Design, Simulation and Fabrication of an Electron Optic System with Sheet Electron Beam for a Sub-THz Traveling-Wave Tube

I.A. Navrotskiy, A.A. Burtsev, R.A. Torgashov,
V.N. Titov, A.G. Rozhnev, and N.M. Ryskin

Saratov Branch, Institute of Radio Engineering and Electronics RAS, Saratov, 410019 Russia
Saratov State University, Saratov, 410012 Russia
RPE “Almaz,” Saratov, 410033 Russia
E-mail of corresponding author: ryskinnm@gmail.com

Introduction

Miniaturized vacuum tubes operating at sub-THz and THz frequencies are of great interest for various applications, such as high-data-rate wireless communication, high-resolution radar, and spectroscopy. Since the transverse dimension is reduced, the tubes require electron beams with a very high current density. Thus, devices with spatially extended electron beams, such as sheet-beam and multiple-beam ones have attracted a strong interest [1-3].

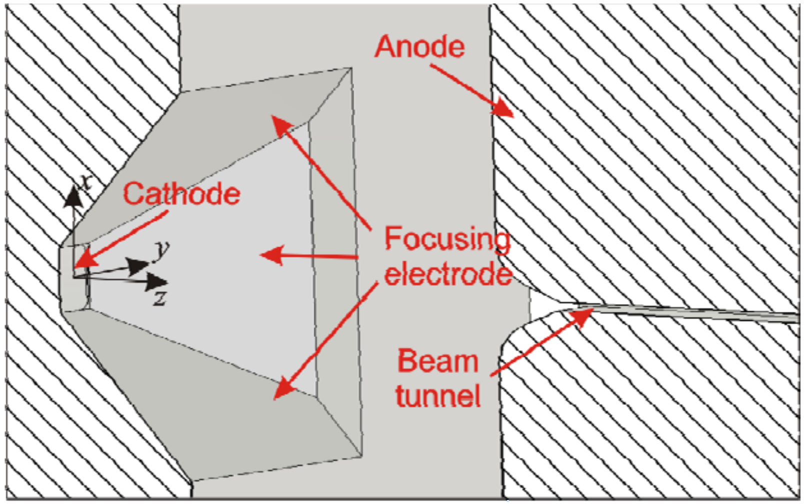
In this paper, we present the results of research aimed at development of the electron-optic system (EOS) for a microfabricated G-band (0.2 THz) traveling-wave tube (TWT) with a high-current-density sheet electron beam.

1. G.S. Nusinovich, S.J. Cooke, M. Botton, and B. Levush, “Wave coupling in sheet- and multiple-beam traveling-wave tubes,” *Phys. Plasmas*, vol. 16, no. 6, 063102, June 2009.
2. M. Field, T. Kimura, J. Atkinson, et al., “Development of a 100-W 200-GHz high bandwidth mm-wave amplifier,” *IEEE Trans. Electron Devices* vol. 65, no. 6, pp. 2122-2128, June 2018.
3. T.A. Karetnikova, A.G. Rozhnev, N.M. Ryskin, et al., “Gain analysis of a 0.2-THz traveling-wave tube with sheet electron beam and staggered grating slow wave structure,” *IEEE Trans. Electron Devices*, vol. 65, no. 6, pp. 2129-2134, June 2018.

Electron Gun With a Converging Sheet Electron Beam

An electron gun with a converging sheet electron beam provides a substantial improvement of the TWT performance as compared with the EOS with straight beam immersed in a uniform magnetic field [4]. The former one facilitates beam focusing and allows reduce of the focusing magnetic field and cathode current density, which, in turn, allows increase of the lifetime.

