FLASH CHAMBER OF A QUASI-CONTINUOUS VOLUME SOURCE OF NEGATIVE IONS

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ABSTRACT

In the work the design is described and results of experimental researches of plasma generator with the cold cathode for a source of negative ions are submitted. The generator consists of three consistently connected chambers with dosed gas leaking between them. The electrode system of the first chamber (of high pressure) and the second one (of low pressure), represents two-chambered inverse gas magnetron. The second chamber through an annular slot connects with the third (emission) chamber in which plasma of the tubular form is generated. In the third chamber plasma is divided into two areas (peripheral and paraxial) where necessary conditions for effective formation of negative ions are created. The submitted generator will allow optimizing a design of negative ions source.

INTRODUCTION

The glow discharges of a direct current, in particular, in crossed E x H fields, are attractive to generation of low-temperature plasma in connection with stability of their burning, simplicity of their operation and advanced reliability of a discharge cell at density of a current on the cathode up to tens of A/cm2 and voltage on the discharge in some hundreds of volt. The range of their working pressure is in the area of $10 - 10^{-1}$ Pa. For using of the glow discharges in the ion sources, working in a constant duty, it is necessary to decrease gas pressure in the discharge chamber of a source. This fact is especially important at using of glow discharges in the sources of negative ions, as the negative ions are collected from all volume of their generation, therefore the mean free path of a negative ion in the emission area should be large. For minimization of neutralization of negative ions it is necessary to reduce pressure in front of the emission aperture and behind it, where the speeds of negative ions are small and cross section of their neutralization on gas is large.

Under decreasing of gas leaking into discharge system with cold cathode, sharp increasing of ignition and burning voltage of the glow discharge begins to be shown. From gas discharge devices, known at the present time, with the glow discharge, which work at the lowest gas pressure, it is possible to choose the inverse gas magnetron. Using inverse gas magnetron in the negative ions source working in a pulse mode with pulse gas leaking [1] it is possible to decrease gas pressure to a level excluding a noticeable neutralization of negative ions. It is obtained due to gas-dynamics of gas current in the discharge space and various speeds of movement of the neutral and charged particles. There is an opportunity to decrease an ignition voltage and also reduce working pressure of gas for the stationary discharge at low pressure. It can be obtained due to auxiliary discharge at high pressure, which delivers plasma into the discharge cell with low gas pressure. The auxiliary discharge works as a plasma cathode, which supplies a discharge of low pressure with primary electrons.

In this work the results of experimental researches on creation of three-chambered discharge system with cold cathode, which generates stationary cold plasma at low pressure in its output chamber, are given.

THE CONSTRUCTION DIAGRAM 0F ELECTRODE SYSTEM AND PHYSICAL REPRESENTATIONS ABOUT PROCESSES IN ITS GAS-DISCHARGE INTERVAL

The gas discharge system (fig.1) represents an axisymmetric construction, consisting of three chambers with dosed gas leaking between them.

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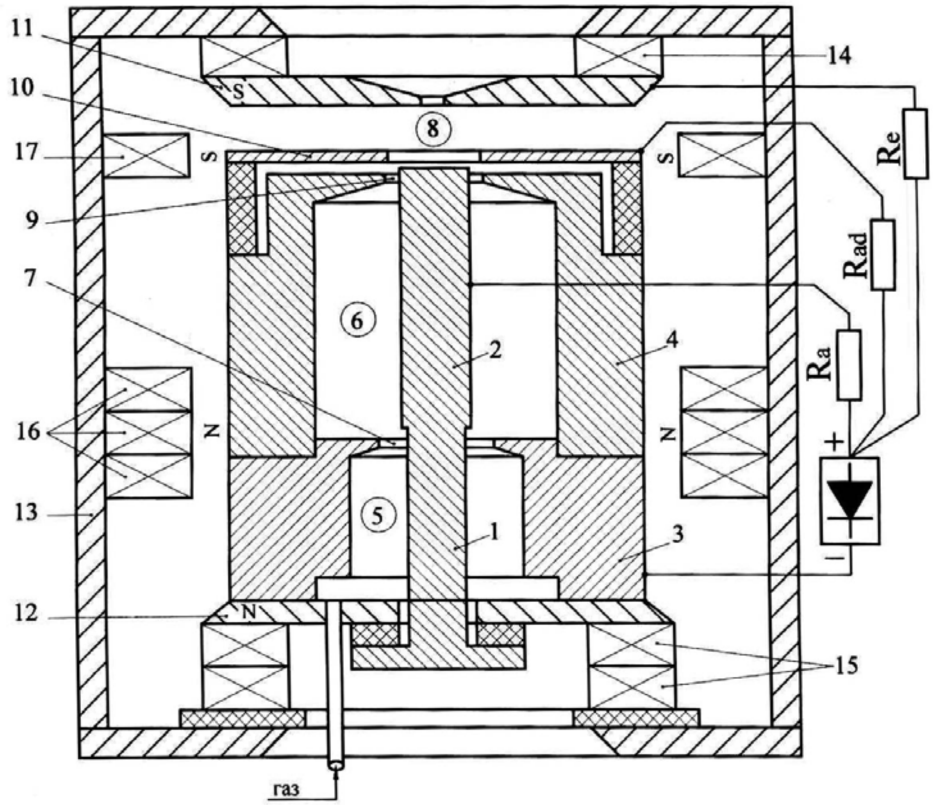

