ELECTRON SOURCES FOR PLASMA ELECTRONICS AND DIFFERENT TECHNOLOGICAL APPLICATION

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There are the following advantages of applying electron guns with plasma cathodes in devices exciting microwave radiation: stability of their parameters, high density of current, relative insensitivity to ion bombardment and the possibility of operating over a wide range of pressure values of a plasma-generating gas [1-5]. The given work aims at constructing the guns with the parameters necessary for the excitation of microwaves of high amplitudes in the slow-wave structures: the beam energy is 20-30 kV, the current is up to 5 A, and the pulse duration is 0,1 ÷ 1 ms.

The principal problem arising during construction of heavy-current electron sources with plasma emitters consists in the following: it is necessary to provide such conditions of the gas volume, under which the discharge firing would be stable and the emissive plasma generation be effective, whereas a gas breakdown in the accelerating gap must be eliminated.

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DETERMINING EMISSIVE PROPERTIES OF PLASMA CATHODES

Hybrid plasma structures operate under the gas pressure 10^{-4}-10^{-3} mm Hg, whereas the thermocathode can function under the pressure 10^{-6} mm Hg. Hence, some additional powerful pumping out is required. Firing of the gas discharge - in order to produce the plasma cathode under the pressure 10^{-4}-10^{-3} mm Hg - makes it necessary to realize conditions for oscillations of electrons. As it is planned to locate the plasma source inside the solenoid of magnetic field, oscillations of electrons become possible only in the magnetron-type system of coaxial electrodes [3]. The main our attention is given to investigations of this type of plasma sources from the viewpoint of finding the optimal conditions for its steady operation in the range of pressure values 10^{-4}-10^{-3} mm Hg, which is required for the hybrid HF tube. The scheme of experimental investigations is presented in Fig. 1.

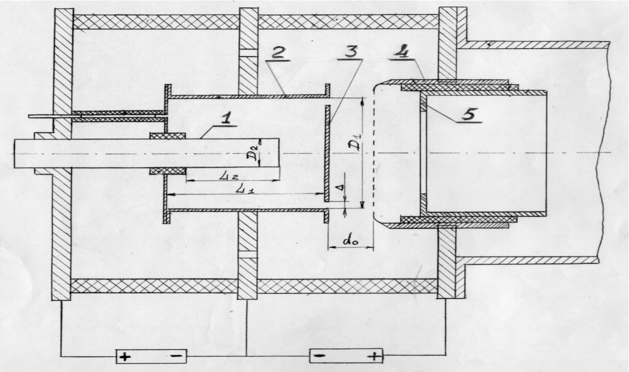

Fig 1. The scheme of experimental investigations.

1 is the magnetron anode, 2 is the magnetron cathode, 3 is the butt-end emissive electrode,4 is the anode in the accelerating gap, 5 is the collector, L_1 is the longitudinal size of the magnetron cell, L_2 is the anode length; D_1 and D_2 are the cathode and anode diameters, correspondingly; d_0 is the accelerating gap size, and δ is the width of annular emissive aperture.

The magnetron cell of discharge (discharge in the crossed fields $E \perp H$) is formed with the stainless-steel cylindrical cathode (the diameter 80 mm), the butt-end electrodes and the anode. Sizes of the latter (its diameter d and the length L) are variable during the experiment.

The process of gas discharge burning is under control through varying of electric voltage and the ballast resistance in anode-cathode circuit, pressure and the kind of gas, magnetic field voltage, the ratios d_1 / d_2 and L_2 / L_1 as well as through connecting of the emissive emitter 3 either to the cathode of magnetron or its anode.

