COMPACT DYNATRON MODULATOR

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It is proposed to use a dynatron effect to modulate the voltage across the vacuum inverted coaxial diode with magnetic insulation supplied by an external pulsed high-voltage source connected to the modulator via the RL-circuit. Oscillations of the voltage due to oscillating regime of diode charging and/or azimuthal instability of a rotating electron flow stimulates back-bombardment electron flow to the cathode and leads to power spikes of secondary emission current exceeding the primary one. As a result, the amplitude of oscillations grows and the system can turn to self-supporting regime. Results of computer simulations are given to illustrate the main physical processes inside the modulator and its possible applications.
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1 INTRODUCTION

In investigating regimes of self-sustaining secondary emission of electrons in devices with crossed ExB fields main attention was paid to analysing the dynamics of intense electron beam formation with a dominant influence of the space charge in geometrically simple magnetron guns. These can be considered as a coaxial diode in an external magnetic field where the inner electrode serves as a cathode [1 – 5]. In papers [4, 5] it was proposed that the secondary emission of electrons be used to capture and store particles in a magnetron diode as an intermediate stage in forming a short pulse beam of a large charge. To control (initiation and quenching) the secondary emission, its threshold characteristics, and dependence on angle of incidence and energy of particles were used. After a certain transition process, such integral characteristics as voltage on the diode, current in the external circuit and average number of particles in the accelerating gap reached a constant level. At the same time, there arose within the gap regular structures of electron flows in dynamic equilibrium with large (comparable to the external) variations of electric fields.

In inverse coaxial diode, where the external electrode is the cathode, would appear to be quite attractive. For the same external dimensions, one could expect to obtain large currents from the cathode. Investigation of non-stationary regime of operation of inverted magnetron diodes showed that in a certain range of parameters such a device with a secondary-emission cathode and external circuit is capable of operating in a self-generator regime at rather large frequencies.

2 PHYSICAL PROCESSES IN AN INVERTED MAGNETRON DIODE

As a rule, when analysing the non-stationary dynamics of intense beams in such devices, the external circuit is not considered. The regime of operation, for that or other reasons, is chosen from the condition of aperiodic charging of a capacitance, which the diod represents. At the same time, inclusion of an external RLC-circuit with a source of voltage $V_0(t)$ in the scheme of calculation is necessary. This is particularly so when modelling non-stationary processes.

When there is no emission of particles in a magnetron diode, it can be represented by a condenser C charged by a voltage $V_0(t)$ from a source of voltage via an additional RL-circuit. In the general case the charge can occur in an oscillating regime with natural frequency of damping oscillations $\omega = (\omega_0^2 - \delta^2)^{1/2}$, where $\omega_0 = 1/(LC)^{1/2}$ and $\delta = R/2L$ - is damping constant. If in the diode there is a constant emission of primary beam and a cathode with secondary emission is used, then these voltage oscillations on the diode represent "seeding" for the growth of secondary emission. In the usual magnetron diode, where the inner electrode serves as the cathode, these oscillations promote rapid growth of the secondary-emission process. However, the characteristics of the beam insignificantly differ from the case of aperiodic charging. In an inverted magnetron diode, where the outer electrode serves as the cathode, these oscillations can increase and develop into a self-sustaining regime (self-generator) in a certain range of parameters.

From the physical standpoint, the pattern of the processes is quite simple and, generally speaking, constitutes simply manifestation of the dynatron effect used earlier in electric bulbs. Suppose that from the external electrode of the diode electrons are continuously emitted (for example, as a result of thermal emission) with noticeable current. With increasing voltage on the diode, the emitted electrons cannot return to the cathode and accumulate in the gap. A drop in voltage on the diode as a result of oscillations leads to an increase in the back-bombardment of the cathode. This causes an abrupt spike of secondary emission current, which to an even greater extent "pulsed" voltage on the diode. As a result, the accelerating gap may be completely cleared of all electrons in it if the voltage changes sign or some of them if the voltage sign does not change.

The difference in the behaviour of direct and inverted-polarity diodes is that in a certain range of parameters the beam in an inverted diode is strongly unstable with respect small voltage variations and the large cathode surface permits briefly drawing from it large secondary emission currents, thereby securing deeper modulation of the voltage on the diode. After withdrawing the charge in the gap, the diode again begins to charge and if the emission of the primary beam is continuos the process is repeated.

3 RESULTS OF COMPUTER SIMULATIONS

The dynamics of voltage on an inverted magnetron diode was investigated by means of KARAT code [6] in two two-dimensional geometries. In the first case, it was assumed that the beam is homogeneous in the axial (z) direction. In the second case - homogeneous in the azimuthal (θ) direction. Calculations performed for the model of a circuit with lumped parameters can also be generalised for the case of systems with distributed parameters.