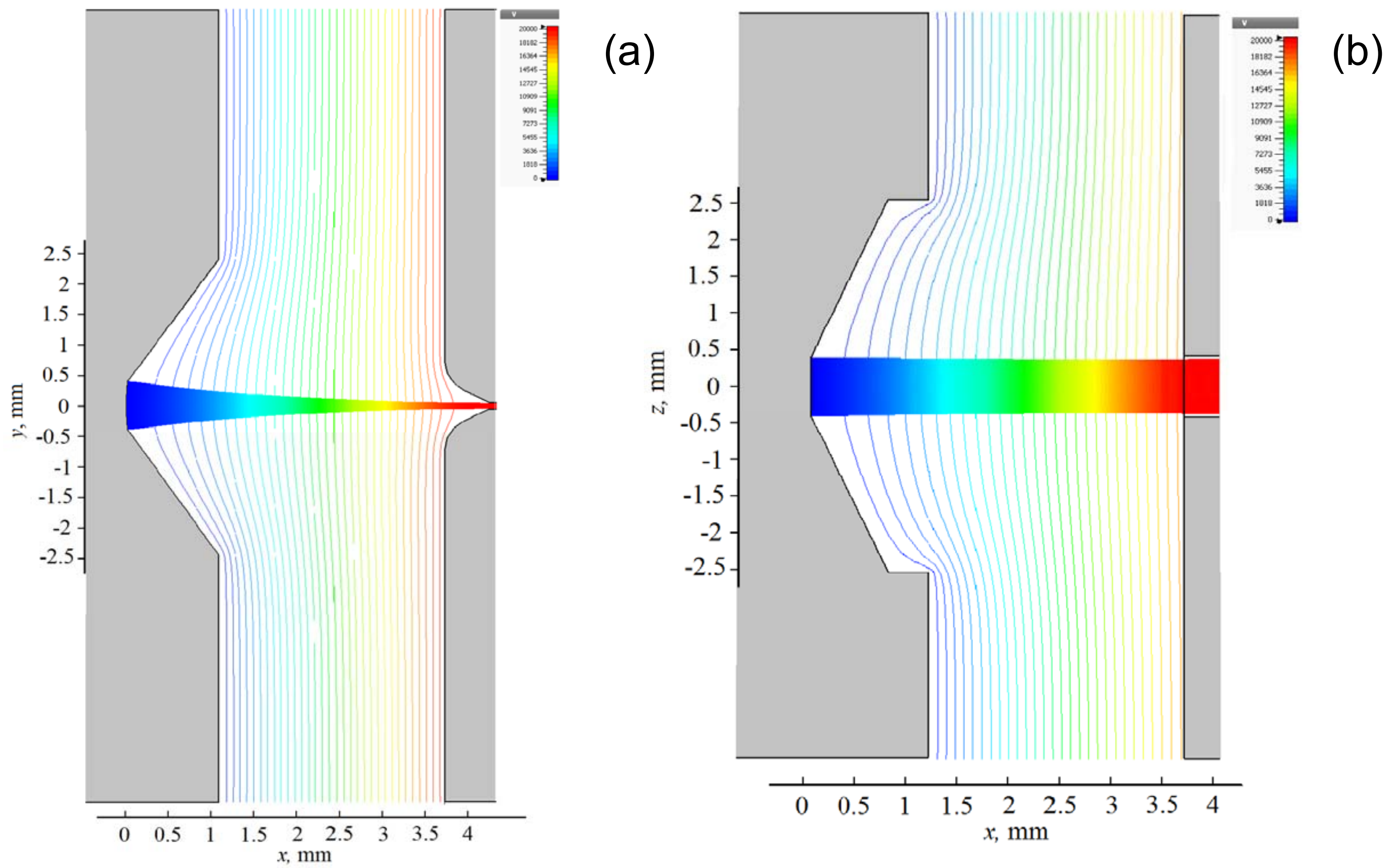
4. A.E. Ploskih, N.M. Ryskin, A.A. Burtsev, A.V. Danilushkin, and I.A. Navrotsky, "Performance improvement of a sub-THz traveling-wave tube by using an electron optic system with a converging sheet electron beam," *Results in Physics*, vol. 12, pp. 799-803, 2019.