The experiments are conducted in two regimes: 1. - when $d_1 / d_2 = 1{,}14$ and $L_2 / L_1 = 0{,}9$, and 2. -when $d_1 / d_2 = 4$ and $L_2 / L_1 = 0{,}9 \div 0{,}5$. If $L_2 \langle\langle L_1$ and the electrode 3 is coupled with the anode 1, the regime of hollow cathode comes into existence in which magnetic field is unnecessary for the electron oscillations. In the hollow cathode, we have succeeded in firing of the discharge under the pressure ~10^{-2} mm Hg, but high voltage ~5 kV is necessary for its emergence. The requirement of high voltage and relatively high pressure for realization of the discharge burning in the hollow cathode makes this device to stay in the background. The attention is mostly paid to the discharge firing in the coaxial magnetron cell. Regarding the electron emission from the magnetron cell, it would be better to get the same positive potential at both the external and butt-end electrodes. Therefore, attempts are made to firing of discharge in the modification where the cathode is placed inside the anode. However, increase of voltage with the source available up to 5 kV causes discharge firing only under the pressure $\geq 10^{-2}$ mm Hg in this case. If the external electrode of magnetron cell is under the negative potential (the inverse magnetron), the discharge is easily set on fire under the field durability $\leq$ 1 kV in the pressure range 10^{-4} - 10^{-3} mm Hg, in which we are interested.

All facts considered, investigation of self-sustained discharge of the «inverse- magnetron type» in crossed $E \perp H$ fields deserves cardinal attention as in this case the conditions for multiplying and oscillations of electrons are the best. This discharge can be fired even in high vacuum (down to 10^{-10} mm Hg and its the most suitable for our goal *t*o obtain the electron beam with plasma emitter operating under the gas pressure 10^{-4} mm Hg.

In Fig. 2, the curves of pressure- and gas-kind dependences of the discharge voltage are presented for various ratios of the cathode- to anode diameters. The curves 1, 2 and 3 are obtained when d_1 / d_2=1,14 and the curves 4, 5 and 6 are obtained when d_1 /d_2=4 (for He, N_2 and Ar, correspondingly). As the graphs indicate, the minimum pressure, under which the low-voltage glow discharge is burning $U_b \leq 500$ V, decreases with the increase of the ratio d_1 /d_2 and with the growth of the atomic number of the working gas. In our experiment, it's reduced down to 10^{-4} mm Hg in argon when d_1 /d_2=4. Under these conditions the butt-end electrodes are mechanically and electrically connected with the magnetron cathode - i. e., there is the case of the magnetoelectrostatic confinement of electrons generated in the discharge because of the gas ionization and secondary electron emission from the cathode. This regime is characteristic for the magnetrons applied as vacuum meters [6] and electromagnetic traps.

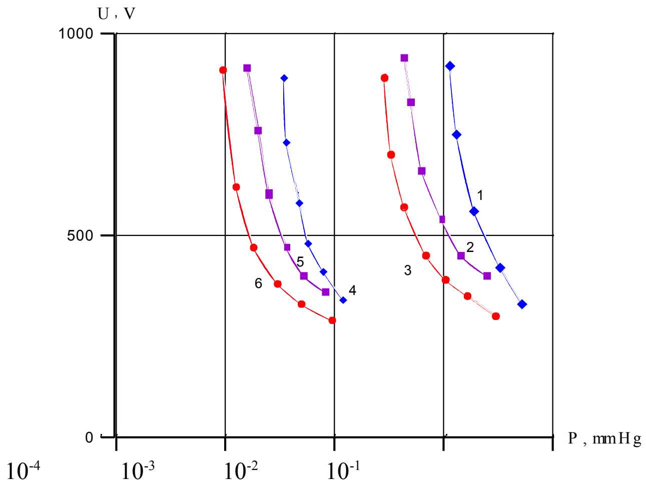

Fig. 2. The dependence of the discharge voltage versus the plasma-generating gas pressure.

Experiments shows that when d_1 /d_2 =4, not only the working pressure is decreasing, but also the magnetic field voltage goes down; its minimum is 200 Oe. Thus, for this discharge the magnitude of $(pd)_{ef}$ in Pashen curve makes 0,1-1 - i.e., if p=10^{-4} mm Hg, the effective path length of the electron reaches 10^3-10^4 cm. The current-versus-voltage characteristic (CVC) of the discharge in the heavy-current regime is demonstrated in Fig. 3 when the pressure is 3*10^{-4} mm Hg and the parameters p, H and d_1 /d_2 are optimized.

Duration of the diffusive stage of burning of the discharge δt is in the inverse proportion to the discharge current (if $t \geq \delta t$, the discharge enters the arc stage). As a matter of fact, for currents $\leq$ 10 A, the magnitude of δt could reach the value 10^{-3} sec after prolonged degassing of the electrodes with discharges. For currents $\rangle$ 10 A, as a rule, the discharge duration doesn't exceed 50 μ s.

