A Three-stage Depressed Collector for 220 GHz Sheet Beam Traveling-wave Tubes

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Abstract: *In this paper, a three-stage depressed collector suitable for 220 GHz sheet beam traveling-wave tube (TWT) is studied. The condition of spent sheet beam is analyzed by using the CST 2016 Particle Studio. The positions distribution and velocity of the sheet beam are also obtained. Based on the analysis of the sheet beam at the entrance of the collector and the characteristics of the sheet beam after the interaction of 220 GHz sheet beam TWT, an efficient and low back streaming current three-stage depressed collector with the rectangular inlet and elliptical cavity shape is proposed. The collector efficiency is about 90% and the back streaming current is only 1.6 mA, which is accounting for 1% of the sheet beam current. This paper can provide some basic guidance for designing multistage depressed collector for 220 GHz sheet beam TWT.*

Keywords: 220 GHz, three-stage depressed collector, sheet beam TWT

Introduction

Sheet electron beam adopts a thin rectangular cross-section electron beam with a large width to height ratio, which breaks through the limitation of the space charge force on the strong current beam, can make its work in microwave and millimeter wave even terahertz frequencies. The beam-wave interaction efficiency and power capacity of traveling-wave tube (TWT) are improved, so that a TWT with a high average output power can be obtained [1]. Therefore, sheet beam has become the first choice in the design of TWT. The frequency of 220 GHz is important for electromagnetic wave transmission window in atmosphere, and is also an important reference frequency point center in the TWT design.

At present, the research on 220 GHz sheet beam electron gun and slow-wave structure (SWS) has been carried out successively [2, 3]. As an important factor to measure the quality of TWT, the improvement of TWT efficiency is the goal pursued by people. However, for G band high frequency TWT, it is quite difficult to improve TWT efficiency by improving its interaction efficiency. Therefore, in this paper, a three-stage depressed collector suitable for 220 GHz sheet beam TWT is designed, so as to improve the efficiency of the 220 GHz sheet beam TWT.

Analysis of spent electrons

During the operation of the TWT, due to the interaction of electron beam and wave, velocity size and motion direction of electrons are disordered, forming several velocity groups. In order to collect these disordered electrons and improve the recovery efficiency, it is very important to design a suitable collector. Prior to the design of a collector, one must understand the spent beam conditions at an entrance of the collector [4]. To do so, based on the particle-in-cell (PIC) solver in CST 2016 Particle Studio, the particles at the end of the interaction within one cycle of the SWS is intercepted, analyzed the sheet beam state of the existing 220 GHz SWS after the interaction. The TWT has an operating voltage of 23.3 kV, a sheet beam current of 140 mA and an output power of 50 W [5].

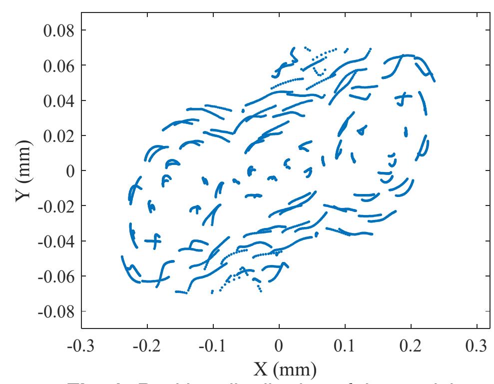

Fig. 1. Position distribution of the particles.

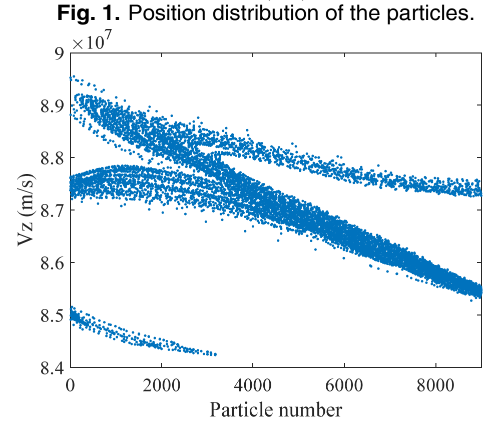

Fig. 2. Z direction velocity distribution of the particles.

Fig. 1 shows the position distribution of particles, and the particles are mainly distributed between -0.25 mm and 0.25 mm on the X-axis, which is basically consistent with the cathode width of 0.5 mm. The Y-axis is mainly distributed between -0.07 mm and 0.07 mm, slightly larger than the cathode height of 0.1 mm. Fig.2 shows the distribution diagram of particle velocity in Z direction. Particle velocity in Z direction is mainly concentrated in the vicinity of 8.9×10^7 m/s, 8.75×10^7 m/s and 8.5×10^7 m/s. Compared with the initial

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particle velocity of 8.76×10^7 m/s, the sheet beam after interaction can be obviously divided into three velocity groups, with obvious divergence of velocity.

Design of three-stage depressed collector

Using the above conditions of sheet beam entrance, a three-stage depressed collector is designed. The simulation results show that after the interaction of sheet beam TWT, the sheet beam from SWS will not be deformed immediately, and it will remain approximately flat for a period of time. After entering in collector, the divergence of sheet beam is also different from the cylindrical beam TWT [6]. Therefore, according to characteristics of the sheet beam TWT after interaction, the entrance of the collector is set as a rectangle slightly larger than sheet beam channel, with the wide side h=1 mm and narrow side w=0.4 mm, as shown in the Fig. 3(b). The shape of the collector electrode is designed as an elliptic cylinder cavity, and the electron entrance between the two electrodes is also designed as an ellipse, size and direction of the major and minor axes of the ellipse are related to the shape of the sheet beam after interaction. The collector model is shown in Fig. 3. The first-stage electrode length s_1=10 mm, the elliptic cylinder cavity in the first-stage cavity has a long semi-axis a_1=8 mm, a short semi-axis b_1=6 mm, the second-stage sheet beam elliptical channel has a long semi-axis a_2=2 mm, a short semi-axis b_2=1 mm, and the elliptic cylinder cavity in the second-stage cavity has a long semi-axis a_3=8 mm, a short semi-axis b_3=7 mm, the second electrode length s_2=10 mm.

