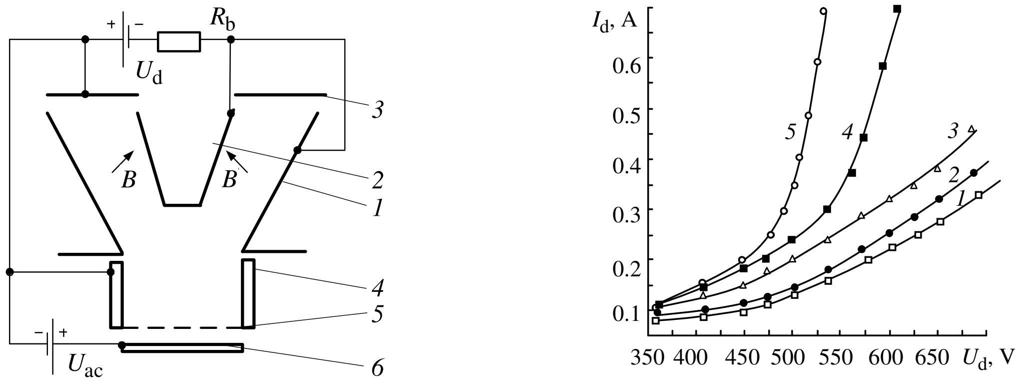
This article presents the results on the formation of beams of charged particles of large cross section for the implementation of technologies for modifying the surface properties of various materials. The structure, design sketch and the main characteristics of the developed source are given.

For the implementation of plasma-chemical and strengthening technologies, it is advisable to use beams of charged particles of large cross-section with an area corresponding to the area of the treated surface. In the structures of plasma sources of charged particles with a large cross-section beam, the accelerating electrode is usually absent and the accelerating potential is applied to the workpiece (surface), the focusing system of the electron beam is also absent. Therefore, to obtain electron or ion beams of large cross section in a plasma generator, it is necessary to form a plasma emitting surface corresponding to the beam cross-sectional area, providing an emission current density sufficient for technological purposes. During the formation of a developed emitting plasma surface, it is impossible to ensure a significant pressure drop between areas of plasma generation and electron beam formation. Therefore, if it is necessary to ensure a low gas pressure in the region of the beam acceleration and the technological region, additional gas-discharge structures are usually used to inject electrons or plasma into the region of the formation of the emitting plasma. When an increased gas pressure is required in the process area, in order to form a process plasma, and the required density of the emitting plasma is achieved without auxiliary gas-discharge structures, it is usually necessary to ensure the stability of the emitting plasma surface. This is achieved by the method of grid stabilization of the emitting plasma surface [1-3]. This paper presents a source of charged particles capable of forming beams of charged particles of large cross section for the implementation of technologies for modifying the surface properties of various materials. The data on the grid stabilization of the emitting plasma surface are presented. The structure, design sketch and the main characteristics of the developed source are given.

The source for the formation of large cross section charged particles beams. The essence of the grid stabilization method is as follows. The emitter electrode is made in the form of a grid electrode (with geometric mesh transparency ξ) that prevents the emitting plasma from penetrating into the accelerating gap (the mesh cell size should not exceed twice the thickness of the wall layer) and the accelerating electrode restricting the field penetration into the discharge chamber. However, the electrical transparency of the grid (D) for the field of the accelerating electrode is a quantity that depends not only on the geometric transparency, but also on the field strength in the accelerating gap. With an increased gas pressure, when a secondary plasma [4, 5] is formed in the acceleration gap, at the surface being treated with a potential close to the potential of the accelerating electrode, the field strength at the grid emitter electrode increases, which increases the permeability of the accelerating field through the grid electrode. To ensure the stability of the emitting surface, in this case it is necessary to use either grid electrodes of lower geometric transparency, which reduces the efficiency of the plasma emitter, or double grid electrodes made of two grids with the maximum possible geometric transparency and separated by equipotential space. One of the grids ensures stability of the plasma surface, the other limits the penetration of the field into the discharge chamber. As a result, stable emission characteristics are ensured both at elevated pressure and at significant fluctuations.

When using charged particles with a large cross section of additional plasma injectors in plasma sources, a large plasma surface is usually formed in a special cylindrical electrode having an anode potential (hollow anode) [1, 5].

Figure 1 shows the electrode structure and the current-voltage characteristics (CVC) of the discharge in a modified structure with an expander electrode for forming a developed plasma surface. Plasma is formed in the space between the cathodes and, expanding, fills the volume of the expander electrode. Plasma penetration into the expander takes place mainly through peripheral areas, where the escape of charged particles is the most intense. This ensures a high degree of homogeneity of the plasma distribution over the cross section of the expander. In addition, in the expander, as in the main region of the discharge, ionization processes occur due to the ionization ability of plasma electrons.