Schematic 3-D view of the electron gun

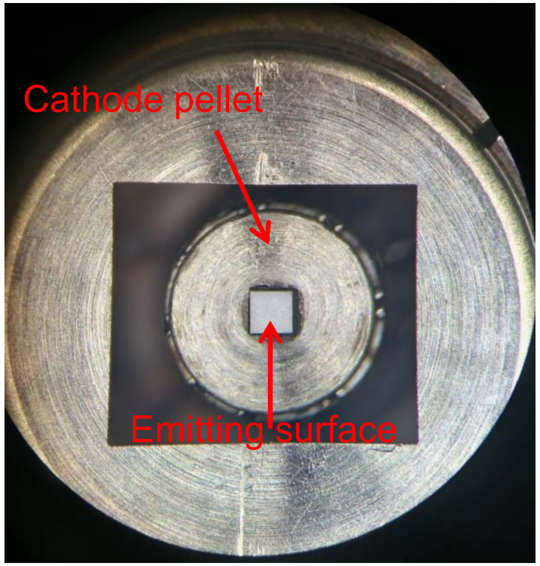
The electron gun with a 0.8×0.8 mm^2 curved cylindrical cathode with a 4.93-mm curvature radius was designed. The beam-focusing electrode (BFE) has the form of a rectangular horn.

The extracting voltage was set to 20 kV and the cathode-to-anode distance was about 4.3 mm. The beam thickness at waist position is ~ 0.05 mm, i.e. a compression ratio ~16 is provided.

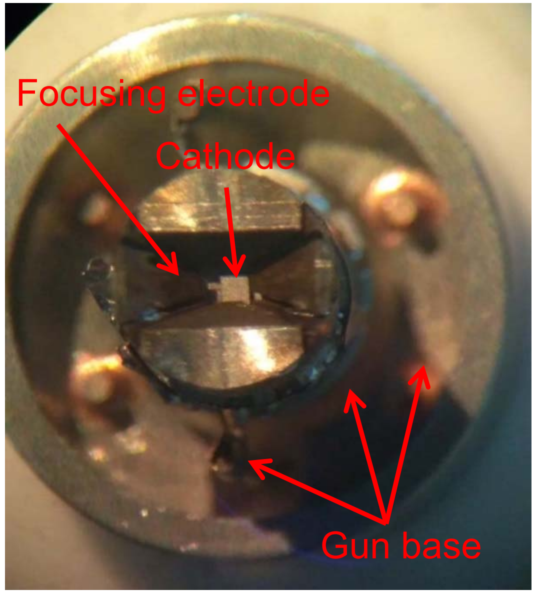


The results of 3-D modeling of the electron gun:
(a) *XY*-projection; (b) *XZ*-projection. Equipotential lines of focusing electrostatic field in the gun are plotted.

