FORMATION OF LOCALISED ELECTRON FLOW INSIDE AN INTERACTION REGION OF RELATIVISTIC MAGNETRON

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For an increasing of the efficiency of relativistic magnetrons it is very important to prevent the axial drift of electrons away from an interaction region and the generation of a parasitic e-beam at the end of a cathode, which does not take part in energy exchange between electrons and waves at all. A special driver for double-sided powering of relativistic magnetrons and several methods of localised electron flow forming in the interaction region of relativistic magnetrons are proposed and discussed. Two experimental installations are presented and discussed. One of them is designed for laboratory research and demonstration experiments at rather low voltage. Another one is a prototype of a full-scale installation for an experimental research at relativistic levels of voltages on the microwave generation in the new integrated system consisting of a relativistic magnetron and symmetrical induction driver.

Work supported by RFBR under grant No. 03-02-17300.
PACS: 29.25.Bx

1. INTRODUCTION

The high efficiency of "ordinary" classic magnetrons has been achieved as a result of intense experimental and theoretical investigations [1,2]. Relativistic magnetrons, in spite of a 20-year history of development, are in an "initial" stage. The main purpose of experimental investigations was the demonstration of achievement of extremely high RF-power [3,4]. Most results were obtained using high-current accelerators in existence as drivers, but not specialised drivers.

Actually RM generators were adapted for use with those drivers and looked like an additional part to alien drivers. However, achieved levels of pulsed power exceeding several GW are attractive, though the efficiency of RM is low as compared with low voltage classic magnetrons.

It appears that one way of increasing the efficiency of RM is symmetric powering of RM that suppresses parasitic beam current in the longitudinal direction, i.e., the construction of a specialised driver for this purpose.

2. BEAM FORMATION

The main idea of symmetric powering is rather clear and will not be discussed here. Investigations of beam dynamics inside a simple model of a smooth-bore RM were carried out with 2.5-D electromagnetic PIC-code KARAT [5]. Calculations were carried out for 2-D r-z-geometry under condition of azimuthal symmetry of considered models. Usual scheme of an electron beam formation in a magnetically insulated diode is illustrated in Fig.1.

It is suggested that the diode is powered from the left side. Emitted electrons form a dense cloud inside the gap. Self-electric field of the cloud push out electrons to forward and backward longitudinal directions. Backward flow of electrons is reflected by an electrostatic mirror, which is formed by increased radius of the cathode stem. A beam reaching an anode is formed under the action of longitudinal electric field at the upper end of the cathode and azimuthal magnetic field B_θ of a current flowing along the stem.

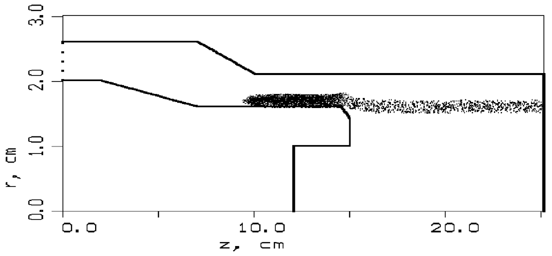

Fig.1: Formation of a beam in a magnetically insulated diode

The direction of a drift velocity of electrons ($v_z \propto v_r B_\theta$) coincides with the direction of Pointing's vector. The presence of longitudinal electric field of opposite direction counteracts drift motion in forward directions and can lead to formation of backward electron flow even for one-sided powering. The situations where accelerating fields exist at both edges of a cathode are shown in Fig.2.

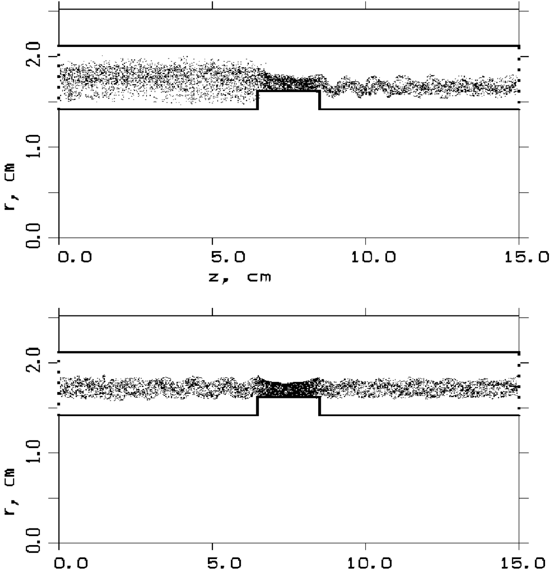

Fig.2: Configurations of electron flows for double sided (below) and one-sided powering (above)

In this figure configurations of electron flows inside a coaxial diode with an insertion (cathode) are presented under conditions of symmetric and non-symmetric powering. In the latter case a TEM-wave is launched through the left side of the diode. The diode is embedded in a longitudinal magnetic field of 8 kGs. A maximum voltage of 500 kV and maximum emission current of 10 kA were taken in the calculations.

