# A Novel Tunable PCM Focusing System for a 220 GHz Sheet Beam Electron Gun

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***Abstract:*** *Sheet beam electron gun and focusing system are key parts of sheet beam traveling wave tube. In this paper, a 220 GHz sheet beam electron gun is designed and a novel tunable periodic cusped magnet (NTPCM) focusing system for this sheet beam electron gun is proposed. The beam current of the designed sheet beam electron gun is 0.13 A at 22 kV beam voltage, and the sheet beam size at beam waist is around 0.5 mm × 0.1 mm. Furthermore, the simulation results show that the sheet beam with current density greater than 260 A/cm² can transport more than 90 mm under the focusing of this NTPCM.*

**Keywords:** electron gun, sheet beam, novel tunable periodic cusped magnet (NTPCM), focusing system

## Introduction

In recent years, with the development of electronic information technology to higher frequency, the utilization of frequency resources becomes tougher. Many research institutes are beginning to exploit the terahertz (THz) spectrum, such as 140 GHz, 220 GHz, 340 GHz, 650 GHz, 850 GHz and other key frequency bands [1,2]. Traveling-wave tube (TWT) is an attractive vacuum electron radiation source in THz band, which is widely used for high-resolution radar, broadband satellite communications, biomedical imaging, deep-space research, and other fields [3]. However, in the THz frequency band, dimensions of the device and beam tunnel become very small due to the scaling effect of electromagnetic wave theory, this poses a great challenge to the development of THz TWT. One of the difficulties in the realization of THz TWT is the transport of electron beam, because electron gun and focusing system are difficult to achieve ideal assembly accuracy, especially for sheet beam is more challenge. For this reason, tunable focusing system have become one of important solutions. Compared to a uniform magnetic field focusing system, the open-sided periodic cusped magnet (PCM) have a better focusing effect on sheet beam [4]. In addition, the PCM is facilitate the design of tunable focusing systems.

This paper presents a novel tunable periodic cusped magnet (NTPCM) focusing system to focus sheet beam, it will make the device more compact than a uniform magnetic field focusing system. This proposed NTPCM is used for a 220 GHz sheet beam TWT. Moreover, it can be employed in the THz sheet beam BWO, Klystron, EIK, and many more.

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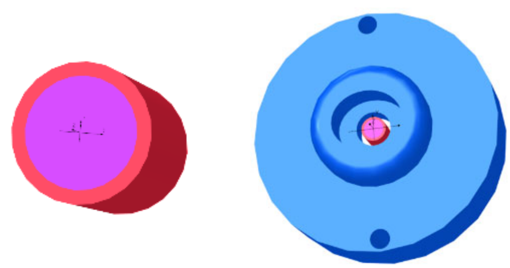
## Sheet Beam Electron Gun

The emission current of the cathode is almost the same as before [5-7]. The cathode of 220 GHz sheet beam electron gun adopts a circular planar cathode with area of 0.5 mm$^2$ emission surface, and the electrons from the cathode face are compressed by elliptical focus electrode to obtain a sheet beam. 3-D model of the cathode and the focus electrode are shown in Fig. 1. Based on the simulation software of Opera-3D, the optimized 220 GHz sheet beam electron gun is formed.

The key parameters are listed here: the beam current is 130 mA at 22 kV beam voltage, the beam size at beam waist is 0.5 mm × 0.1 mm, and the sheet beam compression ratio is about 10. Besides, it can be found that the beam trajectory of the electron gun is relatively smooth and keeps a good laminarity, which will facilitate the design of the focusing system. Currently, the sheet beam electron gun is in fabrication.



(a) (b)

**Fig. 1.** The views of cathode (a) and focus electrode (b).

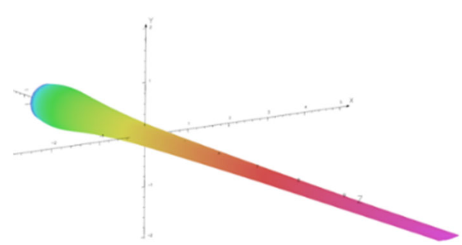
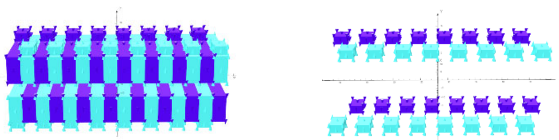


**Fig. 2.** Simulated beam trajectory of the sheet beam electron gun.

## Simulation of Sheet Beam Transport

We propose a NTPCM for focusing sheet beam, the Brillouin magnetic field value of the sheet beam is calculated as 0.19 T. Fig. 3 is 3-D model of the NTPCM system, which consists of PCM and staggered magnets.



