STUDYING THE PROCESSES OF ELECTRON BEAM FORMATION IN MAGNETRON GUN WITH SECONDARY EMISSION METALLIC CATHODES

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INTRODUCTION

Recently a great attention of specialists has been attracted to researches of magnetron guns with cold cathodes of both usual [1-6] and reverse [6,7] types, which work in the regime of secondary emission. The interest in such guns is caused by a number of their advantages (a long lifetime, high density of current, rather simple design, etc.). These advantages allow using the magnetron guns with the cold secondary-emission cathodes in the process of creating powerful RF sources of a long lifetime [3] as well as high-speed high-voltage pulse engineering [8]. The principle of magnetron gun operation is based on back bombardment of a cathode (at voltage recession) by electrons accumulated in a gap between a cathode and an anode; secondary-emission multiplying of electrons, creation of an electron cloud and removal of electrons out of a gun. These problems were studied in papers [1-5]. However there is lack of both experimental and theoretical papers on research of different aspects of beam generation. Particularly, it is interesting to investigate time of space charge accumulation in magnetron diodes at large velocities of voltage recession (>1000 kV/ ms), on the one hand, and in short periods of voltage recession (1-10 ns), on the other hand, at a magnetic field larger than that of Hell cut off (H>Hkp).

EXPERIMENTAL INSTALLATION AND RESEARCH TECHIQUE

The present work is devoted to an experimental research of beams formation and their parameters measurement with nanosecond times of a starting pulse recession, numerical modeling of electrons trajectories in magnetron guns with secondary emissive process start by recession of voltage pulse from the external generator. Experiments were carried out at the installation which circuit is shown in Fig. 1. The power to the gun is supplied from the modulator (1) that forms a rectangular voltage pulse with the amplitude **U** of 4 -- 100 kV, pulse duration of 2 - 10 μs, pulses frequency of 10 - 50 Hz. The pulse of negative polarity is applied to the cathode 5 of the gun. Anode 6 of the gun is grounded.

The external pulse generator (2) with voltage amplitude **Ut** of 1.5 -- 15 kV and duration of recession **τ** from 1.5 up to 15 ns was used to start the secondary emissive process.

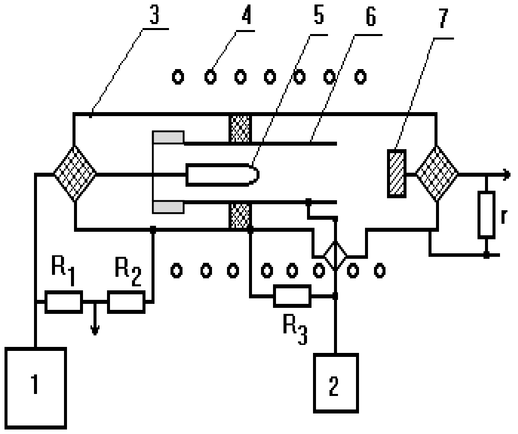

Fig. 1 - Experimental installation circuit.

It allowed to change a steepness of voltage recession from 100 up to 1200 kV/μs. To determine time characteristics of trigger pulse chains the measurements of its parameters have been made. The oscillograms of a signal applied between a gun cathode and anode received for two cases are shown in Fig.2.

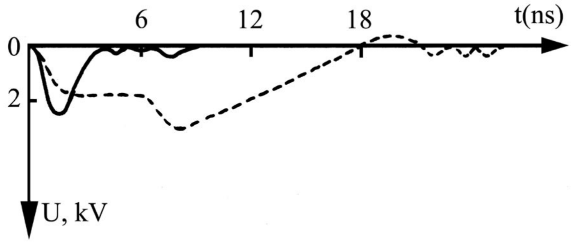

Fig.2. Form of a trigger pulse.

In the first case generator pulse duration was equal to 2 ns, in the second case 10 ns. On an anode of the diode the signals were registered by an oscillographer I2-7 (a band width = 3000 MHz). It is seen that the fall-time of a trigger pulse is so little as 2 ns and 11 ns relatively.

The magnetic field was formed by the solenoid (4) with magnetic field **B** intensity up to 3000 G and heterogeneity of ~±8% in the longitudinal direction. Fig. 3 shows the distribution of magnetic field intensity along the solenoid axis, the arrangement of magnetron gun and Faraday cup. The measurement of beam current was made with the help of the Faraday cup (7) and resistor **r** and sizes of the beam - with the help of imprint on a x-ray film and on Mo foil.

