Formation of Electron Flows for Diagnostic Gyrotrons by Electron-Optical Systems with Multi - Tip Field Emitters

Gennadii Sominskii
Peter the Great St.Petersburg Polytechnic University
Saint-Petersburg, Russia
sominski@rtphf.spbstu.ru

Evgeny Taradaev
Peter the Great St.Petersburg Polytechnic University
Saint-Petersburg, Russia
evgeny_tar@hotmail.com

Vladimir Manuilov
Plasma physics and
High Power Electronic department
Insitute of Applied Physics RAS
Nizhny Novgorod, Russia,
mavnik1@yandex.ru

Mikhail Glyavin
Plasma physics and
High Power Electronic department
Insitute of Applied Physics RAS
Nizhny Novgorod, Russia,
glyavin@appl.sci-nnov.ru

Abstract: *The authors have developed silicon multi-tip field emitters with two-layer metal - fullerene coatings suitable for use in miniature high-voltage electronic devices operating in a technical vacuum. Currently, methods are being developed for creating electron flows for diagnostic gyrotrons by electron-optical systems (EOS) with such emitters. The report describes the developed methods for studying the spatial structure and velocity spectrum of the electron flow formed by the EOS. In addition, the first data on characteristics of the flows generated by the EOS is reported.*

Keywords: gyrotron, field emitter, non-adiabatic electron gun, electron beam, technical vacuum, electron-optical system, diagnostics of electron flow

Introduction

Field emitters have obvious advantages over the thermionic ones, as they do not require heating and practically are inertialess. Given these distinctive features, it seems attractive to replace thermionic cathodes with field emitters in some types of miniature, but high-voltage microwave devices, for example, in the sub-terahertz and terahertz gyrotrons. Such devices are increasingly used, in particular for dense plasma spectroscopy, and also for implementation of the method of nuclear magnetic resonance with dynamic nuclear polarization, which has promising applications in medicine and biology [1].

To ensure the operation of moderate power spectroscopic gyrotrons (of the order of tens of Watts), it is necessary to use field emitters that are able to operate stably under technical vacuum conditions of 10^{-7}-10^{-8} Torr with field emission currents of the order of or more than several tens of milliamps and current densities of the order of 100 - 200 mA / cm^2. Emitters that meet the above requirements and are suitable for creating helical electron beams (HEB) of annular section were developed at the Peter the Great St. Petersburg Polytechnic University [2-5]. These are multi-tip silicon cathodes with two-layer metal-fullerene coatings. At present, the authors of this report are working out methods for the formation and study of HEB for spectroscopic gyrotrons. Diagnostic methods have been developed and implemented to determine the transverse structure of the electron beam, as well as to measure the longitudinal and transverse electrons velocities in different parts of the electron beam transport channel in a non-uniform along the axis magnetic field. The report describes the created experimental setup and informs on the first results of the study characteristics of beam, formed using an electron-optical system (EOS) with a field emitter.

Research methods and equipment

The studies were performed in an experimental setup with continuous pumping using magnetic-discharge pump and cryopump. The pressure in the measurement system could be changed from 10^{-10} – 10^{-9} Torr to 10^{-6} Torr and back due to the use of nitrogen puffing. The emission characteristics of cathodes and characteristics of electron flows were measured in technical vacuum at a pressure of about 10^{-7} Torr. The experiments were performed in static and pulsed (1-2 μs, 50 Hz) regimes.

The multi-tip annular cathodes that were created and studied to date are practically impossible to use in the usual magnetron-injection guns of gyrotrons [1]. But electron beam of an annular cross section can be created by a non-adiabatic electron-optical system (EOS) with a flat annular field emitter [1]. Taking it into account, EOS with a non-adiabatic electron gun was created. The gun was equipped by the annular cathode with a average diameter of 14 mm, having the width of emitting multi-tip band of 0.65 mm, and a control electrode (anode) with an annular diaphragm of 2 mm wide located at a distance of 2 mm from it. The flow of electrons from the cathode, passing through the diaphragm, propagated further in an extended (about 70 cm) electron drift tube (collector) with an internal diameter of 50 mm and deposited on its inner surface. The EOS was equipped with a magnetic electron confinement system which formed an inhomogeneous along the axis magnetic field. The magnetic field increased from the minimum value at the cathode B_c to the maximum value of B_m in the center of the solenoid. In the continuous mode, the existing magnetic system provided the maximum magnetic compression coefficient $K_m = B_m / B_c$ no more than 8-10. A schematic view of the EOS cross section is shown in Fig. 1. In the well-adjusted EOS, only negligible fraction of the electron flow (less than 0.01%) was intercepted by the control electrode. To minimize heating of the collector under the action of electronic bombardment, it was equipped with a water cooling system.