Electron gun fabrication



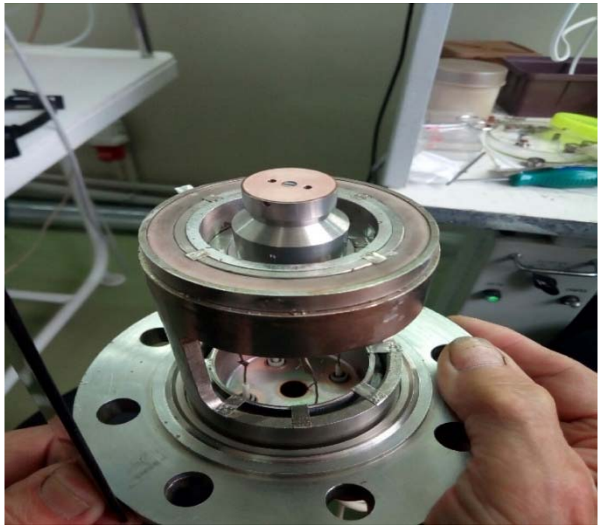
View of the 0.8×0.8 mm^2 cathode pellet



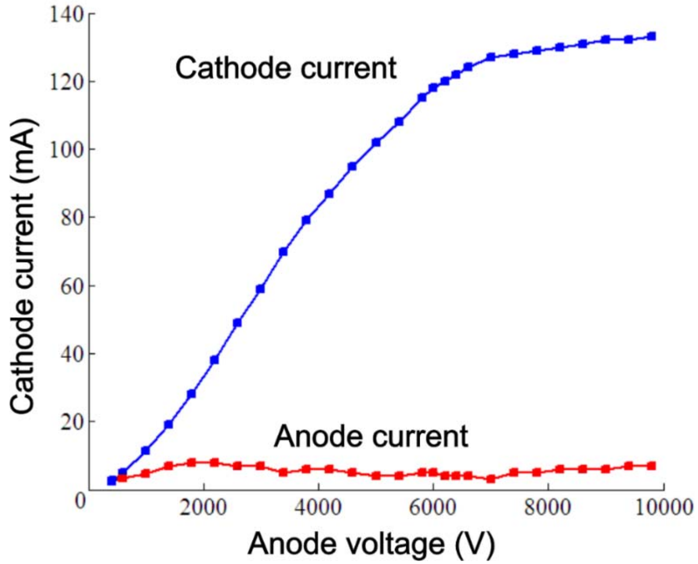
General view of the electron gun

The cathode pellet was manufactured from porous tungsten matrix impregnated by BaO and coated with Os nanoparticle film, which lowers the work function and increases the emission uniformity. Operating temperatures of the cathode are 1100–1300ºC. The BFE was manufactured from hafnium by electron discharge machining (EDM).

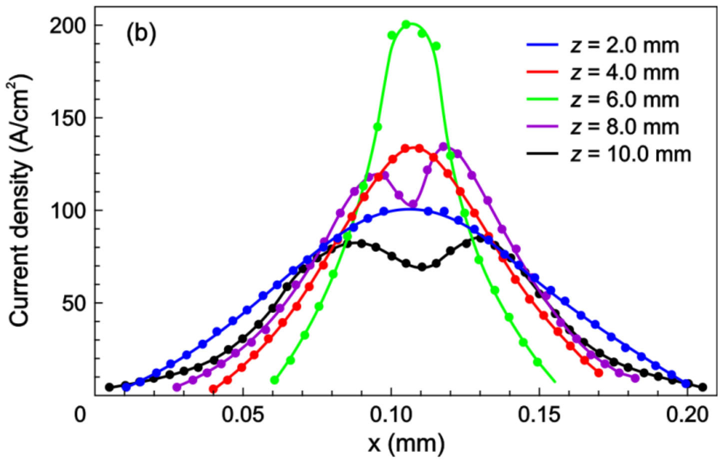
Electron gun fabrication and measurement