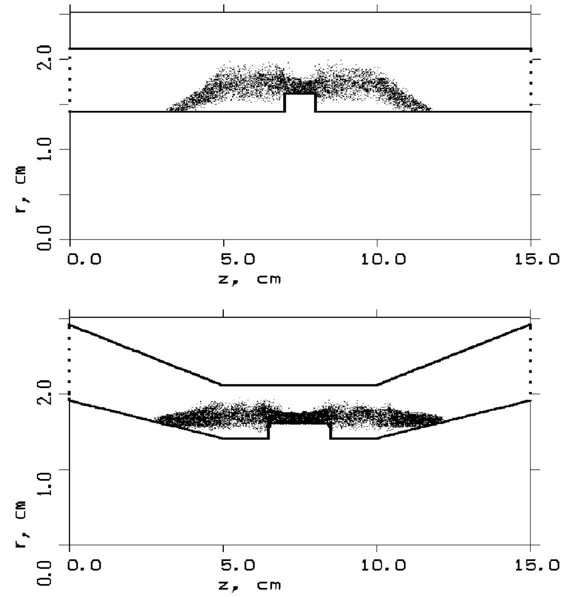

Fig.3: Configurations of electron flows for double-sided powering with magnetic bumps (above) and electrostatic bumps (below)

Fig.3 illustrates two possible methods of localising electron flow within the interaction region: use of symmetric magnetic bumps or electrostatic mirrors on both sides of the diode, under condition of symmetric powering. In the latter case the electrostatic mirrors are formed by curved coaxial electrodes embedded in a longitudinal magnetic field.

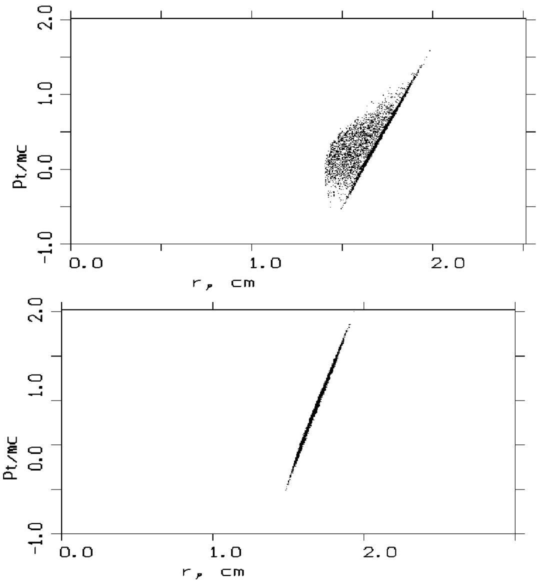

Fig.4: Phase maps (p_θ, r) of electron flows for double-sided powering with magnetic bumps (above) and electrostatic bumps (below)

Variation of magnetic field distribution and/or shape of electrodes permit to form a desirable geometry of electron flow. Comparison of characteristics of flows inside diodes with magnetic and electrostatic bumps shows that the scheme with electrostatic bumps is preferable for RM (see Fig.4).

3. INDUCTION DRIVER

From our point of view a symmetric induction driver corresponds to a certain extent the idea of two-sided powering of RM. Fig.5 shows the scheme of such a driver integrated with a magnetron. The driver consists of two identical sections of LIA (areas 1 and 2 in Fig.5) placed symmetrically relative to the magnetron (area 3) and connected with a magnetron by a common central electrode - the voltage adder. Both ends of the central electrode join to flanges, which are at ground potential. The central part of the electrode performs as the RM cathode. This inner electrode adds the voltages from the inductively insulated cavities (inductors) and delivers the power to a high voltage anode-cathode gap of a magnetron. Inside the each of two LIA sections the voltage is increased stepwise from zero level at the grounded end of the electrode up to the maximum level equal to the sum of the voltages from the all cavities of the LIA section. The full voltage appears only across the coaxial structure at the magnetron region. For identical left and right LIA sections powered from one common pulse generator, the total output voltage of the left and right sections are the same. The power flow is also symmetric. A coaxial magnetron schematically shown in Fig.5 consists of a central cylindrical cathode, multivane resonant anode structure and insulating magnetic field coils.