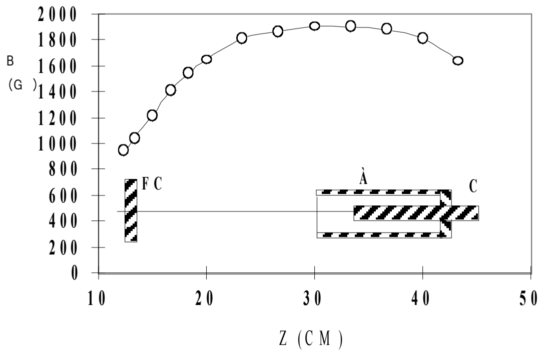

Fig. 3 - Distribution of magnetic field along the solenoid axis and gun arrangement (FC - Faraday cup, A - anode, C-cathode).

EXPERIMENTAL RESULTS AND THEIR DISCUSSIONS

The dependence of electron beam parameters from the geometrical sizes of the gun were investigated within the limits of change of the cathode (**d**) and anode (**D)** diameters 1 -- 3 mm and 5 -- 14 mm, respectively (gun length -- 100 mm).

d мм	D, мм	U, кV	I, A	B, T	Ut, кV	τ, ns
2	**7**	**7**	**1.9**	**0.3**	**2.4**	**2**
2	**10**	**5**	**0.8**	**0.19**	**4**	**13**
2	**10**	**7**	**1.6**	**0.21**	**3**	**11**
3	**14**	**8**	**2.3**	**0.14**	**3**	**14**

The table shows that in the magnetron gun there is a current beam generation at a voltage of 5...8 kV on a cathode. This is a new result, as in the papers of other authors the value of a minimum voltage when stable beam generation begins is equal to 12 kV [9]. In our case the secondary emission multiplying and electron cloud forming take part at less voltage, when an energy of electrons bombarding a cathode surface (300...600 eV) is about 10% of an energy of beam particles. On the other hand, time of electron cloud forming is some nanoseconds, that pointed out to the fact, that due to a rapid voltage recession, electrons get energy required for the secondary electron multiplying for some hyroperiods. In the case, when a space charge cloud has already formed, the process of the secondary emission multiplying at a steady state remains unchangeable for a long period of time, and a diode works in a self-support regime.

The current could be generated in various moments of time on the voltage pulse plateau by changing the beginning of the secondary emission. Fig. 4 shows typical oscillograms of voltage pulses on the cathode, pulse of secondary emission start and current of the beam from the Faraday cup. The measurement of beam current dependence on the steepness of recession has shown that the dependence has threshold character. So, the start of the magnetron gun (cathode and anode diameters are 2 mm and 7 mm, respectively) with the cathode voltage ~ 7 kV occurred only with the steepness of recession more than 1000 kV/µs (voltage amplitude of starting pulse ~ 2.4 kV, duration of recession ~ 2 ns). The electron beam with the current of ~ 2 A was received with the minimal meaning of cathode voltage ~ 7 kV and magnetic field ~ 3000 G.

The generation of a beam with the minimal voltage on the cathode of 5 kV occurs with the minimal steepness of recession of 300 kV/µs (voltage amplitude of starting pulse is 4 kV, duration of recession is 13 ns) in the moment of start of the magnetron gun with other geometry (cathode and anode diameters are 2 mm and 10 mm, respectively).

Thus, the current of the electron beam 0.7 -- 0.9 A was received with the magnetic field of about 1900 G.

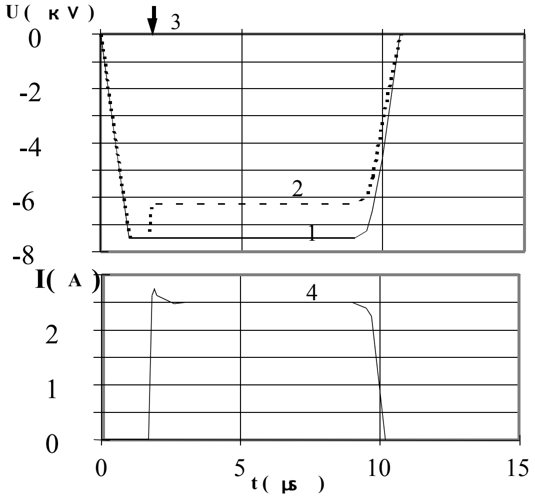

Fig.4. Oscillograms of pulses (1 - voltage of free running modulator, 2 - with beam generation; 3 - a moment of trigger pulse applying; 4 - current of the beam).

The received experimental results show, that in the first case the electronic beam arises through ~ 1.5 - 2 ns and in second one through ~ 10 ns after amplitude recession of start pulse. It was also observed on downloading of voltage pulse on the cathode (see Fig. 4). Thus the temporary instability of the beam's current pulse beginning does not exceed the duration of start pulse and can reach the nanoseconds units. In these experiments the magnetic field changed according to change of electrical one and optimized from the beam's generation point of view.