So, it's found that the minimum pressure necessary for discharge firing decreases as the ratio d_1 /d_2 increases; it nonmonotonically depends on the magnetic field strength. This is explicable with the fact that, as the d_1/d_2 increases, not only the distance between the electrodes varies, but also the ratio of the anode- to cathode arias (in our case, S_a / S_c=0,15).

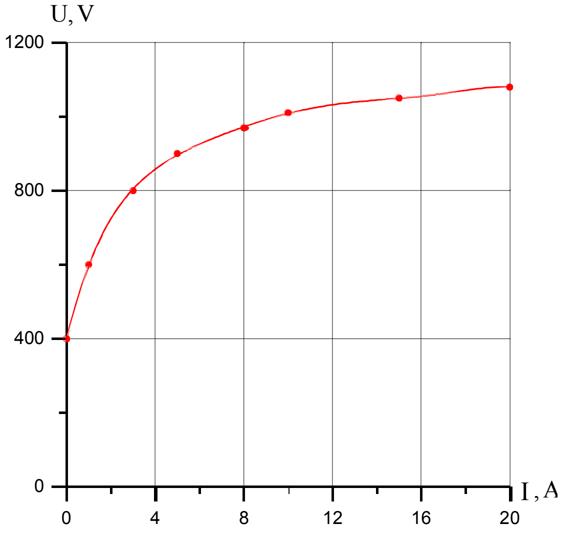

Fig. 3. The current-versus-voltage characteristic of the discharge in the heavy-current regime.

Probably, diminution of the anode area can cause prolongation of the electron life-time and, hence, the ionization effectiveness increases as well. The following fact also affirms this statement: the minimum pressure for the discharge firing decreases as the L_2/L_1 diminishes. However, it should be noted that the decrease of L_2 / L_1 down to the value $\leq$ 0,5 worsens the characteristics of burning. This could be conditioned by the fact that in this case the discharge is burning only in the anode gap.

The results presented in this subsection demonstrate that it's easy to fire the gas discharge in the system of the «inverse magnetron» -type in the low-voltage ($U \leq 1000$ V) regime under low pressures (down to values of the order of 10^{-4} mm Hg). In the gas discharge, plasma density reaches the value $\approx 10^{12}$ cm^{-3} when the discharge current is ~ 50 A. This plasma density can provide the electron emission with the current density $\approx$ 5 A/cm^2 , which is no worse than in modern powerful thermocathodes. Realization of discharges under the given pressure is possible only in the case when the butt-end electrodes serve as reflectors of electrons - i.e., in the regime of the magnetostatic confinement of plasma.

So, principal results of the investigations consist in the following: a possibility of maintaining a self-sustained gas discharge under pressures over the range 10^{-4}-10^{-3} mm Hg, which makes the necessary condition for operation of hybrid plasma- filled slow-wave structures, does really exist. Hence, in principle, construction of the isobaric HF tube with plasma cathode is possible.

The electron emission from a plasma cathode is realized by applying a high voltage across the area between the discharge cell and the accelerating electrode (the latter is a grounded fine-mesh grid) through an opening in the butt-end electrode (the discharge gap cathode) - see Fig. 2 in the section 2. The experiments are carried out in both the cases when $\delta r \leq l_{c.d.}$ and $\delta r \rangle l_{c.d.}$ (δ r is the aperture size). As it's found, when the emission annular aperture is $\approx$ 2-3 mm, is comparable with the size of $l_{c.d.}$, any essential emission of electrons from the magnetron discharge isn't observed. As a matter of fact, in the isobaric gas regime under the pressure $\leq 10^{-3}$ mm Hg, the emission has been detected only when the circular aperture with the diameter > 10 mm has been used - i.e., in the case when $\delta \quad r \rangle l_{c.d.}$. This regime corresponds to the emission from a free plasma boundary. Another regime (when δ $r \leq l_{c.d.}$) could provide emission only by virtue of the dip of the accelerating electrode voltage.

