GENERATION OF ELECTRON BEAMS IN MAGNETRON GUNS WITH SECONDARY EMISSION CATHODES OF A SMALL DIAMETER

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This paper is concerned with investigations on electron beam generation in magnetron guns with cold secondary-emission metallic cathodes of a small diameter with a large aspect ratio. The parameters of electron beams are given as a function of electric and magnetic field values using different methods of voltage pulse formation for secondary-electron multiplication and beam generation.

Introduction

Investigation of magnetron guns with cold metallic cathodes operating in the secondary-emission regime [1-8] is related to a number of advantages (long life-time, high current density, comparative simplicity of construction etc.) that allows one to use them as electron sources in the accelerator technique and for development of powerful long-living RF-devices [2, 9-11]. A principle of operation of such guns is based on back bombardment of a cathode with primary electrons. There takes place the process of secondary- electron multiplication, electron cloud formation and electron beam generation [1-4, 8] in crossed electric and magnetic fields. The magnetron guns with a small aspect ratio of anode diameter to cathode diameter (so-called " plane" geometry) are investigated adequately. At the same time, with cathodes of small diameters and, respectively, large aspect ratio the behaviour of electron motion in the anode-cathode space can be changed appreciably that is connected with a very nonuniform electric field in a cylindrical geometry of the gun. The present paper is concerned with investigations on the electron beam generation in magnetron guns with secondary- emission cold metallic cathodes of a small diameter (2 mm).

Experimental facility and research methods

Investigations on electron beam generation in magnetron guns with cold secondary- emission metallic cathodes of a small diameter were conducted at the facility the schematic diagram of which is represented in Fig.1. In these experiments the pulse of a negative polarity from modulator 1 forming the voltage pulse (amplitude 4 to 100 kV, duration 4 to 10 μm and repetition rate 50 Hz) is feeded to cathode 5 of the gun and its anode 6 is grounded via resistor R_3 and connected to pulse generator 2. In the first case the process of secondary-electron multiplication took place at the falloff of the voltage pulse having a special shape which was formed by modulator 1, and in the second case it ocurred at the falloff of the voltage pulse of generator 2.

The magnetron gun with a copper cathode of 2 mm in diameter and an anode made from stainless steel or cooper having 120 mm length was placed inside vacuum chamber 3 evacuated to a pressure of $\leq 10^{-6}$ Torr.

A magnetic field for beam generation and transport was created by solenoid 4 composed of 4 sections with a total length of 550 mm, taking a current from separated sources of electric power that made it possible to change a spatial distribution of the magnetic field and its amplitude. The beam transport was done at a distance of 80 to 160 mm from the anode end face to the Faraday cup.

The beam current was measured with Faraday cap 7 fabricated in the form of a coaxial line part and resistor R4 =12 Ohm equal to the wave-making resistance of the line; the voltage on the cathode was measured with a divider R_1R_2. The beam spot size was measured using the beam spot image on X-ray film and on the molibdenum foil placed at the end of the coaxial line.

Experimental results and discussion

1) Peculiarities of beam formation in magnetron guns. In papers [6, 8] is shown that in magnetron guns with secondary-emission cathodes a tubular electron beam is formed. The inside beam diameter is equal approximately to the cathode diameter, and the wall thickness is from 1.5 to 2 mm. To obtain small transversal dimensions of the beam we studied experimentally the generation of beams and measured their parameters in every of guns with a cathode diameter of 2 mm and anode diameters of 10 mm, 22 mm, 50 mm and 78 mm. In these experiments the aspect ratio was (R_a/r_c), i.e. the value of the ratio between the anode radius R_a and the cathode radius r_c was measured in a wide range from 5 to 39. This range of the aspect ratio practically is not studied.

The electric field in the anode-cathode space necessary for beam generation should have two time intervals: the first one is the part with a field falloff where the secondary-electron multipication and cloud formation take place around the cathode, and the second one is the part with a steady field providing a stationary stage of the secondary-emission process and beam generation [1, 3, 8]. The sharpness and duration of the droop determine the stability of beam generation and temporary instability of the beam- current pulse front. The value of falloff sharpness which ensures the process of secondary-electron multiplication should be higher than 20- 30 kV/μs [1, 8]. Further, at a steady amplitude of the pulse top a stationary stage of beam generation takes place. A nonuniformity of the pulse plane part can lead to modulation of the beam current pulse or to its breakdown on nonuniform top parts of the voltage pulse or to generation of several electron clusters in one voltage pulse [8], as well as determines a permissible spread of electron beam energies. Therefore, when carrying out the experiments much attention has been given to forming the required time dependence of the voltage between cathode and anode of the gun. A given time dependence of the electric field between cathode and anode is reached by forming the voltage pulse of a special form with an surge droop at the top with a short falloff and long plane part on the cathode (in this case generator 2 is off) or with simultaneous feeding of two voltage pulses onto the cathode (a pulse of long duration with a plane top) and the anode (pulse of a short duration from 2 to 80 ns with a falloff sharpness up to 1000 kV/μs) forming a given electric field.

2) Investigation of beam generation processes and measurement of beam parameters.

Investigation of beam parameters has been carried out with the use of both methods of forming a voltage pulse. Experiments show that the amplitude of the beam current at the Faraday cup has a threshold dependence on the falloff sharpness and does not depend on the excitation scheme of the secondary-emission process. Fig.2 represents the current at the Faraday cup as a function of the voltage amplitude on the cathode for a diameter of 2 mm and anode diameter 10 mm (curve 1), 22 mm (curve 2), 50 mm (curve 3). It is seen that the measurement results are in agreement with the calculation for a current by “3/2” law. In the course of measurements in each of voltage pulse, the value of magnetic field was set by the maximum value of beam current. For example, in the gun with a 2 mm cathode diameter and 50 mm anode diameter at the 50 kV voltage amplitude on the cathode, a beam current of 7A was obtained that corresponded to the pulse power in the beam of 350 kW and to the microperveance of ~ 0.6. The magnetic field strength was 2600 Oe.