Changing cross sizes of beam, it was revealed that in both cases the beams in crossed section look like rings with uniform distribution of intensity on azimuth with internal diameter approximately equals to that of the cathode with thickness of the “wall” of ≈1 mm. The measurement of the beam's sizes was made on distance of 180 mm from the anode cut off. Thus, as follows from a curve (see fig. 3), the magnetic field near to x-ray film arrangement decreased approximately in 1.8 times in comparison with that the magnetron gun is situated in.

The given results show that the electron beam is magnetized enough strongly because when moving through the defocusing magnetic field its sizes practically do not change in comparison with that ones at 5 cm distance behind the anode cut off. It can be used with injection of electron beam from the magnetron gun into other systems.

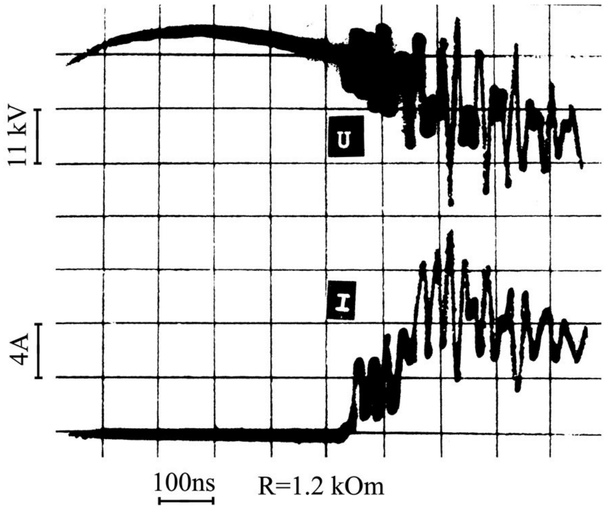

Fig. 5. Pulse oscillograms.

Calculations executed in one-partial approximation confirm the above given results. They show that electrons flowed from the cathode at recession of the start pulse voltage can collect the energy > 300 eV which is sufficient for secondary emissive duplication during 1 ns. It does not contradict to calculations executed in the work [9] for cylindrical magnetron diode with the secondary emissive cathode. In this case the quantity of primary electrons is insignificant but as the steepness of recession is great the process of secondary emissive duplication goes rather effectively.

It should be to noted that in experiments executed with magnetron guns within the limits of cathode diameter change from 5 mm up to 80 mm and anode one from 26 mm up to 140 mm in the mode of autostart [4] with the steepness of recession 20...50 kV/µs, the start of the gun occurred through 100...500 ns (depending on experiment conditions) from the recession beginning of the voltage pulse. In this case it is necessary to accumulate significant number of primary electrons for creation of the electron layer of spatial charge. Therefore, the process of accumulation is longer in time and also carries a statistical property with disorder of tens nanoseconds that defines the temporary instability of the current pulse beginning. In our case, time non-stability is some nanoseconds, that is very important for RF-systems and high-speed high-voltage pulse engineering.

Influence of a value and distribution of a longitudinal magnetic field on the beam generation has been investigated. It was shown, that at enlargement of a magnetic field, beam current on Faraday cup increases rapidly, it also has a flat plateau and rapid recession. This is caused by a change of trajectories as well as by conditions of electron getting energy in a anode-cathode gap when changing a magnetic field.

A change of magnetic field distribution in a gun results in a change of a form and an amplitude of a beam current pulse. Thus, in a magnetron gun (cathode diameter -5 mm, anode diameter - 50 mm, voltage on a cathode - 60 kV), when changing a magnetic field from 1,4 to 2 kG, the beam current changes from 1 to 10 A. Moreover, as in the experiments a magnetic field was created due to a solenoid, which consists of 4 coils, it was possible to change an amplitude and longitudinal distribution of a magnetic field and to create conditions of multi-peaked character of electron beam generation due to adjusting current in the coils. A value of the current in the second coil in the field of magnetron gun location influences this process essentially deep. At a voltage on a gun cathode of 55 kV and at a magnetic field power of 1150 G an electron beam pulse has been obtained with an amplitude of 15 A and duration of 8 µs (cathode diameter - 40 mm, anode diameter - 78 mm). At reduction of a magnetic field up to 700...800G a beam current pulse gets a multi-peaked character (Fig.5) with a generation period from 10...30 ns up to 1 mks and with a current amplitude value of 15A.

CONCLUSIONS

The carried out researches have shown the possibility of spatial charge accumulation during 1.5 - 2 ns and reception of electron beam with the cathode voltage of 5 -- 7 kV.

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