The curves in Fig. 3 depict the emissive ability of the PSE of the inverse-magnetron type in the case of the injection through the butt-end electrode under the cathode voltage. The curves demonstrate the dependence of the emission current versus the accelerating voltage for various values of the discharge current. The curves 1, 2, 3 and 4 are obtained when I_d = 2, 4, 6, and 8 A, correspondingly (the emissive aperture diameter is 10 mm). The injection efficiency, determined as $\alpha = I_{em}/I_d$ weakly depends on the discharge current, being of the order of 0.2 - 0.25. The practically achievable duration of the injection pulse varies from 0.5 ms up to 0.05 ms under the discharge currents 10 A and ≥ 50 A, correspondingly. In the latter case, the injection pulse duration is restricted by the development of the discharge in the accelerating gap. The discharge transition into an uncontrollable arc phase has been observed under the discharge currents ≥ 100 A; it doesn't influence the injection pulse duration.

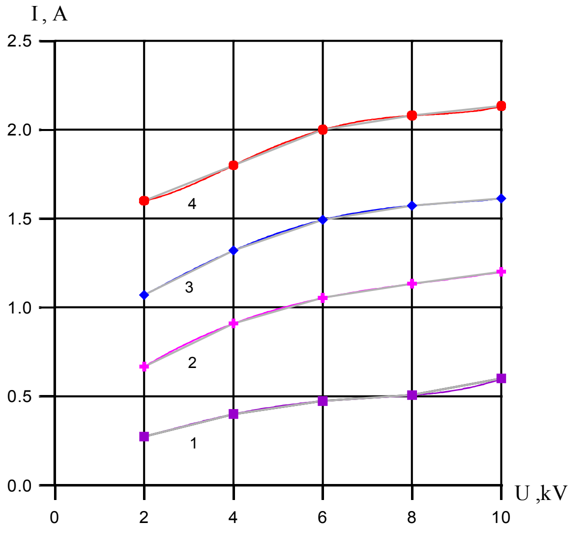

Fig. 4. The dependence of emission current versus the accelerating voltage.

The empirical scaling $j_{em} \cdot \Delta t \leq 5*10^{-5}$ A/cm^2*sec is obtained. Under this conditions the emitter can reliably operate in the pulse-periodic regime. So, with the plasma cathode submitted, the current density 0.1-1 A/cm^2 is achievable, which suits the experimental investigations of temperate-power microwave devices.

CONCLUSION

The results of the work can be formulated as follows:

1. In the systems of the «hollow cathode» - and «inverse magnetron» -types, the experiments on firing a gas discharge and controlling its parameters are carried out. They permit to determine the principal parameters of gas discharges in the systems mentioned and optimize them with respect to the minimum expenditure of the plasma-generating gas and the minimum magnitudes of the electric and magnetic fields which are necessary for the discharge burning. In the system of the «inverse magnetron»-type, the firing and steady burning of the discharge is realized: currents are up to 50 A in the low-voltage regime ($U_b \leq 1000$ V) under the gas pressure ≈ 10^{-4} mm Hg. Realization of such discharges is found to be possible only in the case when the butt-end electrodes reflect electrons - i.e., in the regime of magnetoelectric retention of electrons.

2. Experiments on electron emission from a plasma discharge of the « classical inverse magnetron»-type have been carried out. It's demonstrated that under the low pressure 10^{-4} mm Hg the discharge can be used for constructing a plasma cathode of a circular aperture in the butt-end electrode only in the case when the latter is connected with the magnetron cathode in the case of the electron emission from the plasma free boundary. The emission through a circular aperture of the diameter 10 mm in the butt-end has been obtained, the emissive current being 2 A under the voltage 20 kV. Such a system may be recommended for applying in a slow-wave structure of the «chain of coupled cavities»-type in the investigations of the isobaric mode of operation.

3. An annular electron beam of a large diameter has been excited (the diameter is 80 mm, the rim is 5 mm); its power is up to 200 kW (the accelerating voltage is 25 kV; the injection current is 8 A) under relatively low pressures of the working gas (~$5*10^{-4}$ mm Hg).

4. These experiments are of the independent value because the plasma cathodes are examined with respect to their application in generators of microwave radiation and other electron devices. As it should be especially noted, the experimental data indicate that, in general, it's possible to use plasma cathodes for realization of the isobaric mode of operation of the microwave device when the plasma-generating gas pressures could be equal in both the areas of discharge burning and beam-plasma interaction (hybrid slow-wave structures). This permits to construct a hermetic modification of a powerful microwave device without applying any of additional effective vacuum pumps.

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