Design of a new compact THz source based on Smith-Purcell radiation

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Abstract In recent years, people are dedicated to the research work of finding compact THz sources with high emission power. Smith-Purcell radiation is qualified for the possibility of coherent enhancement due to the effect of FEL mechanism. The compact experiment device is expected to produce hundreds mW level THz ray. The electron beam with good quality is provided under the optimized design of the electron gun. Besides, the grating is designed as an oscillator without any external feedbacks. While the beam passes through the grating surface, the beam bunching will be strong and the second harmonics enhancement will be evident, as is seen from the simulation results.

Key words Smith-Purcell radiation, permanent ring magnet, THz source

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1 Introduction

Since Tera Hertz (THz) radiation finds wide applications in sensing and imaging, etc., the topic of THz radiation generation has been attracting continuous interest over the last decade. Among all kinds of THz sources, the Smith-Purcell radiation was first observed by S. J. Smith and E. M. Purcell[1] in 1953. When an electron passes close to the surface of a metal diffraction grating, moving perpendicular to the tooth, the Smith-Purcell radiation is emitted, as is shown in Fig.1, where the plane (η, ζ) is the emission plane.

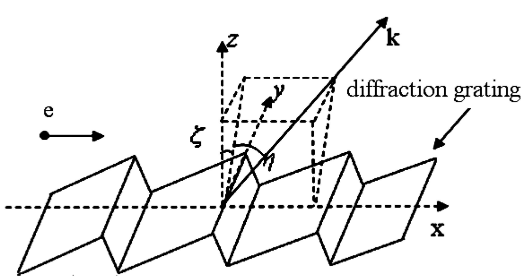

Fig. 1. Schematic of the Smith-Purcell radiation.

In Smith-Purcell radiation, the quality of the electron beam is crucial for the production of THz ray, thus the deliberate design of the magnet and electrode structures is important to obtain a high quality electron beam.

We are designing a new compact Smith-Purcell radiation THz source using a pair of permanent magnets to generate the axial magnetic field. For the design purpose we have performed electron trajectory simulations with the software of "Possion / Pandira" and Egun. The magnet and electrode structures were designed based on the simulations.

The magnetic field strength produced by the permanent magnets is considerably lower than that by the superconducting magnets, resulting in a larger electron beam diameter, and hence, in a lower current density. However there are several advantages in comparison with the superconducting magnets; for example, lower running cost, smaller size, and simpler structure.

2 The overall design

The overall design of the new Smith-Purcell radiation THz source is shown in Fig. 2. The electron gun head, the radiation part, and the collector are

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arranged horizontally. The vacuum vessel consists of stainless steel tubes and the magnets are placed inside the vessel. The horizontal length of the whole set is 1 meter, small enough to be placed on a usual desk.

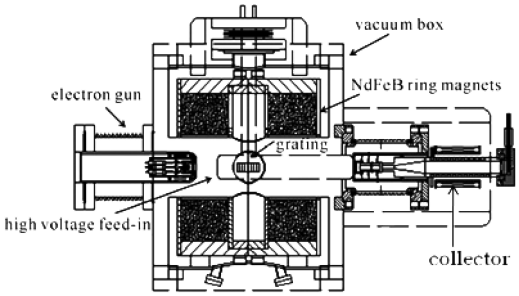

Fig. 2. Set-up of the compact THz source.

2.1 Magnet and electron gun

A pair of axially magnetized NdFeB ring magnets, will be used. One magnet has a north pole on the inner face, the other one with the south pole innermost vessel. These rings consist of 23 magnetized wedges and one nonmagnetic wedge. The nonmagnetic wedge is placed along a horizontal plane to induce the THz radiation out. The magnetic fields were calculated with the Possion code for the magnets with 24 magnetized wedges.

These calculations were performed for the magnetic rings with an outer diameter of 300 mm, an inner diameter of 130 mm, a length of 100 mm, and a separation of 82 mm. The magnetic field strength along the electron-beam axis is reduced because of the nonmagnetic wedge by about 4%, uniformly between the electron gun and the collector. The small change does not cause significant degradation of the beam quality. The magnets were treated as cylindrically symmetric throughout the electron-beam trajectory simulations.

The electron beam is produced by electron gun which includes cathode, focus and anode electrodes. Our main design efforts were devoted to the design of the soft iron and the optimization of the position of the electron gun with respect to the magnetic field. The electron gun has a spherical concave shape, and the cathode's diameter is 3 mm. The configurations of the gun are taken from the Shanghai Electron Beam Ion Trap (EBIT)[2, 3], which has successfully generated a 200 mA electron beam.

The voltages applied to the electrodes were optimized to have better electron flow, then the thin electron beam was obtained as shown in Fig.3. The first anode and second anode voltage respecting the cathode are 6 kV and 10 kV, and the focus electrode voltage is -5 V. The beam's longitudinal and radial distributions after the gun until the middle of grating are shown in Fig 4.

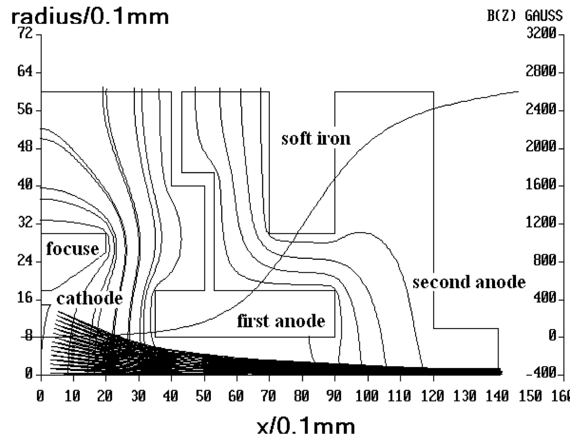

Fig. 3. The structure and electron beam trajectories in the electron gun head. The voltages on the electrodes are optimized for the 35 keV, 200 mA electron beam.