Figure 1. Schematic diagram of three-chambered discharge system.
R_a = 680 Ω, R_{ad} = 630 Ω, R_e = 13 Ω.

The copper anode (1 and 2) and copper cathode (3 and 4) are made of two parts. Part 3 of the cathode and part 1 of the anode create the first discharge chamber 5 (of high pressure), and part 4 of the cathode and part 2 of the anode create the second discharge chamber 6 (of low pressure). Chamber 5 is connected with chamber 6 by convergent ring channel 7, and the discharge chamber 6 is connected with the third emission chamber 8 with the help of another convergent ring channel 9. Due to resistance to a gas current in the convergent ring channels, the decrease of pressure in each following chamber is obtained. And in the emission chamber 8, the additional decrease of working gas pressure due to its expansion to large volume and its differential pumping-out in a radial direction is carried out. Magnets $Sm\text{-}Co_5$ (14 and 15) is established between the emission electrode 11 and a magnetic pole 12. The framework of the discharge system 13, which is a component of magnetic system, represents a six-sided prism. Between the longitudinal sides of a prism the gaps of width ~ 35 mm (not shown in figure) for radial pumping-out of interelectrode space are provided. High-pressure chamber is supplied with working gas through the aperture at its lower end.

The electrode system, forming discharge chambers 5 and 6, represents two-chambered inverse gas magnetron, which works on the basis of glow discharge in crossed E x H fields. Both discharge chambers are connected to one power supply, as shown in figure1. The voltage between the electrodes of plasma generator is set with the help of automatic displacement on the resistances.

The efficiency of discharge at low pressure is limited basically by a lifetime of electrons. In this construction of the inverse magnetron, both magnetic and electrostatic keeping of fast electrons can be realized. The superposition of a longitudinal magnetic field, created by magnets 14 and 15, increases a lifetime of fast electrons, which start from a cylindrical surface of the cathode to the central anode. Face walls of the magnetron, having a cathode potential, provide keeping of electrons along the magnetic field. As a result, a lifetime of fast electrons in the magnetron chambers is large and they feel numerous collisions with gas atoms and have enough time to make sufficient number ionizations for maintenance of the independent discharge, before they get on a surface of the anode.

Physical processes in the two-chambered magnetron discharge with compressed plasma are rather difficult, therefore a creation of mathematical model, allowing to carry out engineering calculation of the construction is difficult, because of the complexity and multiparametrical dependence of phenomena taking place here.

Computer modeling of equipotential curves in the discharge chamber, depending on the form of electrodes and values of their potentials, has allowed us, as a first approximation, to choose geometry of electrode system of the plasma generator, which was optimized experimentally later on.

EXPERIMENTS AND DISCUSSIONS

In the real ion source it is difficult to receive a homogeneous magnetic field along all the length of the discharge chamber. In the construction of discharge system, represented here, the basic permanent magnets 14 and 15, which excite a magnetic field, are located in the bottom and top part of the chamber. They create a distribution of intensity of a magnetic field in the interpolar space, which is shown on fig.2 (curve 1).