3.1 r-θ-Geometry

Below are presented calculation results for a magnetron diode with anode radius r_a = 0.66 cm and cathode radius r_c = 1.06 cm. The diode is immersed in a magnetic field B_0 = 3 kGs. By way of example, here was chosen a trapezoidal form of external voltage pulse. The rise time and fall of $V_0(t)$ was 8 ns and the flat top had a duration of 8 ns. The chosen coefficient of secondary emission was the standard for a metal [1]. The voltage amplitude at the external source was 50 kV. For the given variant of calculations illustrating the possibility of operation an inverted magnetron diode in a self-generator regime, we chose a constant primary beam emission current from the cathode of 30 A from 1-cm unit length in the z-direction. A reduction of primary beam emission current leads to a change in the modulation of voltage.

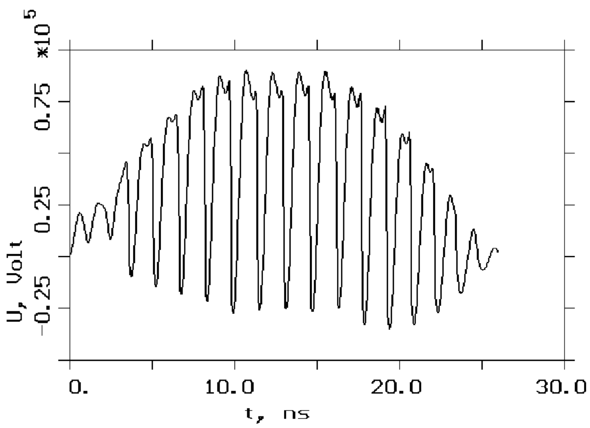

Fig. 1. Behaviour of the voltage on the inverted diode.

Fig. 1 shows the behaviour of voltage on the diode. The dynamics of changing the number of primary ("b") and secondary ("e") electrons in the accelerating gap and the spiking behaviour of secondary-emission current (in amperes) can be seen in Fig. 2.

The frequency of voltage oscillations on the diode is approximately equal to the natural frequency of the circuit and correspondingly at least in a certain range, can be regulated by external parameters. The amplitude of oscillations and average voltage also can be regulated by a choice of the existing parameters, in particular, magnetic field and primary beam emission current.

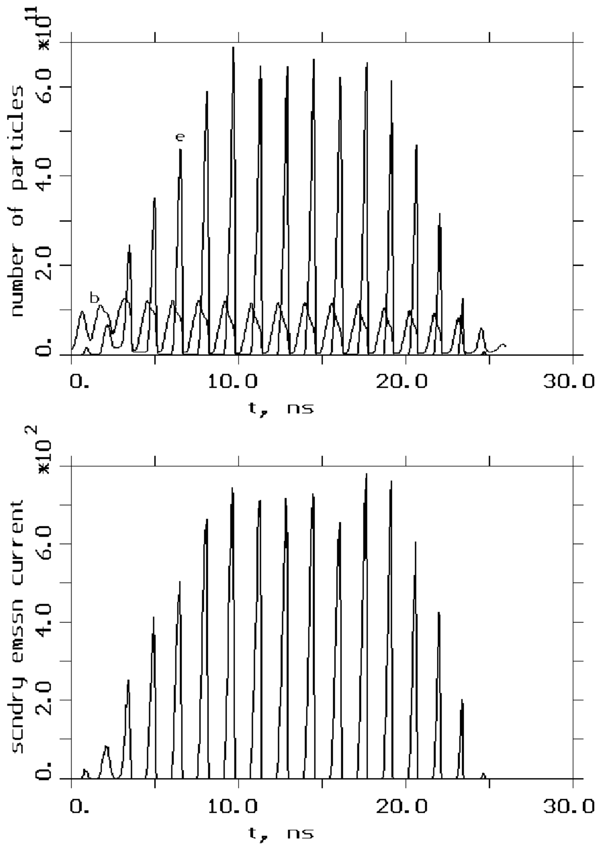

Fig. 2. The dynamics of the change in the number of primary and secondary electrons in the accelerating gap and behaviour of secondary emission current.

3.2 r-z-Geometry

Approximately analogous results are also obtained in r-z-geometry. Fig. 3 shows the geometry of the gun.

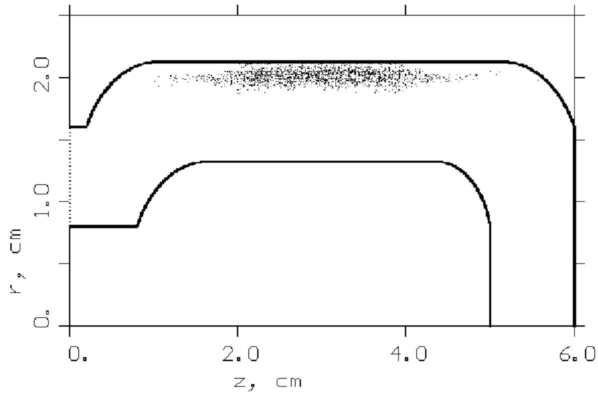

Fig. 3. Gun geometry.