We have carried out the studies on electron beam generation in magnetron guns with a cathode diameter (d) of 2 mm and anode diameters (D) of 50 mm and 78 mm depending on the value of magnetic field amplitude. It is shown that for the voltage amplitude in a plane pulse part from 40 to 55 kV and low magnetic fields (from 700 to 1200 Oe) the generation of electron beams with a current from 0.5 to 1.5 A takes place. The Hull cutoff field in this case was ~400 Oe and ~600 Oe, respectively, and the outside diameter was ~15 mm. The increase of the magnetic field up to 2500 - 2700 Oe resulted in obtaining the electron beams of 5 to 7 A. In this case the beam of the magnetron gun with 2 mm cathode diameter and 50 mm anode diameter at a distance 130 mm from the anode end face has had the outside diameter of ≥ 4 mm and the inside diameter of ~2 mm.

In the table given are the values of current on the Faraday cup, voltage on the cathode U, magnetic field strength H for the 2 mm cathode diameter and different anode diameters (from 10 to 78 mm).

Table

No	D, mm	D, mm	U, kV	I, A	H, Oe
1	2	7	6	1.4	3000
2	2	10	12	4,0	2800
3	2	22	32	6	2800
4	2	50	50	7	2600
5	2	78	55	1	1100

As is follows from the above results at small magnetic fields the Larmour electron radius is rather large but the electrons being in motion acquire the energy sufficient for secondary-electron multiplication and beam generation. The electron layer takes a significant area of the interelectrode space near the cathode in a tranverse direction. And a potential dip in the cathode-anode space associated with a spatial charge of the electron layer provides a process of secondary-electron multiplication and beam generation at the stationary stage of gun operation. At large magnetic fields the Larmour radius decreases and tranversal dimensions of the electron layer near the cathode are appreciably less. In this case the potential dip is larger and this provides the electron energy increase up to the value necessary for developing the secondary-electron multiplication on the lesser length. This enables one also to have a higher space charge of the electron layer and, as a consequence, a larger beam current. From the foregoing it follows that, probably, in the guns with a large aspect ratio, there is a broad zone (or several zones within it) of beam generation depending on the magnetic field with different transversal dimensions and beam current values.

In Fig.3 one can see the beam microperveance in the magnetron gun (with the 2mm cathode diameter) as a function of the anode diameter. The figure shows that the microperveance value is changing in wide ranges and the measurement results are in good accord with the perveance dependence on the anode diameter as $1/(R_a\text{-}r_c)$. It can be explained by that the electron currrent dependence in the elongated cylindrical diode at a direct voltage on the cathode and a rather large aspect ratio ($(R_a\text{-}r_c > 5$) varies inversely with the anode radius (see, e.g. ref [2]).

Conclusion

The investigations we have carried out show a possibility to initiate the secondary-electron multiplication and beam generation by different methods of voltage pulse formation. The experiments prove the existence of a broad zone of magnetic field for beam generation in magnetron guns with a large aspect ratio. In magnetron guns with cold secondary-emission metallic cathodes of a small diameter and a large aspect ratio, the formation of the electron beam with different radial dimensions depending on the magnetic field value takes place. At the magnetic field stress of ~2500 Oe the electron beam with an outside radius ≥ 4 mm and particle energy from 5 to 60 keV were generated.

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Figure captions

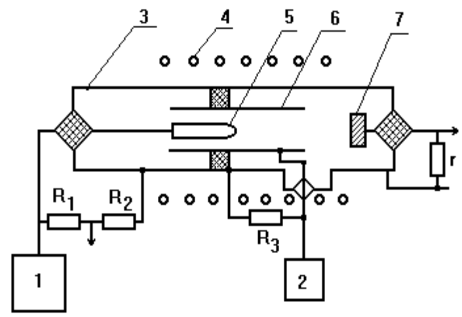

Fig.1.Schematic diagram of the experimental facility

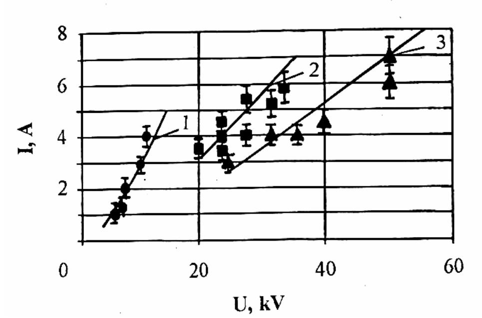

Fig.2.

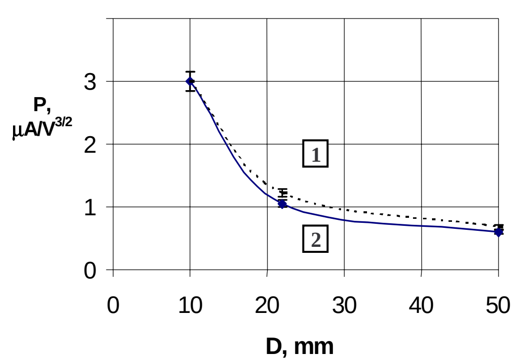

Fig.3.Microperveance versus anode diameter.
1 - calculated curve; 2- experimental curve.