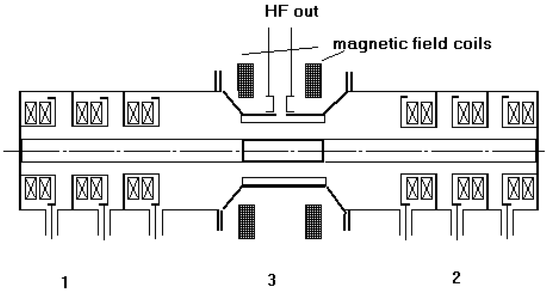

Fig.5: Schematic of a driver

RF-power is led out through slots in resonators of the magnetron to radial waveguides followed by short matching sections – transformers of impedance. This scheme has been successfully used in experiments with pulsed high power RM [3,4].

Merits of the driver are the merits of LIA with a voltage adder. Such schemes are broadly used in modern high-current accelerators (HERMES-III, COBRA etc.). The inductive driver provides the high efficiency of the energy transmission from the pulsed power generator to the load and does not contain the high voltage insulator designed for full operating voltage. It is possible to use a relatively low voltage per cavity and consequently low voltage pulsed generators with low voltage transmission lines between the generator and the cavities. Furthermore, the symmetrical inductive driver generates symmetric power flow in the magnetron region provided by powering of all inductive cavities from one common pulsed power generator or in pairs - one cavity of the left side LIA section and second one of the right side section connected to the one of the set of several pulsed power generators. Some of the cavities of the LIA sections and some of the generators may be used for the rough and the fine correction of the shape and the amplitude of the resulting high voltage pulse across a magnetron.

Symmetric induction driver consists of double the number of inductive cavities compared with current inductive drivers for the same output voltage. The larger number of cavities leads to a larger driver, which needs a more powerful pulsed power generator or generators to compensate the energy lost in the second set of the cavities. But all these disadvantages may be negligible compared with the advantages of the higher efficiency of a symmetric RM.

4. CONCLUSIONS

To realise the idea of two-sided powering of RM we have developed two experimental installations. One of them is designed for laboratory research and demonstration experiments at rather low voltage. Another one is a prototype of a full-scale installation for an experimental research at relativistic levels of voltages on the microwave generation in the new integrated system consisting of a relativistic magnetron and symmetrical induction driver.

The choice is based on our wishes to construct a facility consisting of several modules with flexible transmission lines between a pulsed generator and the induction cavities made from standard low-voltage coaxial cables. The number of the cavities, type and parameters of the pulsed power generator may be easily changed depending on the current experimental programme.

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ФОРМИРОВАНИЕ ЛОКАЛИЗОВАННОГО ЭЛЕКТРОННОГО ПОТОКА В ОБЛАСТИ ВЗАИМОДЕЙСТВИЯ РЕЛЯТИВИСТСКОГО МАГНЕТРОНА

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Обсуждаются подходы к формированию локализованного электронного потока в области взаимодействия релятивистского магнетрона с целью увеличения его эффективности. Для предотвращения выноса электронного потока из области взаимодействия предлагается использовать предложенную ранее схему симметричного питания и различные методы локализации электронного потока в области взаимодействия. Приведено описание двух установок, одна из которых рассчитана на проведение демонстрационных исследований на невысоком уровне напряжения, вторая – представляет собой прототип полномасштабной установки для проведения исследований по генерации СВЧ-излучения при релятивистских напряжениях в предлагаемой интегрированной системе.

Работа выполнена при поддержке гранта РФФИ 03-02-17300.

ФОРМУВАННЯ ЛОКАЛІЗОВАНОГО ЕЛЕКТРОННОГО ПОТОКУ В ОБЛАСТІ ВЗАЄМОДІЇ РЕЛЯТИВІСТСЬКОГО МАГНЕТРОНА

А.В. Агафонов, А.Н. Лебедєв, Е.Г. Крастелев

Обговорюються підходи до формування локалізованого електронного потоку в області взаємодії релятивістського магнетрона з метою збільшення його ефективності. Для запобігання виносу електронного потоку з області взаємодії пропонується використовувати запропоновану раніше схему симетричного живлення і різні методи локалізації електронного потоку в області взаємодії. Приведено опис двох установок, одна з яких розрахована на проведення демонстраційних досліджень на невисокому рівні напруги, друга – являє собою прототип повномасштабної установки для проведення досліджень по генерації Свч-излучения при релятивістських напругах у пропонованій інтегрованій системі.

Робота виконана за підтримкою гранта РФФИ 03-02-17300.