Fabricated electron gun

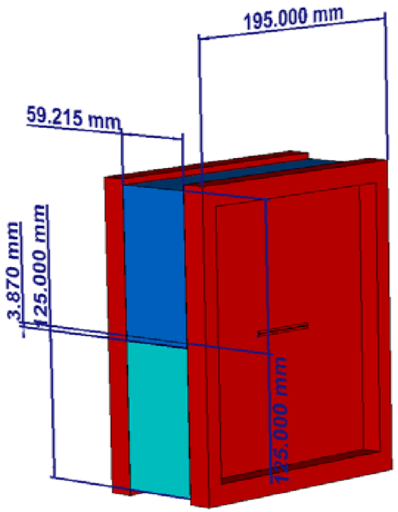


Measured electron gun current

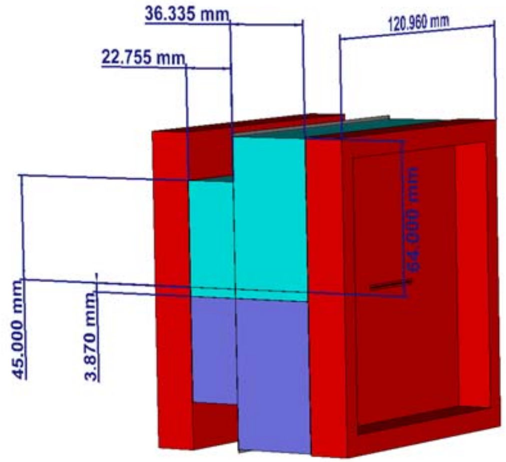


Electron current density profiles at different distances from the cathode were experimentally measured by a pinhole analyzer. The beam thickness at waist position was less than 0.1 mm. Peak measured current density was about 200 A/cm^2.