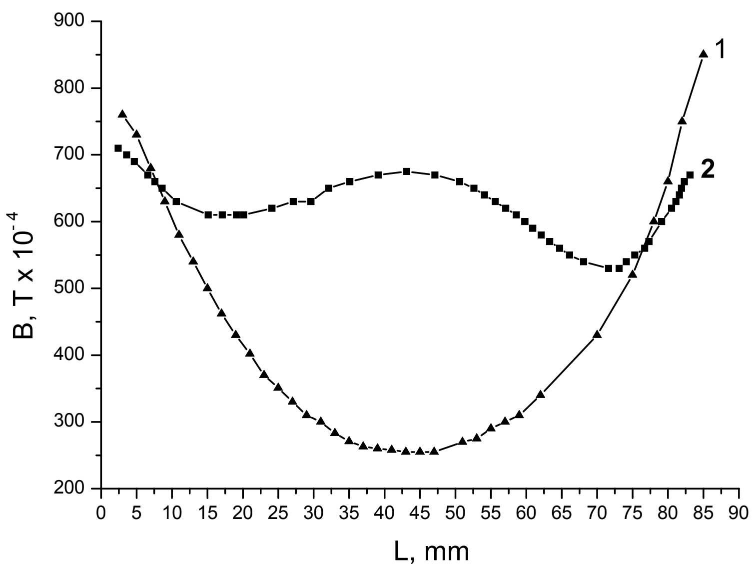

Figure 2. Axial distribution of a magnetic field intensity B_z in the interpolar gap of plasma generator.
1 - without adjusting magnets. 2 - with adjusting magnets.

It is visible, that the intensity of a field along the discharge cell is non-homogeneous. To reduce this non-homogeneity of a field, on each of six sides of the magnetic path 13 the corrective magnets 16 and 17 were installed (see fig.1). As a result of optimization of the location of these magnets, the distribution of intensity of a magnetic field along an axis of the discharge chamber, shown on fig.2 (curve 2), was obtained. All following experimental results were received at this distribution of a magnetic field.

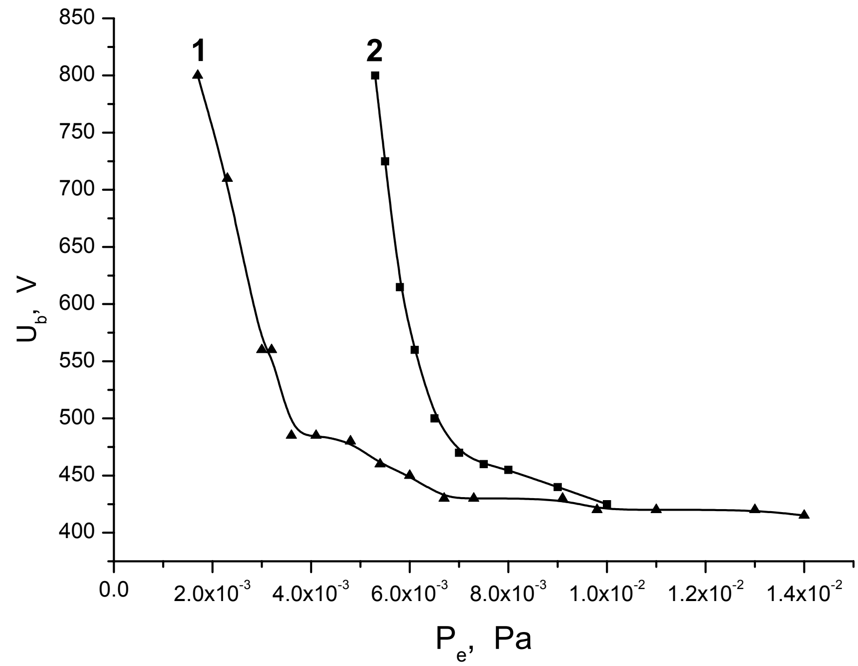

Figure 3. Dependence of ignition voltage discharge in two-chambered (1) and one-chamber (2) gas magnetron on pressure in the emission chamber.

In fig. 3 (the curve 1) the dependence of a ignition voltage U_b in gas magnetron as a function of working gas pressure P_e in the emission chamber is shown (working gas flow is proportional to pressure P_e). The maximal voltage on the discharge interval was 800 V. At voltage (800V) the ignition voltage in the emission chamber takes place when pressure is $P_e \approx 1{,}7 \cdot 10^{-3}$ Pa. At increasing of gas flow, the ignition voltage reduces. Carried out experiment also has shown, that in a range of gas pressure $P_e = (1{,}7 - 3) \cdot 10^{-3}$ Pa the discharge glows only in the first chamber, and at $P_e \geq 3 \cdot 10^{-3}$ Pa the discharge begins to glows in the second chamber, at ignition voltage $U_b = 560$ V (as it follows from the diagram).

For comparison, a similar dependence at use of a single-chamber gas magnetron is shown in the same figure (curve 2). In this case, chamber 5 was filled with a copper insert. The outside surface of this insert adjoined tightly to the internal surface of the cathode 3, and between the anode 1 and the internal surface of the insert, a ring channel of width ~ 0,8 mm for delivery of working gas into the chamber 6 was left.

