DYNAMICS OF MAGNETIC INSULATION VIOLATION IN SMOOTH-BORE MAGNETRONS

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Abstract

The efficiency of large and high-power magnetrons of GW power levels is less than 30% and inherent pulse-length and repetition rate limitations seem to exist because of use of explosive field emission. Another approach is the development of low voltage, high-efficiency magnetrons utilizing a secondary emission magnetron array with high repetition rate. The numerical model of nonstationary, nonuniform secondary electron emission from a cathode surface has been developed. The results of first steps in computer simulations of electron cloud formation inside a smooth-bore magnetron under the condition of back-bombardment instability (BKB) are presented. Calculations have been performed for a coaxial smooth-bore magnetron and for magnetrons with different types of azimuthal inhomogeneities which could promote the growth of BKB. The results of computer simulation are in agreement with experimental data. The main calculations of the beam dynamics were carried out with PIC-code KARAT.

1 INTRODUCTION

Problems of magnetic insulation violation inside a vacuum coaxial diode (magnetron diode — MD) with dense electron flow in crossed $\vec{E}\times\vec{B}$ fields are considered. It is known that the magnetic field suppresses the mobility of charged particles in the direction perpendicular to the magnetic field at distances exceeding the Larmor radius r_{eL} ($d_{AK} > r_{eL} = v_e/\omega_{ec}$, v_e — maximum velocity, $\omega_{ec} = eB_0/mc\gamma_e$ — cyclotron frequency). This effect, so-called magnetic insulation, is almost perfect in axisymmetrical systems with low density electron flow ($en_ed_{AK} \ll V_{AK}/d_{AK} = E_0$). Experimental investigations of MD with high density electron flow ($en_ed_{AK} \sim E_0$) show an appreciable value of electron current to the anode (leakage current) $\bar{J}_{er} \neq 0$. This is due to the occurrance of azimuthal variations of charge density distribution. Attempts to construct a model of MD allowing to estimate the leakage current I_{eA} or the power of back-bombardment flow of electrons with surplus energy to cathode surface have not been successful earlier [1], [2] nor later [3].

Computer simulations have been performed using 2.5-D electromagnetic PIC code KARAT [4] for the MD with parameters close to experimental [1], and with an external voltage source $V_0(t)$ connected to MD via an RL-circuit. Note that calculations without the external circuit could lead to meaningless physical results.

The yield of secondary electrons from the cathode are described by a modified expression [5] to take into account the dependence of the yield on the energy of electrons and the angle between the direction of electron velocity and the perpendicular to the cathode surface, and also the threshold of secondary emission:

$$k_{sec} = (1 - \cos\,\alpha) + \frac{\pi}{2}\sigma_{sec}x^{0.55}\exp(-0.45x), x > 0,$$

$$k_{sec} = 0, x \leq 0,$$

where x = (w - w_{sec1})/w_{sec2}, $\sigma_{sec} = 2$ is the maximum coefficient of secondary emission, α the angle of incidence (see above), w the kinetic energy of primary electrons, w_{sec1} = 100 eV is the threshold value of the energy incident on the surface, w_{sec2} = 600 eV is the energy corresponding to the maximum yield of secondary electrons.

2 MAIN RESULTS

Let us consider first the process of electron cloud formation inside an axisymmetrical MD under the condition of homogeneous initial emission of a low current beam from the cathode. The main parameters of MD are radius of the anode r_A = 0.53 cm, radius of the cathode r_K = 0.33 cm; external longitudinal magnetic field B_0 = 2.5 kGs ($B_0/B_{cr} \simeq$ 1.15, $\omega_{ec}/2\pi$ = 7 GHz, period of cyclotron rotation 0.14 ns); the voltage rise time to maximum value of V_{0m} = 12 kV is 2 ns; maximum emission current of the primary beam I_{em} = 2 A.

For given voltage and geometry of MD the Child-Langmuir current through the MD without a magnetic field equals approximately $I_{CL} \simeq$ 200 A (here and below currents and charge densities correspond to linear values per cm of length in the longitudinal direction). Electrotechnical parameters are $\tau_{L/R}$ = 0.25 ns, τ_{RC} = 0.24 ns, where C is the capacitance of MD. Drift velocity of electrons in crossed fields is $\bar{v}_{e\theta} = cE_0/B_0$ = 2.4×10^9 cm/s, if the electric field is estimated as V_{0m}/d_{AK}.

Dependences of voltage V_{AK} on MD and current in anode circuit I_{AK} on time, and dependences of the numbers of primary N_{e0} and secondary N_{es} electrons inside MD and secondary emission current I_{es} on time are shown in Fig. 1. In Fig. 2 configurations of electron flows at different times are shown.

