DYNATRON MODULATOR

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Abstract

A new scheme of compact dynatron modulator is proposed. The modulator with transverse dimensions of several centimeters can work as an RF-avtogenerator or RF-amplifier in wide range of frequencies. The modulator works on the dynatron effect inside vacuum inverted coaxial diode with magnetic isolation supplied by an external pulsed high-voltage source connected to the modulator via RL-circuit. Under conditions of permanent emission of primary electron beam from an external electrode (cathode) and the growth of the voltage at the diode the storage of primary electrons arises inside the gap. Oscillations of the voltage due to oscillating regime of diode charging and/or azimuthal instability of rotating electron flow stimulates back-bombardment flow electrons to the cathode and leads to power spikes of secondary emission current exceeding primary one. As the result, the amplitude of oscillations in quasi-resonant circuit grows and the system can turn to self-supporting oscillations, i.e. like to avtogenerator. The amplitude, the average voltage and the frequency of oscillations can be changed by varying a part of parameters. Results of computer simulations are given for 2-D geometries (r,theta; r,z) 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 analyzing the formation dynamics of intense electron beams with dominant influence of 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 the cathode [1] - [4]. In paper [4], it was proposed that 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 large charge. To control (initiation and quenching) secondary emission, its threshold characteristics, 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 nonstationary 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.

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2 PHYSICAL PROCESSES IN AN INVERTED MAGNETRON DIODE

As a rule, when analyzing the nonstationary 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 diode represent. 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 nonstationary processes.

When there is no emission of particles in a magnetron diode, it can be represented by a condencer 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 $\omega = \sqrt{\omega_0^2 - \delta^2}$, where $\omega_0 = 1/\sqrt{LC}$ and $\delta = R/2L$ - is damping constant. If in the diode there is a constant emission of primary beam of electrons 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 diode and beam formed in it insignificantly differ from the case, for example, 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 continuosly 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 cause an abrupt spike of secondary emission current, which to an an even greater extent ”puls” voltage on the diode. As

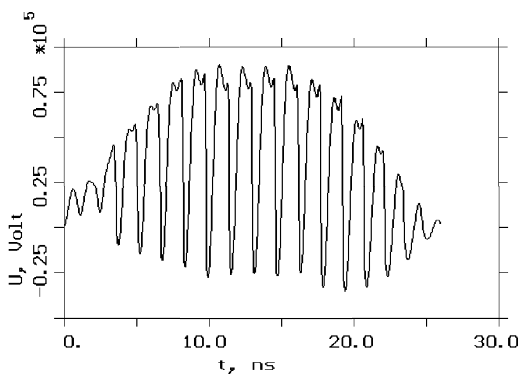

Figure 1: Behavior of voltage on magnetron gun.

a result, the acceleratuing 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 behavior 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 NUMERICAL SIMULATIONS

The dynamics of voltage on an inverted magnetron diode was investigated by means of KARAT code [5] in two two-dimensional geometries: $r-\theta$ and $r-z$. 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 generalized for the case of systems with distributed parameters.

3.1 $r-\theta$-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, there 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 metall [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 shows the behavior 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 behavior of secondary-emission current (in amperes) can be seen in Fig. 2.

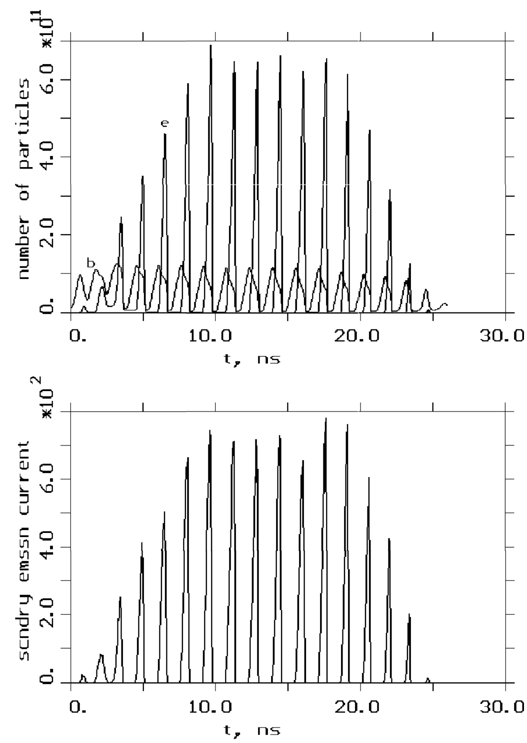

Figure 2: The dynamics of a change in the number of primary and secondary electrons in the accelerating gap and behavior of secondary emission current.