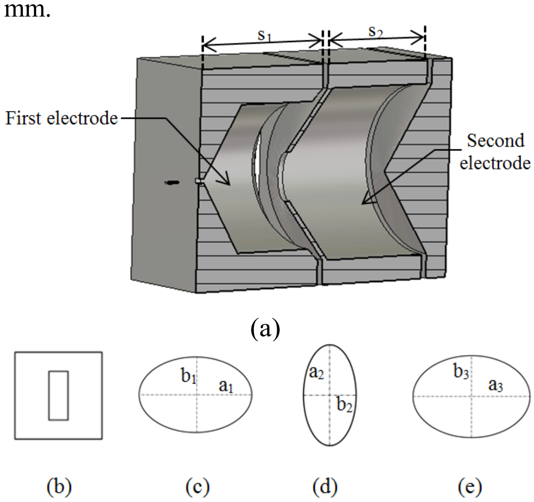

Fig. 3. 3D model of three-stage depressed collector and 2D model of key components ((a) 3D model of three-stage depressed collector (b) Sheet beam entrance channel (c) First stage cavity(d) Secondary sheet beam entrance (e) Second stage cavity).

Through the optimization and simulation of structure as well as voltages of the three-stage depressed collector, it is finally determined that voltages of the collector stage are -21 kV, -22.7 kV and -23.3 kV, respectively. The designed collector efficiency is 95% and the back streaming current is 0 mA. The above result has been achieved without considering the case of secondary electron emission. By replacing the material with the oxygen free high conductivity (OFHC) copper, in the case of considering the secondary electron emission, the collector efficiency is found to be 90%, and back streaming current is 1.6 mA.

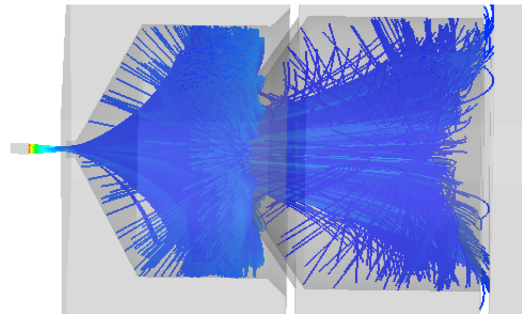

Fig. 4. The electron track in the three-stage depressed collector without secondary electrons.

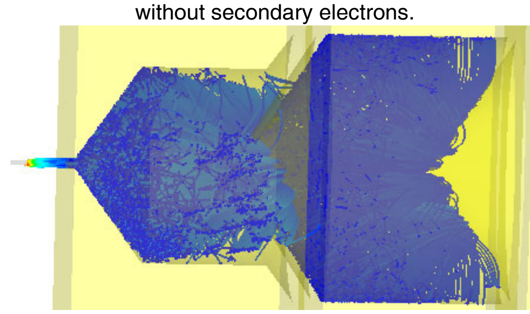

Fig. 5. The electron track in the three-stage depressed collector with secondary electrons.

Conclusion

The position distribution and velocity distribution of the sheet beam after the interaction of the 220 GHz sheet beam TWT are analyzed. Taking this as the condition for the entrance of the collector, a three-stage depressed collector with the rectangular entrance and elliptical cavity that is suitable for the 220 GHz sheet beam TWT is designed. According to the simulation, the efficiency of the collector is 90%, the back-streaming rate is 1%, the sheet beam dispersed evenly inside the collector and lands evenly on the electrode.

References

[1] B. Carlsten, S. Russell, L. Earley, *et al.*, “Technology development for a mm-wave sheet beam traveling-wave tube,” IEEE Trans. Plasma Sci, vol. 33, no. 1, pp. 85-93, 2005.

[2] S. Jiang, Z. Duan, X. Wang, *et al.*, “Electron optical system with uniform magnetic field for 220 GHz sheet beam TWT,” IEEE International Vacuum Electronics Conference, Busan, South Korea, pp. 1-2, 2019.

[3] G. Yang, Z. Duan, S. Jiang, *et al.*, “Transmission characteristics of 220 GHz T-shape staggered double-vane slow wave structure,” IEEE International Vacuum Electronics Conference, Busan, South Korea, pp. 1-2, 2019.

[4] J. Yang, X. Zhang, Y. Du, *et al.*, “Design of a multistage depressed collector for W-band pulsed traveling-wave tubes,” IEEE Trans. Electron Devices, vol. 66, no. 9, pp. 4056-4061, 2019.

[5] Z. Duan, S. Jiang, G. Yang, *et al.*, “Experimental advances in 220 GHz sheet beam traveling-wave tubes,” 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves, Paris, France, pp. 1-2, 2019.

[6] J. Lai, Y. Gong, H. Yin, *et al.*, “Virtual boundary element method for multistage depressed collector of traveling-wave tubes,” Physics of Plasmas, vol. 18, no. 4, pp. 403106, 2011.