Inevitable presence of electric field fluctuations due to noise, discreteness of flow and random conditions of emission of electrons lead to redistribution of the energy of electrons. Under conditions of conservation of full energy and

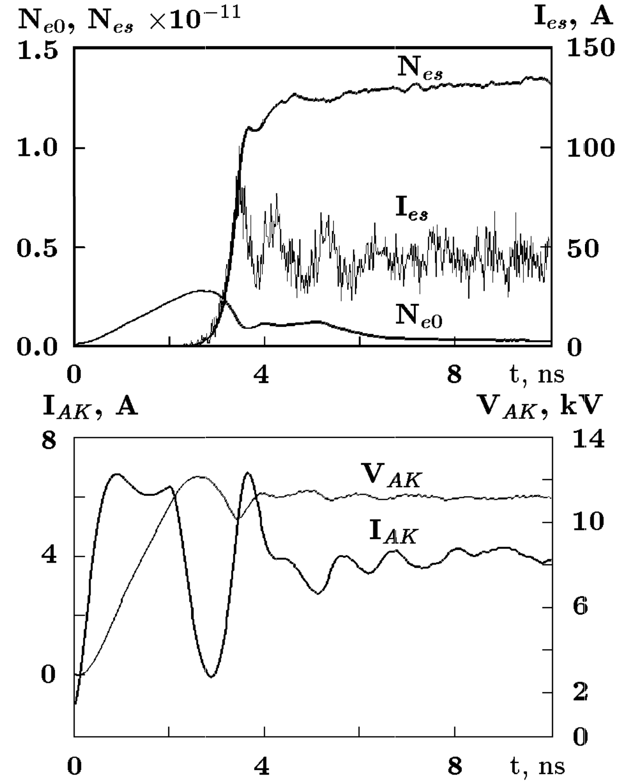

Figure 1: Dynamics of store of primary N_{e0} and secondary N_{es} electrons and the dependence of secondary emission current I_{es} on time (above); the dependences of the voltage V_{AK} on MD and the current in anode circuit I_{AK} on time (below).

momentum a part of the electrons lose energy under the action of the field and drifts to larger radii towards the anode. Another part of the electrons increases its energy and returns to the cathode with an energy exceeding the threshold value for secondary emission.

In view of indicated reasons, the emission of secondary electrons is nonuniform. This effect leads to an intensification of the cathode back-bombardment process and to fast and effective growth of secondary electrons inside MD. The growth of secondary emission current is accompanied by a drop in voltage (see Fig. 1). The secondary-emission current exceeds the primary-beam current by more then order of magnitude and subsequently exerts a determining action on the operation of the MD. The MD passes over to a condition of self-sustaining emission and the primary beam can simply be disconnected. After the transient process, a stable formation consisting of three main bunches is formed. This electron flow rotates as a whole with approximately constant angular velocity.

In Fig. 3 the distributions of electrons reaching the anode (f_{eA}) and returning back to the cathode (f_{eK}) are presented for energy and for angle. The average energy of electrons reaching the anode equals $\bar{w}_{eA}$ = 7.4 keV and at the cathode the average energy $\bar{w}_{eK}$ = 0.44 keV. Thus, for the given conditions $\eta_{BKB} = (eV_{AK} - \bar{w}_{eA})/eV_{AK}$ = 34%

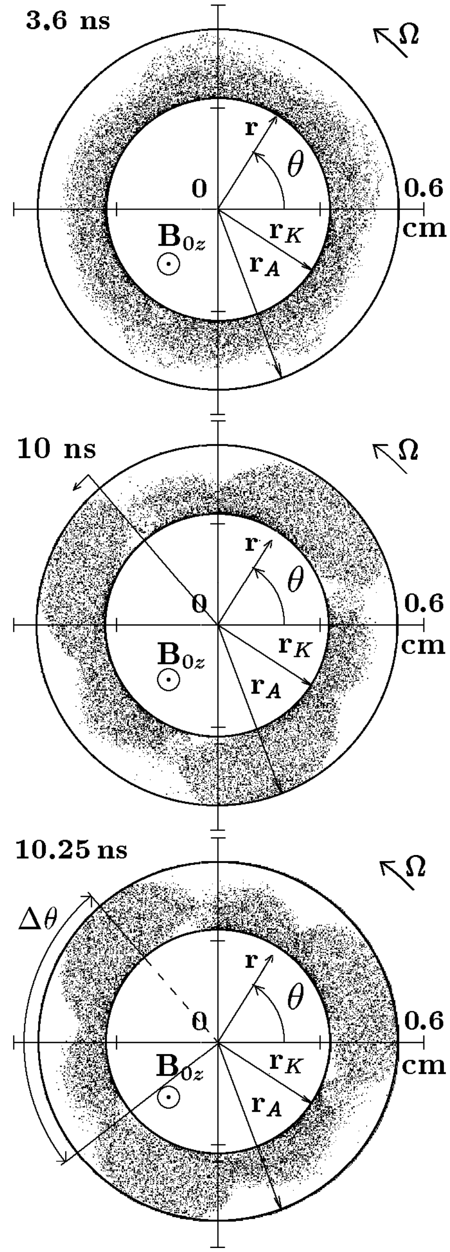

Figure 2: Formation of electron cloud inside MD under the condition of homogeneous emission of low-current primary beam. The rotation of electron cloud as a whole with angular frequency $\Omega \simeq 2\pi \times 10^9$ s^{-1} at 10 ns and 10.25 ns is shown in the last two figures.

for power of back-bombardment flow $P_{eK} \simeq$ 15 kW and power of beam reaching the anode $P_{eA} \simeq$ 30 kW.