From figure it is visible, that the ignition voltage in the chamber 6 at a voltage on a discharge interval 560 V, occurs at pressure $P_e \approx 6 \cdot 10^{-3}$ Pa, which is twice as high as in the case of two-chamber magnetron.

For maintenance of a significant pressure difference between the second and third discharge chambers, and also for a restriction of an output from gas magnetron of the sputtered particles of cathode, it is necessary to reduce a width Δr of the annular slot. Its minimal width is limited by a thickness mass of a volumetric charge, which prevents penetration of plasma into the emission chamber [2]. The thickness of this layer d can be evaluated from Child law:

$$d = 2/3 \left(\frac{\varepsilon_0 \left(\frac{2q}{M} \right)^{1/2} U^{3/2}}{j_i} \right)^{1/2}, \quad (1)$$

where: j_i - ions current density on the cathode; q - ion charge; M - ion mass; U - voltage on the layer; ε_0 - dielectric constant.

Ions current density on the cathode can be evaluated from Bohm law:

$$j_i = 0{,}4en\left(\frac{2kT_e}{M}\right)^{1/2}, \quad (2)$$

At $n = 10^{12}$ cm^{-3}, electronic temperature Te = 5 eV, oxygen ions current on the cathode ~ 49,5 mA/cm^2.

Substituting the found value of density of ion current to the formula (1) and believing, that practically all the voltage drop U = 350 V is concentrated in the cathode layer, we shall receive d = 1,3 mm. Taking into account that, the pre-layer also adjoins to a layer of the volumetric charge [3], then a minimal width of the annular slot can be chosen ~ 1,5 mm.

The maximal value Δr will be limited by allowable gas working pressure in the emission chamber. At setting value of working gas flow, the pressure in the emission chamber can be regulated due to a change of width of annular slot 9 and also due to a change of gas conductivity of the channel of a radial pumping-out from it. This pressure should be such, that the losses of negative ions, owing to their neutralization on the way of their drift, were insignificant.

The losses of negative ions, owing to their neutralization can be determined from the expression $n\sigma_{-0}l \approx 10^{-2}$. As a cross section of the neutralization under ion energies in several tens eV is $\sigma_{-0} \approx 5\cdot10^{-16}$ cm^2, then at a choice of the length of the emission chamber l_e = 1 cm, the pressure should be $P_e \leq 8\cdot10^{-2}$ Pa. The experimental researches have shown that (at l_e = 1 cm) this condition is carried out in all range of working gas flow at $\Delta r \leq 2$ mm.

Physically it is clear, that the formation of an electron avalanche in the emission chamber begins when the electrostatic intensity between plasma and emission electrode will exceed the critical value $E > E_{kr}$. The value E_{kr} will depend on the initial density of electrons, penetrating through a compression aperture. Besides, for the transition of a discharge onto the emission electrode, a gas density in the chamber should also exceed some minimum. For decreasing of this terminal pressure, it is important to have an increased gas density in the initial area of the emission chamber, where, under the certain conditions, plasma will penetrate from the gas magnetron and initiate the development of an electron avalanche.

The first experiment on a stretch of the compression discharge to the emission electrode was carried out at the following characteristics of the interval: Δr = 1,5 mm; $P_e = (5\cdot10^{-3} - 8\cdot10^{-2})$ Pa; l_e = 1 cm. The discharge current Idc varied in a range (0,1 - 3) A. The experiment has shown, that a stretch of the discharge was extremely unstable and it occurred spontaneously only at the maximal values P_e and I_{dc}. It is obvious, that at the chosen values of the interval, to carry out a stretch of the discharge was possible only due to increasing of intensity of field E between plasma, having a potential close to a potential of the anode, and emission electrode. It could be made either due to a connection to the interval of a higher voltage from the additional power supply, or due to an accommodation in the emission chamber, near a face part of the magnetron the additional electrode 10 (see fig.1), which would have a positive potential concerning the anode 2.

In the beginning, the additional electrode was installed on distance Δl =1mm from a face part of the cathode 4, and through the resistor R_{ad} = 630 W was connected to a positive pole of the power supply. Other characteristics of the interval remained constant. Thus, a stable stretch of the discharge began at a discharge current in the magnetron I_{dc} = (0,5-0,7) A. At decrease of Δl, a sustaining current of the supporting charge at which a stable current transmission occurred on the emission electrode, decreased too. At Δl = 0,4 mm the sustaining current was ~ 0,25 A.

