SELF-SUSTAINING SECONDARY EMISSION IN MAGNETRON GUNS, BEAM MODULATION AND FEEDBACKS*

A.V.Agafonov*, V.M.Fedorov, V.P.Tarakanov
*Lebedev Physical Institute of RAS, Moscow, Russia,
IVTAN, Moscow, Russia

INTRODUCTION

This paper reports on computer simulations of an electron cloud formation inside a smooth-bore magnetron. Preliminary results were published in [1–3]. Computer simulations have been performed using 2.5D and 3D electromagnetic PIC code KARAT [4] for the magnetron diode (MD) with parameters close to experimental [5], and with an external voltage source $V_0(t)$ connected to MD via an RL-circuit. The yield of secondary electrons from the cathode takes 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.

DYNAMICS OF SECONDARY EMISSION BEAM IN MD

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 kG ($B_0/B_{cr} \cong 1.15$, $\omega_{ec}/2\pi$ = 7 GHz, period of cyclotron rotation 0.14 ns); the voltage rise time to maximum value of V_{0m} = 12 kV was varied from 2 to 10 ns; maximum emission current of the primary beam I_{em} = 3 A. For given voltage and geometry of MD the Child-Langmuir current through the MD without a magnetic field equals approximately $I_{CL} \cong 240$ 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 $v_{e\theta} = cE_0/B_0 = 2.4\times10^9$ cm/s, if the electric field is estimated as V_{AK}/d_{AK}.

The process of electron cloud formation inside an axisymmetrical MD under the condition of homogeneous initial emission of low current primary beam from a cathode starts due to inevitable presence of electric field fluctuations in rotating flow of electrons stored inside the gap for the time of the growth of the external voltage. Weak azimuthal instability is amplified by nonuniform secondary emission and a feedback on the surface of the cathode. Under conditions of conservation of full energy and 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 secondary-emission current exceeds the primary-beam current by more than an 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 could be switched off. After the transient process, a stable formation consisting of several bunches is formed in this geometry. Electron clouds rotate as a whole with approximately constant angular frequency.

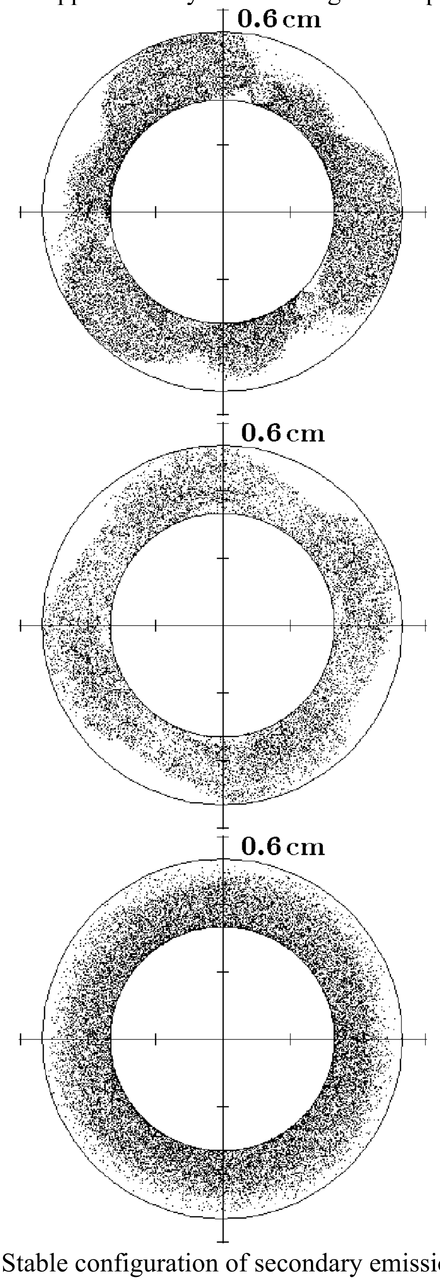

Fig. 1: Stable configuration of secondary emission flow (top), primary flow in saturated working regime of the cathode (middle) and primary space-charge-limited flow (bottom).