Fig. 4 shows flow configurations for various variants of emission of primary and secondary electrons. The nonuniformity of various types leads to the following main effects: broadening of the functions of distribution of electrons at the anode for energy and angle of incidence; formation of flows with non-regular azimuthal structure; change of the spectrum of field frequencies. However, integral characteristics of flow (total charge in the gap, leakage current of

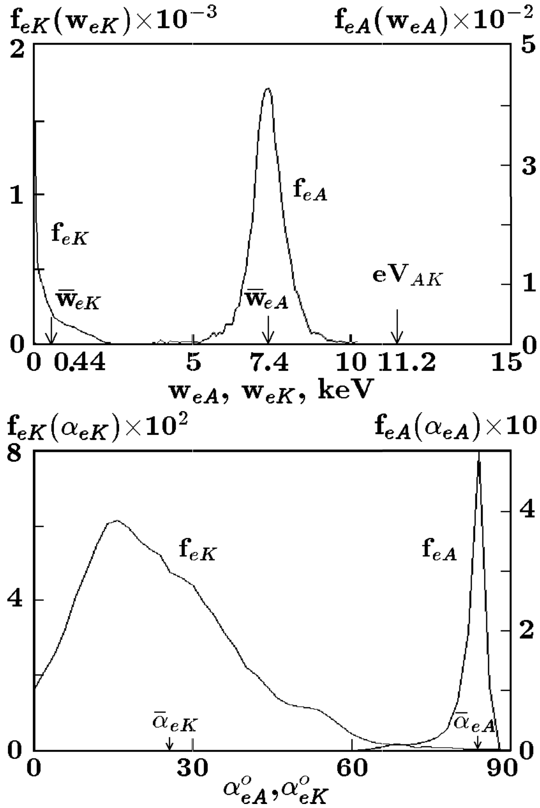

Figure 3: Distribution functions of electrons for energy (above) and angle of incidence (below) at the anode and the cathode.

electrons at the anode) practically do not change, i.e., the system is stable relative to the initial conditions.

3 CONCLUSION

The selfconsistent picture of an electron flow formation inside secondary emission MD has been described. The existence of quasistationary, rotating state of an electron flow has been shown under conditions of conservation of full power and full momentum of the system. This state is characterized by the transformation of supplied power to a power of back-bombardment flow with the efficiency exceeding 30% and to a power of a leakage beam to the anode (magnetic insulation violation). The results are close to the data [1].

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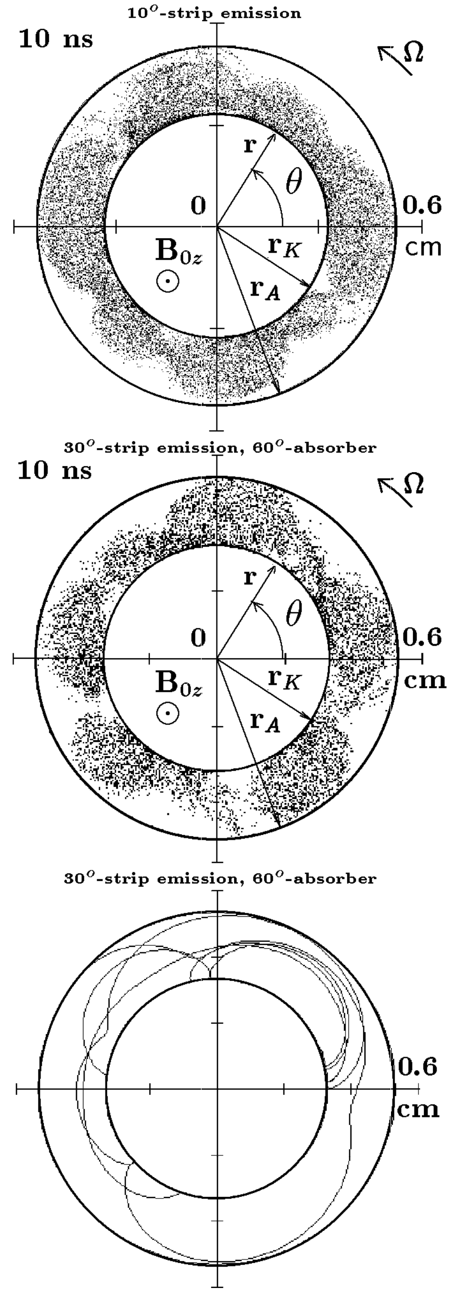

Figure 4: Configurations of electron flows inside MD at t = 10 ns: a uniform emission of primary beam of 2 A from a cathode having a 20^o strip with no emission of secondary electrons; emission of primary beam of 2 A from a 30^o strip at the cathode having a 60^o strip with no emission of secondary electrons; trajectories of electrons which are emitted at t = 5 ns and observed for 2 ns.

4 REFERENCES

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