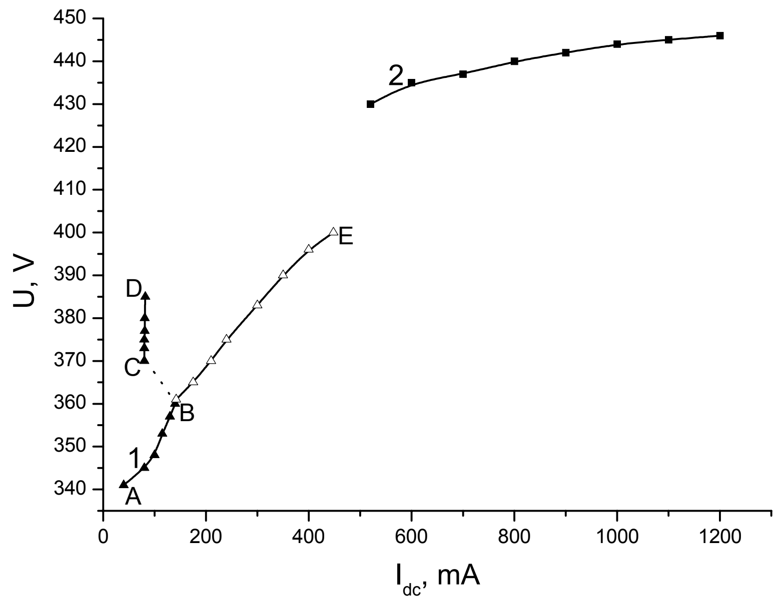

Figure 4. Volt-ampere characteristic of discharge in the gas magnetron (1) and discharge in the emission chamber (2) at $P_e = 1{,}5 \cdot 10^{-2}$ Pa.

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Fig. 4 shows a volt-ampere characteristic of the discharge in the gas magnetron (curve 1) and the discharge in the emission chamber (curve 2) at the following characteristics of interval: Δr = 1,5 mm; $P_e = 1{,}5 \cdot 10^{-2}$ Pa; Δl = 0,4 mm; l_e = 0,7 cm. After the discharge initiation, a voltage between cathode and anode falls from value U_b up to a value designated by a point A on curve 1. Further a volt-ampere characteristic corresponds to AB segment of this curve. At obtaining of the certain current (point B) a discharge initiation occurs in the emission chamber, and then the dependence of a current in the anode circuit from a voltage corresponds to CD segment. When the emission electrode is disconnected, then a volt - ampere characteristic corresponds to ABE curve. The change of gas pressure in the emission chamber results in a displacement of a point B: at its decrease a point B is displaced to larger currents, and at its increase - to smaller ones. The dependence of a current in the circuit of the emission electrode as a function of voltage (after voltage breakdown of the interval) is shown by curve 2.

The carried out experiment also has shown, that after electric breakdown of the interval, the pressure P_e can be decreased up to ~ $8 \cdot 10^{-3}$ Pa at the same discharge current, here a stability of discharge burning is not broken. In other words, a discharge burning occurs at a little bit greater pressure than its stable burning.

CONCLUSION

The work of three-chambered discharge system can be presented as follows. At first, a discharge initiation occurs in the chamber of high pressure 5. The formed plasma, at sufficient width of the annular slot 7, penetrates along a magnetic field into the chamber 6. The flow of penetrating plasma promotes an ignition of the discharge in it and also a formation of plasma at lower pressure, than in the chamber 5. Further, at fulfillment of certain conditions, plasma penetrates from gas magnetron into the emission chamber through the annular slot and initiates the development of an electronic avalanche in it. In the emission chamber the plasma of a tubular configuration is generated, to what the accurate circular trace on the emission electrode around the emission aperture testifies.

Due to formation of double layer before a narrow annular slot 9, delivering fast electrons into the area of local increase of working gas pressure flowing from a gas magnetron, in this peripheral plasma the favorable conditions for the vibrating excitation of molecules are created.

As a result of diffuse expansion of peripheral plasma across a magnetic field, a formation of plasma in the paraxial area takes place. The formed in such a way paraxial plasma, alongside with vibrationally excited molecules, also will contain the increased concentration of slow electrons, as the fraction of fast electrons does not penetrate into this area, because of action "of the magnetic filter" [4].

Thus, in the internal plasma, the necessary conditions for effective process of dissociative connection of slow electrons by vibrationally excited molecules with a formation of negative ions appear with a high probability [5].

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