The feedback on the surface of the cathode exerts the dominant influence on the growth of the instability and on arising of a transverse leakage current to the anode across the external magnetic field exceeding the critical magnetic field of magnetic insulation. This feedback is conditioned by right phasing of a part of secondary emitted electrons by rotating crossed E×B-field. These electrons are captured inside rotating modulated electron flow and stay inside the gap for many revolutions around the cathode, maintaining its azimuthal and time structures. Another part of secondary emitted electrons can stay inside the gap only for a small time comparable with the period of cyclotron motion because they are forced to return to the cathode by the radial component of rotating crossed E×B-field, which changes its direction during the rotation of the flow as a whole.

The regime of self-sustaining secondary emission in MD is characterized by the average radial component of electric field on the cathode surface, which is close but not equal to zero. At given azimuth of the cathode surface it oscillates with a frequency equal to the average rotating frequency of the flow as a whole times the number of bunches, and with amplitudes varying from -10 up to 30 – 40 kV/cm.

Note that strong azimuthal instability and large azimuthal modulation with leakage current to the anode occurred only if the current of primary beam is small in comparison with the full current of self-sustaining secondary emission. Fig.1 (top) shows stable configuration of electron flow inside the MD with secondary emission cathode.

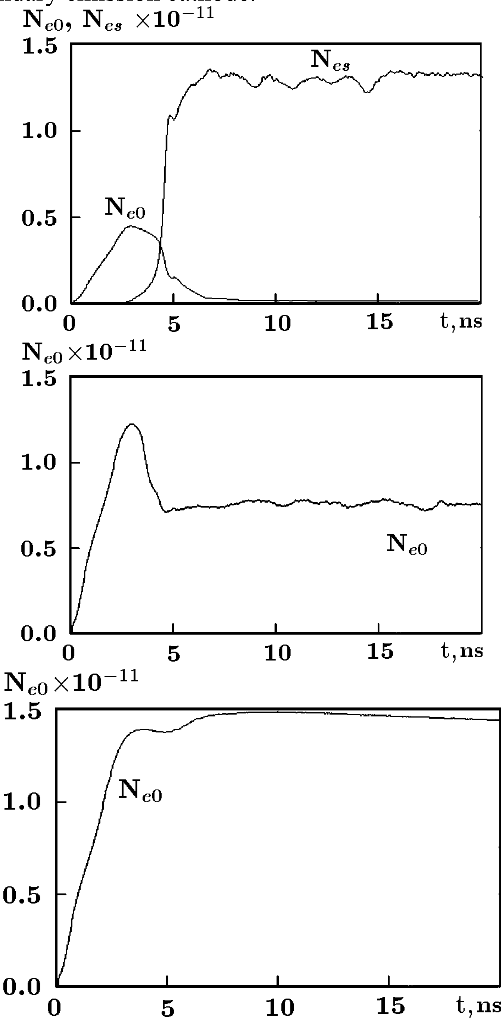

Fig. 2: Dynamics of store of electrons inside the gap for the above mentioned cases

Fig.2 (top) shows dynamics of store of primary N_{e0} and secondary N_{es} electrons inside MD. The time behavior of radial electric field near the surfaces of the cathode is shown in the top of Fig.3.

DYNAMICS OF PRIMARY AND MIXED BEAMS IN MD

Investigation of the instability of pure primary beam of different currents up to space-charge limited current homogeneously emitted from a cathode of MD (an MD without secondary emission) shows that under condition of space-charge limited current no azimuthal instability occurs. Deep azimuthal modulation of the flow and leakage current to the anode arises only if the condition of saturated regime (normal component of electric field does not equal zero) of a cathode is satisfied. The behavior is conditioned by the same feedback on the emitting surface providing additional correct azimuthal modulation of emitted particles similar to the case of secondary emission. The difference is that the radial electric field does not change its direction on the surface of the cathode, but oscillates with large amplitude.