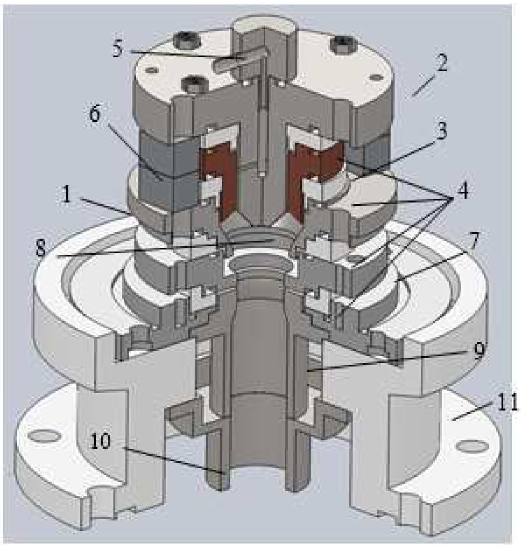
a)   b)

a - electrode system [1, 2] (1 – external cathode; 2 – internal cathode; 3 – anode;
4 – hollow anode (expander); 5 – emitter (grid or perforated) electrode;
6 – accelerating (extracting) electrode-the processed surface; U_d is the discharge burning voltage;
U_{ac} – accelerating voltage; R_b – ballast resistance; B – magnetic field induction;
b – CVC: 1 – system with an open emitter electrode, without grid; 2 – grid $\xi = 0.64$; 3 – double grid $\xi = 0.64$;
4 – grid $\xi = 0.44$; 5 – emission channel in the form of a single hole 3 mm diameter;
1–3, 5 – 4.2 mPa·m^3/s; 4 – 3.3 mPa·m^3/s
Figure 1. – Discharge in a modified structure with crossed E × H-fields

Therefore, under certain conditions (plasma concentration, gas pressure in the discharge, the size of the output aperture of the external cathode 1) the intensity of the ionization processes in the main discharge and the expander are comparable, that is, the expander switches to the "active" mode, performing the role of a hollow anode.

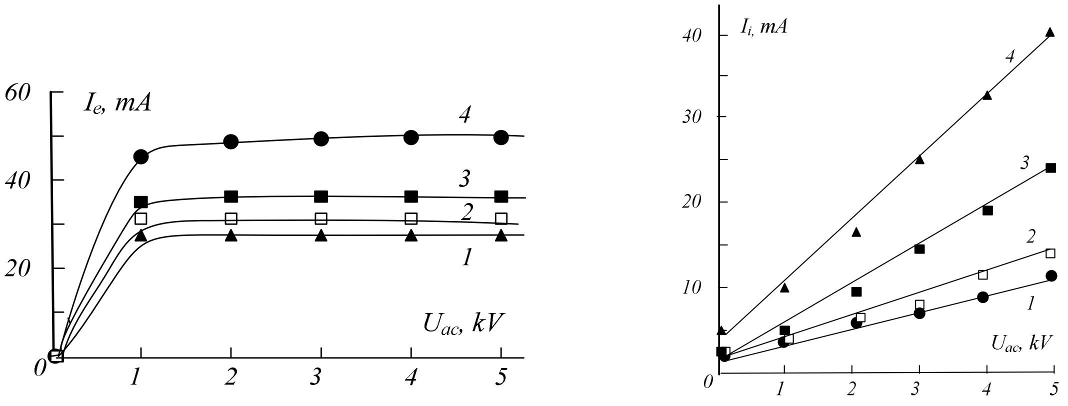
The CVC (Figure 1, b), regardless of the geometry of the emitter electrode, are similar, and their difference is explained by a change in the gas-dynamic parameters of the emitter structures, which leads to a difference in pressure in the region of the discharge initiation and the formation of the emitting plasma, because the effect of grids transparency ξ on the current-voltage characteristics of the discharge is significant. Curve 5 corresponds to the maximum pressure in the gas-discharge structure. Curve 1 corresponds to the minimum pressure that is realized in the electrode structure with the expander fully open (no grid electrodes) with all other conditions being equal. The "active" mode of the expander is realized in the range of the laps values corresponding to curves 2 - 4.

Figure 2 shows the discharge structure for the formation of low-energy beams of charged particles, also developed on the basis of a modified gas-discharge structure with crossed E×H fields, and both Figures 3 and 4 show its main characteristics and photos of the charged particle beams formed in it. In this source, the main gas ionization processes occur in the region bounded by the external and internal cathodes 1 and 2, and the anode 3.