To control the characteristics of an electron beam formed by an EOS, two analyzes were designed and manufactured: an analyzer AL with a luminescent screen (Fig.2) for control the distribution of electron flow in the beam cross section and the

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retarding field analyzer RFA (Fig.3) for measure the velocity distribution of electrons in the beam.

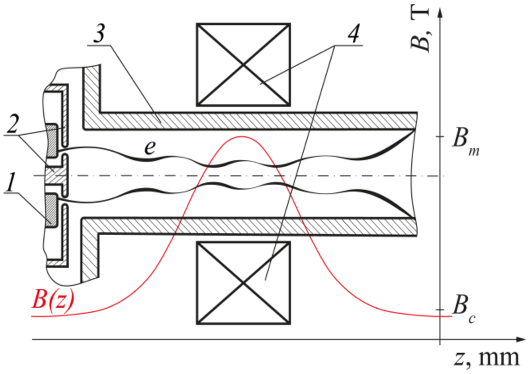

Fig. 1. Schematic view of EOS cross section. 1- cathode system with multi-tip annular field emitter, 2- control electrode, 3 - transportation channel, 4 - solenoid.

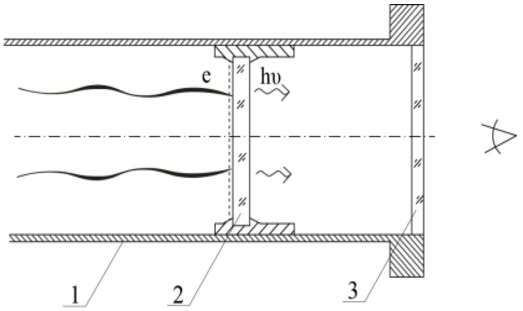

Fig.2. Analyzer AL. 1 - transportation channel, 2 - luminescent screen, 3 - transparent window. e - electron beam

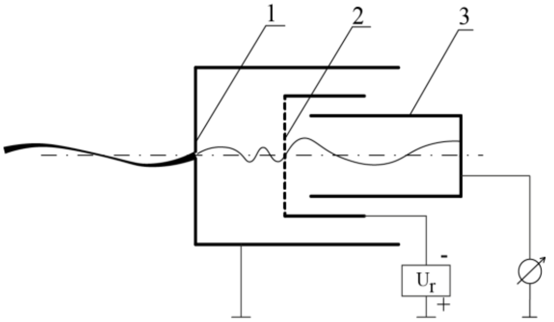

Fig.3. Analyzer RFA. 1 - electrode with round (150 μm) inlet, 2 - electrode with the greed, 3 - collector.

Both analyzers could be moved along the axis of the system. The analyzer RFA could also be moved in the radial direction. This made it possible to measure the velocity distributions of electron flows from different sections of the electron beam cross section. The velocity distributions of electrons were measured in the region of the maximum of the magnetic field distribution, where magnetic lines are oriented along the axis of the system. When measuring the current delay curves on the collector RFA, the retarding voltage U_r was applied to the grid 2 of analyzer relative to the grounded input electrode 1.

Results of measurements

In a continuous mode, the created EOS formed stable and uniform annular in cross section electron flows with currents of up to about 50 mA. A further increase of current was not possible due to the limited power of the source of voltage applied between the cathode and the control electrode of the electron gun. In the pulsed mode, it was possible to obtain significantly more currents of approximately 75 mA.

Fig.4 shows a typical image of the electron beam cross section on the AL screen.

Fig. 4. Typical image of the electron beam cross section on the AL screen

Fig.5 demonstrates typical experimentally determined distributions of the longitudinal $V_{||}$ (along the magnetic lines) and transverse $V_{\perp}$ velocities of electrons. At the small magnetic compression ratio K_m implemented in this work, the pitch factor $g = V_{\perp} / V_{||}$ of the electrons did not exceed 0.4 - 0.5 even at the maximum of the magnetic field. Significantly higher values of the pitch factor can be obtained at larger values of magnetic compression ratio.

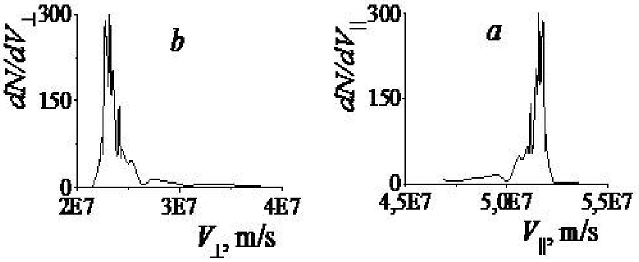

Fig.5. Typical distributions of electrons in the beam on the longitudinal (a) and transverce velocities (b).

Summary

Summing up the main results of work, we can note the following. The created EOS with a field emitter allows to form annular in cross section electron flows with currents sufficient to ensure operation of diagnostic terahertz and sub-terahertz gyrotrons of low (tens of watts) power. The developed diagnostic methods provide information on the characteristics of the electron beam necessary at the design of gyrotrons with such EOS.

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