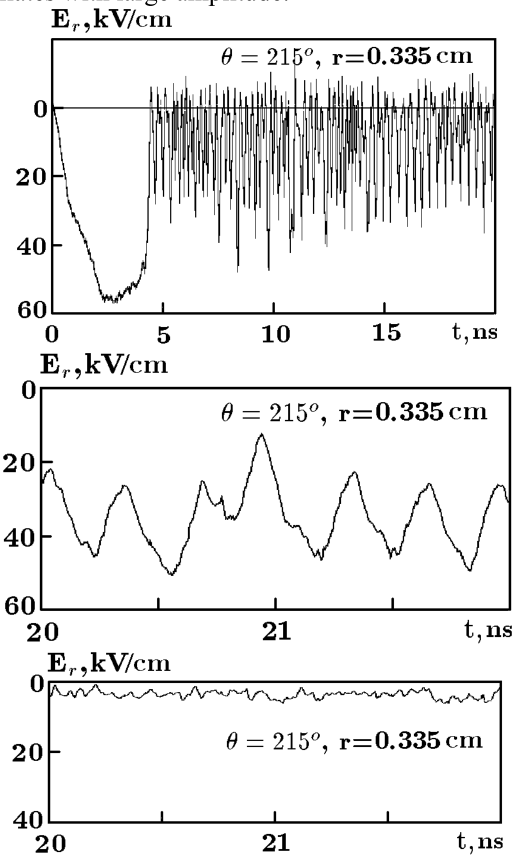

Fig. 3: Behavior of the radial electric field near the surface of the cathode for the aforementioned cases.

In the middle of Fig.1 stable configuration of the flow of primary electrons inside the MD without secondary emission and the cathode operating in saturated regime is shown. The bottom figure shows stable configuration for the case of space-charge limited current of primary electrons. In the middle and in the bottom pictures of Fig.2 dynamics of store of primary N_0 inside MD are shown for aforementioned cases.

The time behavior of radial electric field near the surfaces of the cathode for aforementioned cases is shown in Fig.3. In the case when the current of primary beam is comparable with the current of secondary-emission beam the behavior of the electron flow for later time is similar to the case of space charge limited primary beam. The charge of primary beam emitted homogeneously from the cathode influenced the character of secondary emission and smoothes over a nonuniformity of secondary emission. Secondary-emission current increases initially and then drops to a value, which provides the fall of radial electric field on the cathode surface to close to zero. Azimuthal modulation of the flow and leakage current to the anode do not exist in this case. However, they arise for a time if the current of primary beam decreases approximately by an order of its initial value.

3D COMPUTER SIMULATION

Presented above results obtained for 2-dimensional r-θ geometry of the system. Results of 3D calculations have confirmed all main physical mechanisms and conclusions of 2D calculation. The transverse leakage current drops sharply when $B_O/B_{cr} \geq 1.4$ and longitudinal leakage current prevail.

CONCLUSION

Emphasized is the dominant influence of a feedback on dynamics of electron beam modulation and on arising transverse leakage current to the anode across the external magnetic field exceeding the critical magnetic field of magnetic insulation. The instability arises due to an energy and a momentum exchange between particles and rotating crossed azimuthally modulated E×B-fields. Strong azimuthal instability exists if the current of primary beam is much less then the secondary emission current. If these currents are comparable, the instability is weak and decays in time due to the absence of strong azimuthal inhomogeneity of secondary emission current. In the case of the emission of primary beam alone deep modulation and leakage current arises only if the condition of saturated regime of a cathode is satisfied. Such behavior is conditioned by a feedback on the emitting surfaces which provides additional correct azimuthal modulation of electron flow by rotating crossed ExB-field and amplifies the instability.

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