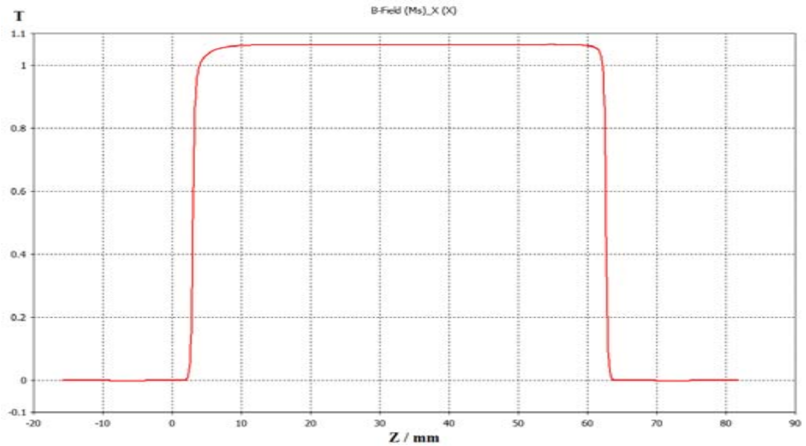
MAGNETIC FOCUSING SYSTEM DESIGN

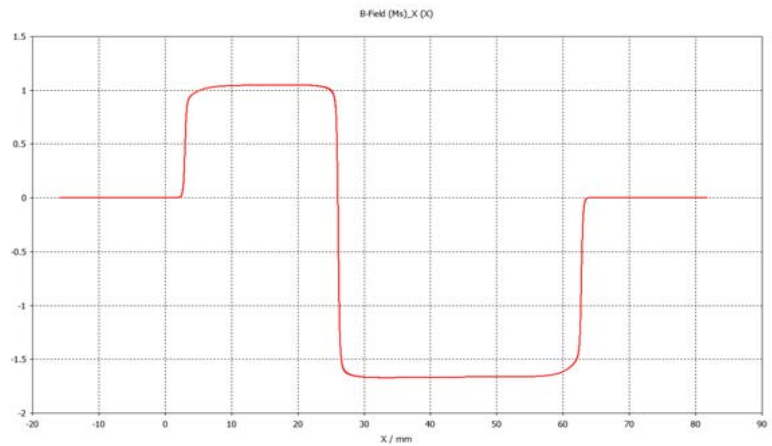


$m \approx 21.5$ kg



$m \approx 6$ kg

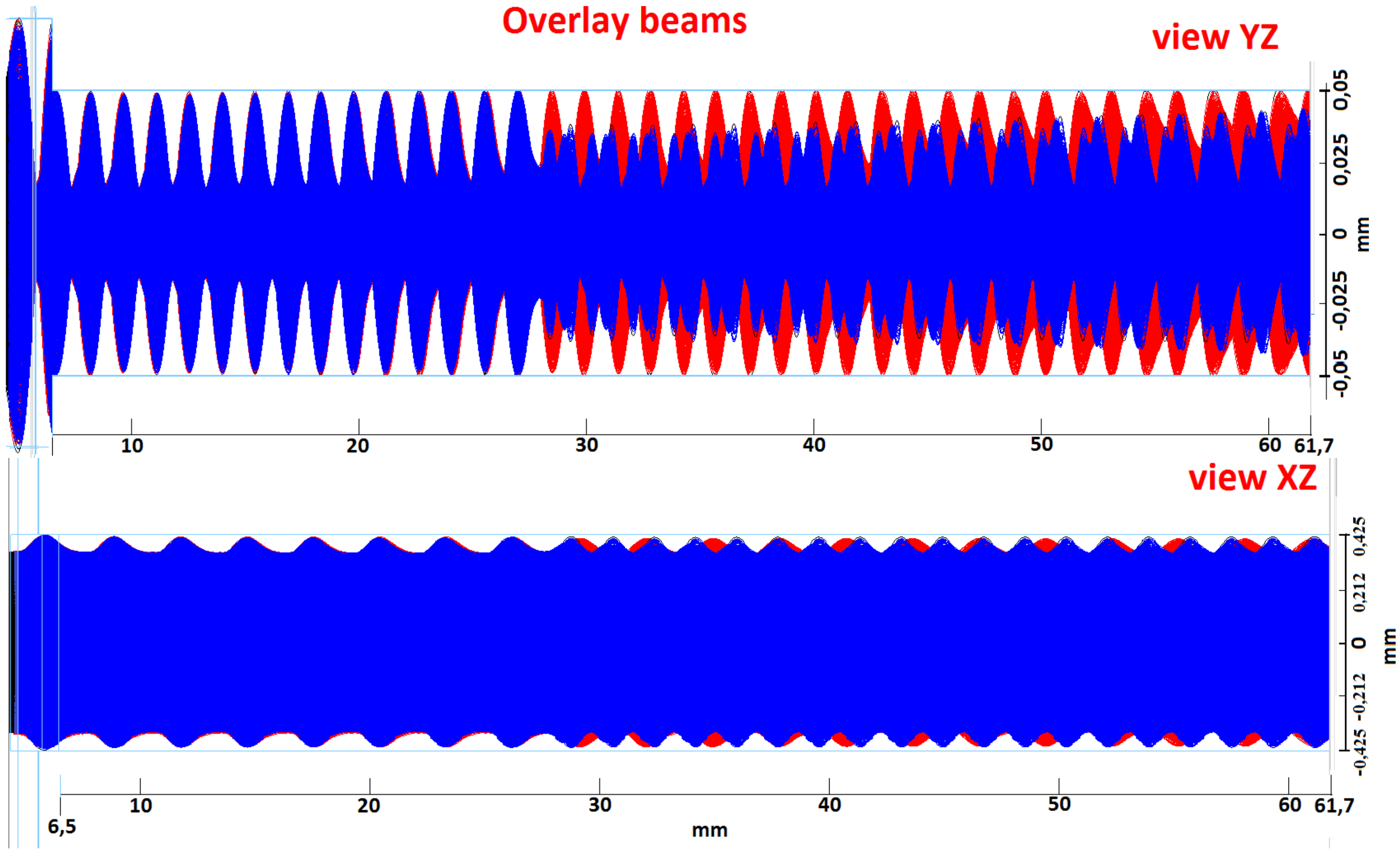




Schematic view of the permanent-magnet MFS with uniform magnetic field

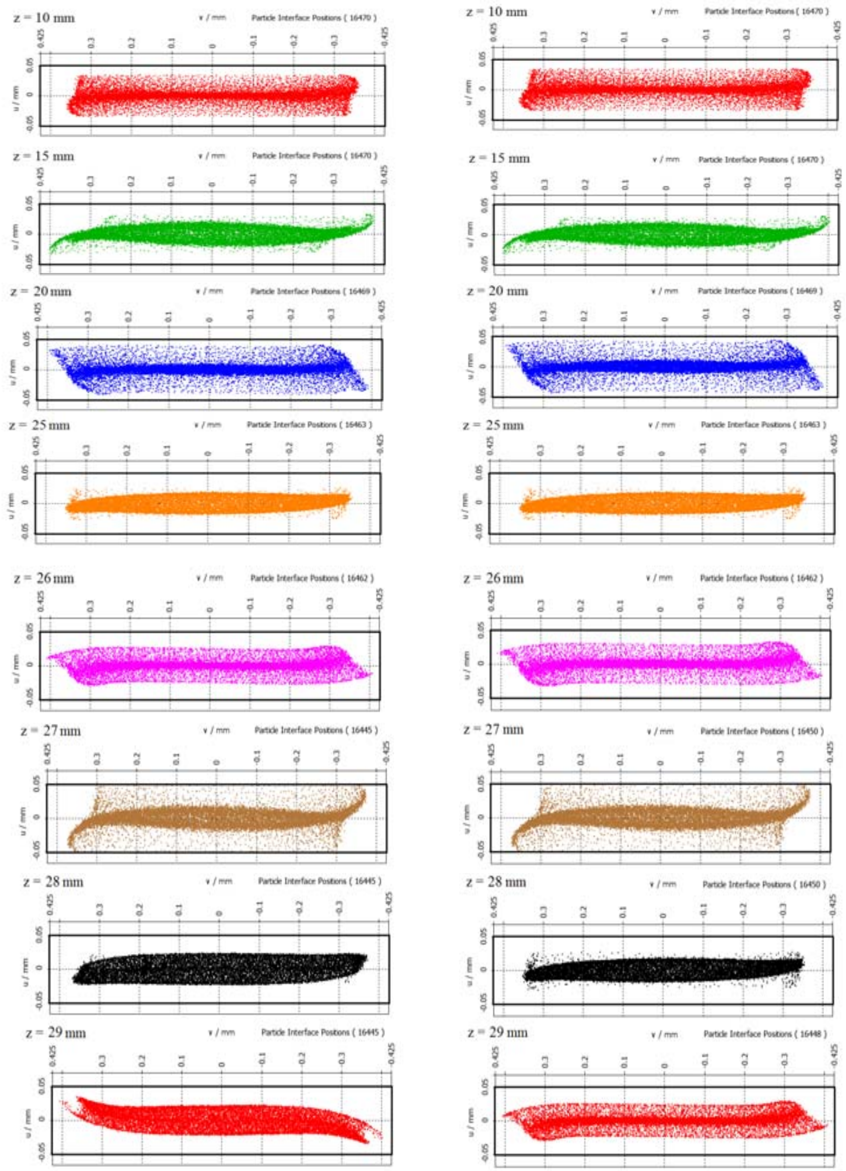
Schematic view of the reversal-field magnetic system

COMPARISON OF FOCUSING IN REVERSAL AND UNIFORM MAGNETIC FIELD



View of the overlay beams in reversal (blue) and uniform (red) magnetic field

Comparison of Focusing in Reversal and Uniform Magnetic Field



Electron beam transverse profiles at different distances from the cathode in the reversal (left) and uniform (right) magnetic field

Conclusion

In conclusion, the electron gun with a converging sheet electron beam with ~16-times beam compression in the vertical direction was designed. The gun produces a 100-mA, 20-kV sheet beam with 750×75 mm^2 dimensions. Using of the converging sheet electron beam facilitates beam focusing and allows substantial reduce of the cathode current density. The latter allows increase of lifetime and makes possible CW operation.

The designed electron gun was fabricated and nearly 140-mA beam current was measured experimentally. In addition, electron current density profiles at different distances from the cathode were measured. The beam thickness at waist position was less than 100 mm.

The permanent-magnet reversal magnetic focusing system is designed and simulated. Such a magnetic system has a significantly smaller size and weight compared to the permanent magnet. The simulation confirms stable beam transportation in 850×150 mm^2 beam tunnel over 40-mm distance without interception. Over 95 % beam transmission was obtained in the simulation.

Moreover, the reversal magnetic field provides better focusing than the solenoidal one and allows further reduce of the beam tunnel height to 100 mm.

This research was supported by the Russian Science Foundation under Grant No. 17-12-01160 and 20-12-18034.