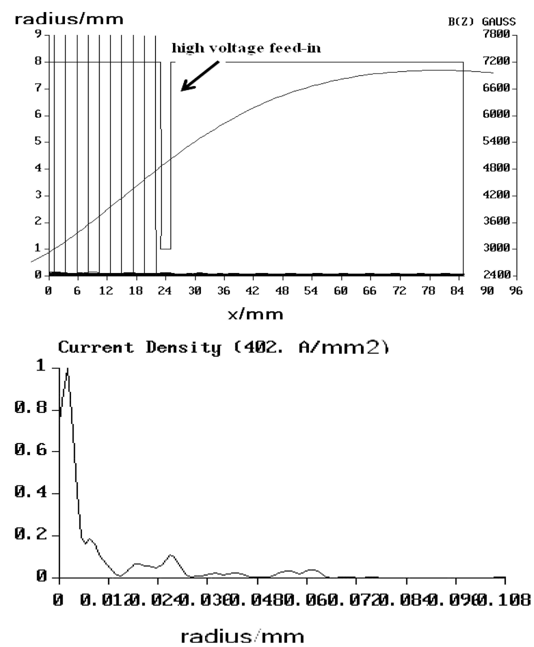

Fig. 4. Dynamic characteristics for electron beam. (a) Longitudinal distribution of e-beam, (b) Radial distribution(normalized current density) at the center of grating.

The electron gun is surrounded by soft iron as a shield of the magnetic field, because the magnetic field at the cathode surface should be as small as possible to obtain the highest compression of the electron beam[4]. Since the soft iron influences the initial magnetic field gradient, the shape and position of the soft iron are adjusted to match the electron-beam trajectories to the axial magnetic field. The magnetic field strength at the center of the trap is estimated to be 0.7 T.

2.2 Radiation part

According to the theory of evanescent surface waves, the dispersive relation is determined when the electron and grating parameters are given. Correspondingly, we could optimize the grating parameters to meet the experiment requirements. As the observation angle is around 60 degrees, the emission frequency at this angle should be two times the evanescent wave's frequency. The optimum parameters are listed in Table 1.

Table 1. Parameters used in the simulation.

beam and grating parameters	
beam voltage/kv	35
beam current/A	0.2
beam radius/μm (rms)	75
b field/T	0.7
grating height/μm	200
groove depth/μm	150
grating period/μm	173
groove wide/μm	100
number of periods	101
beam-grating distance/μm	50

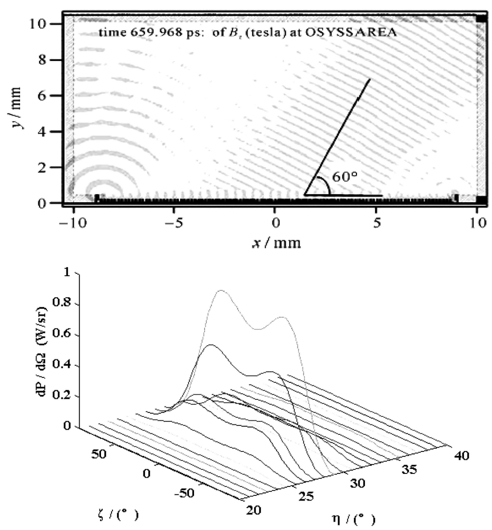

Fig. 5. Simulation and calculation results of SPR. (a) Simulation result of radiation distribution, (b) Calculation of emission power per solid angle.

The PIC code and post processing method[5] are used to simulate the Smith-Purcell radiation and calculate the exact emission power respectively, as is shown in Fig. 5.

The total power could be calculated using the numerical integral method and the result is 0.065 W. As for our experimental condition, in the angular acceptance ($5° \times 5°$), the accepted power should be about 2 mW.

2.3 Collector

The electron beam is collected in the collector. The electrode where the electron beam is collected has a conical inner face and is cooled by oil. Several other electrodes are in the collector to control the primary beam and secondary electrons inside the collector.

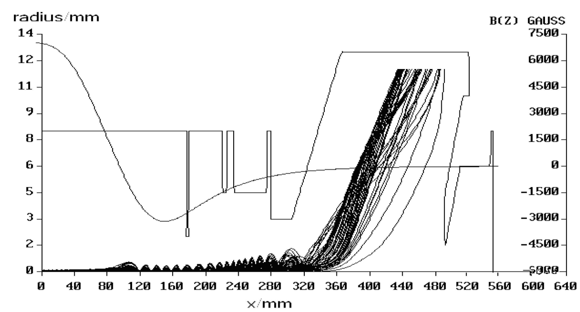

Fig. 6. Simulation of beam dynamics in collector.

3 Conclusion

We have performed the electron trajectory simulations to design a new compact THz source. The magnet and electrode structures of the compact THz source were optimized based on the results obtained with the simulations. The results of the simulations show that we can obtain the electron beam with almost the same quality over a wide range of the electron beam energy and current.

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