The primary beam of 50 A is emitted from a flat part of cathode of radius r_c = 2.12 cm and 2-cm long in the axial direction. The anode radius r_a = 1.32 cm and rise time of the external voltage $V_0(t)$ to the maximum value of 25 kV is 8 ns, after which the voltage holds constant. The magnetic field in the given case is 1 kGs. The behaviour of the voltage on the diode and the frequency spectrum of oscillations are presented in Fig. 4. In this case, the coefficient of secondary emission is increased

1.5 times relative the results of calculations for the r-θ-geometry.

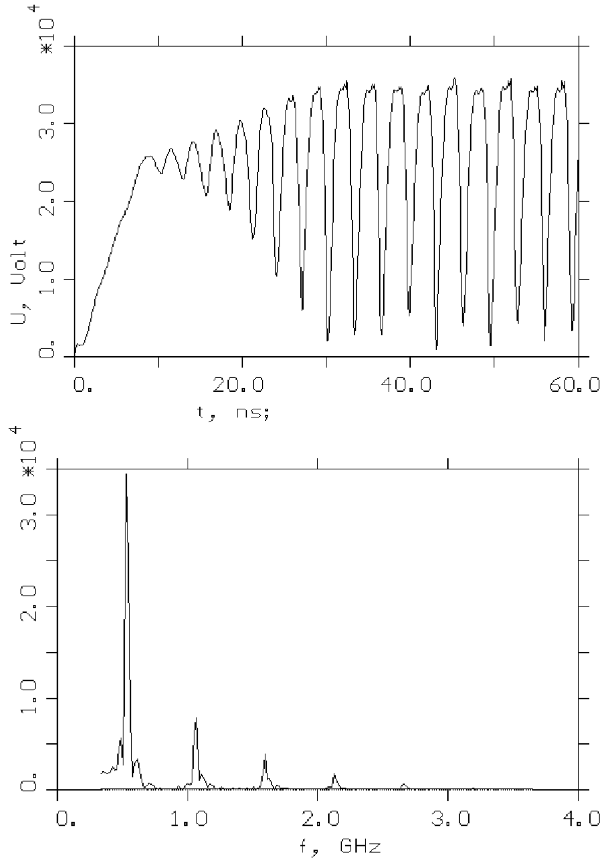

Fig. 4. Behaviour the voltage on magnetron gun and frequency spectrum of oscillations.

It should be noted that the values of primary current used in the given calculations are quite large and for technical reasons are difficult to realise for diodes of indicated dimensions. For experiment, it is desirable to use cathode material of large coefficient of secondary emission, which permits to decrease the value of primary beam current and also of external injection of primary beam.

To conduct experimental investigations of coaxial diodes with magnetic insulation and secondary emission cathodes, a special setup was developed on which various methods of initiating secondary emission could be realised and also controlled, including by means of a primary beam of electrons from a thermionic cathode. In experiments on the generation of RF-oscillation, a quarter-wave coaxial resonator will be connected to the inverted diode (see Fig. 5).

The central electrode of the coaxial resonator, which one side connected to the diode anode and the other on a passing-through ceramic insulator, is mounted on the resonator flange. For high frequency, the insulator is shorted by shunting condenser. The rate of rise of the voltage applied to the diode via the resonator central electrode, insulated for direct current, is varied bay changing the value of the condenser. To sharpen the pulse of the voltage on the diode, an additional spark gap is provided between the central electrode and shunting condenser.

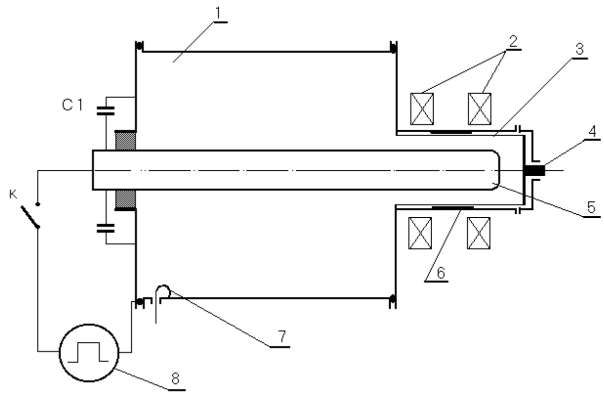

Fig. 5. Schematic diagram of the experimental setup. 1 - Capacitance-loaded quarter-wave resonator; 2 - solenoid; 3 - tungsten-wire thermionic cathode; 4 - feed input; 5 - central resonator electrode - diode anode; 6 - working area of secondary emission cathode; 7 - excitation loop/diagnostics; 8 - pulsed high-voltage generator; C1 - blocking condenser.

4 CONCLUSION

An inverted magnetron diode with an external circuit has been proposed and shown to be promising as a compact modulator for various applications. Results of computer simulation of the modulator operation, the principle of which is based on the dynatron effect, are presented. Calculations performed on a model of the external circuit with lumped parameters can be generalised for the case of a system with distributed parameters. Modulators of proposed construction could be easily integrated into construction of guns to obtain modulated intense beams and also can be used for other applications.

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