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.

3.2 $r-z$-Geometry

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

The primary beam of 50 A emits 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 behavior 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 $r-\theta$-geometry.

It should be noted that the values of primary current used in the given calculations are quite large and for technical

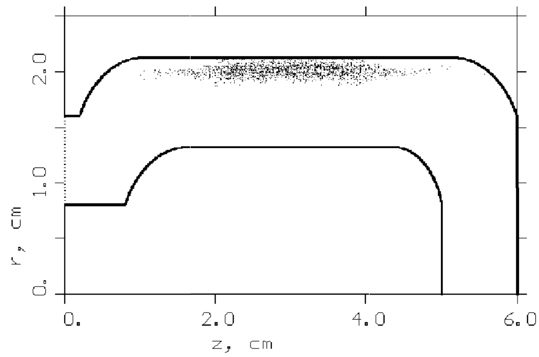

Figure 3: Gun geometry.

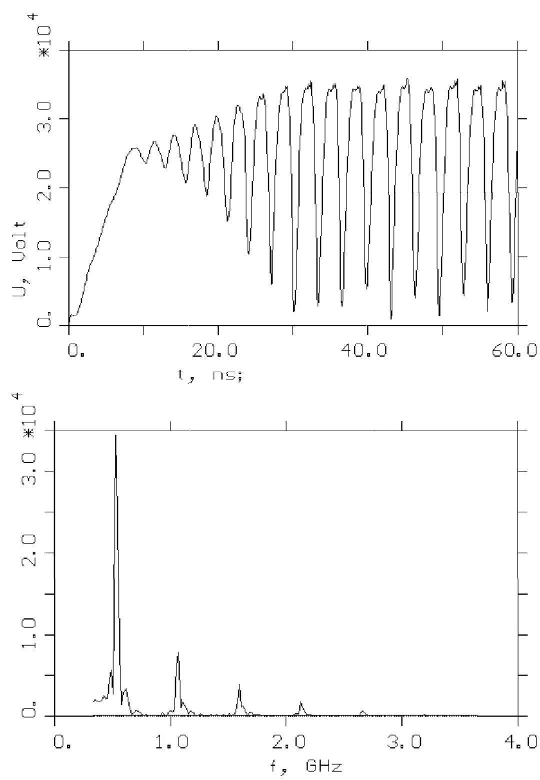

Figure 4: Behavior the voltage on magnetron gun and frequency spectrum of oscillations.

reasons are difficult to realize 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 realized 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 quarte-wave coaxial resonator will be connected to the inverted diode (see Fig. 5).

The central electrode of the coaxial resonator, which

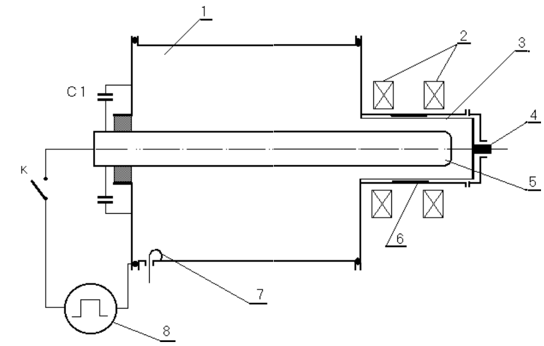

Figure 5: Scheme of the experimental setup. 1. capacitance-loaded quarter-wave resonator; 2. solenoid; 3. tungsten-wire thermionic cathode; 4. feed input; 5. central resonator electrode – diode anode; 6. working area of secondary emission cathode; 7. excitation loop/diagnostics; 8. pulsed high-voltage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

one side connected to the diode anode and the other on a passing-through ceranic 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.

4 CONCLUSION

A 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. Calcukations performed on a model of the external circuit with lumped parameters can be generalized for the case of a system with distributed parameters. Modulators of proposed construction can be easily integrated into construction of guns to obtain modulated intense beams and also can be used for other applications.

5 REFERENCES

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