1 - external cathode; 2 - internal cathode; 3 - anode;
4 - insulators; 5 - fitting for plasma gas inlet;
6 – permanent magnets; 7 – additional electrode;
8 – gas inlet; 9 – plasma expander electrode;
10 – accelerating electrode; 11 – flange
Figure 2. – The discharge structure for the formation of low-energy charged particle beams

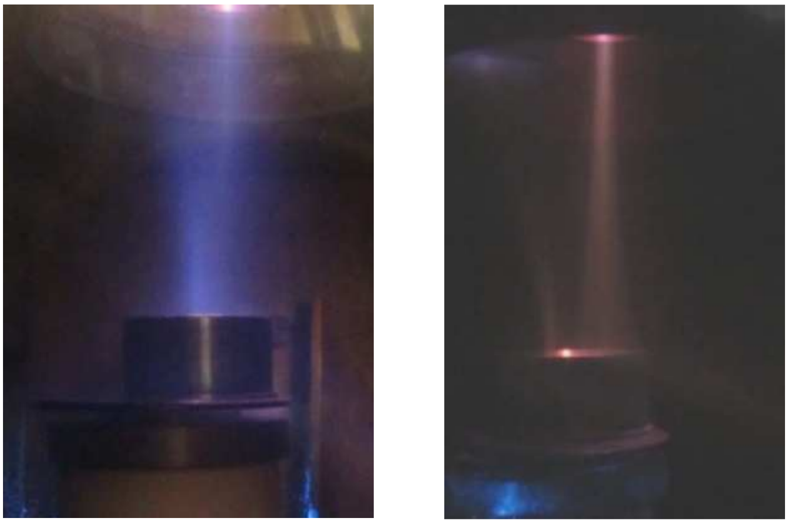
The magnetic field is formed with the help of permanent magnets 6 located between the cathodes. Moreover, a necessary condition for the operation of the structure is the direction of the magnetic induction vector. It should have a perpendicular direction relative to the working surface of the cathodes, since due to this, there is a restriction of the electron mobility from the plasma to the anode, leading to an increase in the plasma density in this region. Through the upper opening in the expander, the plasma penetrates into the expander 9. Plasma-forming gas into the discharge structure is fed through channel 8 in choke 5 and cathode 1. The use of an additional electrode 7 located between the inner cathode and the expander improves the extraction efficiency and stability of the emission current [6, 7].



a) b)

1, 2 – anodic, 3, 4 – cathodic; discharge current: 250 mA

Figure 3. – Characteristics of the extraction of electrons a) and ions b) for different potentials of the expander electrode [7], potential of the expander electrode



a) b)

Figure 4. – Appearance of electron (a) and ion (b) charged particle beams

Since the plasma emitter is able to emit both ions and electrons, depending on the polarity of the accelerating voltage, and the frequency of change of the accelerating voltage is determined mainly by the time of formation of conditions on the target for the formation of microarcs, and, depending on the material being sprayed, range from one to tens of kilohertz. This method can be implemented on the basis of this single ion-electron optical structure. In addition, such a structure is promising for the implementation of such plasma-chemical technologies as electron beam dispersion, ion-plasma nitriding, electron-beam sputtering of dielectric materials, lithography and the application of multilayer coatings where low-energy beams of charged particles with energy up to 5 keV and impact on a large surface.

These characteristics indicate the possibility of using the presented source for the implementation of existing technologies for modifying the surface properties of materials and developing new technologies.

REFERENCES

1. Universal plasma electron source. / V.A. Grusdev [et al.] // Vacuum. – 2005. – № 77. – P. 399–405.
2. A.V. Zharinov, Yu. A. Kovalenko, I.S. Roganov, P.M. Tyurukanov, Tech. Phys. - The Russian J. of Appl. Phys. 56 (1986) 66.
3. A.V. Zharinov, Yu. A. Kovalenko, I.S. Roganov, P.M. Tyurukanov, Tech. Phys. - The Russian J. of Appl. Phys. 56 (1986) 687.
4. Zalesski, V.G. Energy efficiency of electron plasma emitters) / V.G. Zalesski // Plasma Physics Reports. – 2011. – Vol. 37 (13). – P. 1196–1201.
5. Zalesski, V.G. Peculiarities of plasma electron sources operation at high pressures / V. G. Zalesski, D.A. Antonovich // J. Phys. D, Appl. Phys. – 2007. – № 40. – P. 7771–7777.
6. Gruzdev V.A. Emission current formation in Plasma electron emitters / V.A. Gruzdev, V.G. Zalesski // Plasma Physics Reports. – 2010. – Vol. 36 (13). – P. 1191–1198.
7. Goebel, D.M., Forrester, A.T. Plasma studies on a hollow cathode, magnetic multipole ion source for neutral beam injection/ D.M. Goebel, A.T. Forrester // Review of Scientific Instruments, – 1982. – 53(6). – P. 810–815.
8. Gruzdev, V.A. The electron gun with a plasma emitter and isolated emitter electrode / V.A. Gruzdev, V.G. Zalesski, I.S. Rusetski // Electrotechnica and Electronica (Bulgaria). – 2012. – V. 47, № 5-6. – P. 89–92.