(a) (b)

**Fig. 3.** 3-D model of the NTPCM system (a) and staggered magnets (b).

In order to illustrate that the focusing magnetic force provided by NTPCM can balance the space charge force of the sheet beam better, the joint simulation of the sheet beam electron gun and NTPCM are carried out in the Opera-3D. Fig. 4 shows the simulated axial magnetic field *Bz* generated by NTPCM, the maximum value of the axial magnetic field is 0.32 T, about 1.68 times Brillouin's magnetic field.

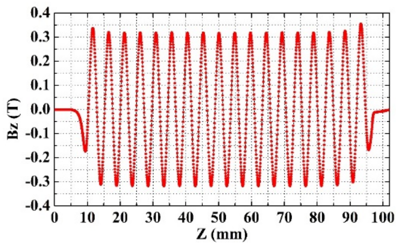



**Fig. 4.** The magnetic field *Bz* of the proposed NTPCM versus Z for X = 0 and Y = 0.

Fig. 5 shows the simulated results of the sheet beam trajectory. The simulation results show that the beam current transport to Z = 100 mm is consistent with the emission current, indicating that the focusing magnetic field provided by NTPCM can well offset the space charge force of the sheet beam. In addition, according to the simulated results of the sheet beam trajectory in y-z plane (beam narrow side) and in x-z plane (beam wide side), as shown in Fig. 6, it can be seen that the fluctuation amplitude of the sheet beam in the direction of the narrow side is small, indicating that the axial magnetic field *Bz* is sufficient for the focusing of the beam narrow side. The sheet beam in the wide side direction can also be limited to the channel of 0.8 mm, so the electron optical system composed of this NTPCM can be used for focusing the sheet beam with a relative long distance transport.

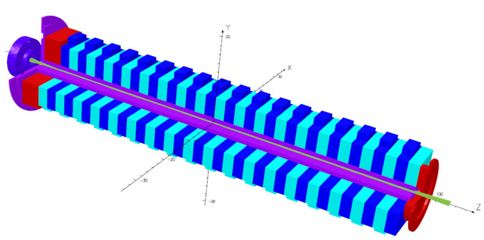
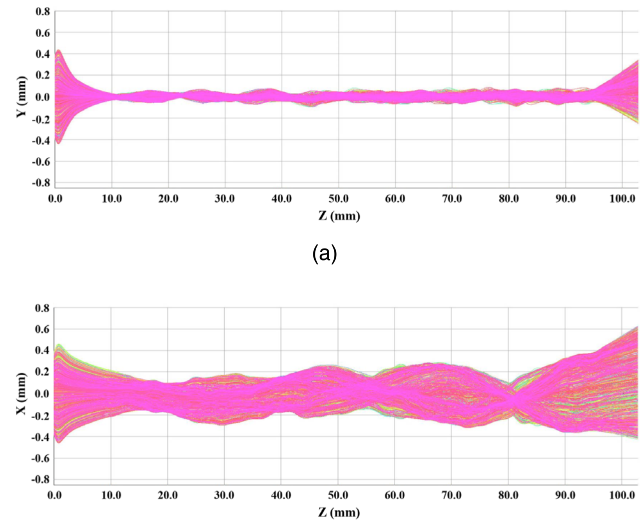


**Fig. 5.** Simulated results of the sheet beam trajectory.




(a)

(b)

**Fig. 6.** Simulated results of the sheet beam trajectory in y-z plane (a) and in x-z plane (b).

## Conclusion

In this paper, we present simulation results that demonstrate a sheet beam electron gun and a NTPCM focusing system. A 130 mA sheet beam with a beam size of 0.5 mm × 0.1 mm at beam waist is obtained, and beam voltage is 22 kV. This sheet beam achieved a transport efficiency of 99% through a 0.8 mm × 0.16 mm rectangular beam tunnel over a distance of 90 mm with NTPCM focusing system. The electron optical system composed of this NTPCM can meet the requirements of higher gain for our 220 GHz sheet beam TWT.

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