Design of A G-Band EIK Three-Stage Depressed Collector

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Abstract: *In this paper, the method of directly exporting the particle data from the CST interaction results to the collector is used to effectively improve the accuracy of the collector design. A three-stage depressed collector for 220GHz extended interaction klystron was designed with an efficiency of 90% and a reflow rate of zero.*

Keywords: EIK(extended interaction klystron), MDC(Multi-Stage Depressed Collector), Beam-wave Interaction, Efficiency, Returning Electrons ,SEE(Secondary Electron Emission), SEY(Secondary Electron Emission Yield)

Introduction

With the increase of frequency, the output gain and bandwidth of microwave electric vacuum devices are greatly limited. The EIK adopts distributed interaction cavity technology to make it has high gain , high efficiency, and sufficient bandwidth[1]. The function of the collector in the microwave tube is to collect the spent electrons after the beam-wave interaction, recovering a large portion of energy in the spent electron beam. Using MDC can effectively improve the efficiency of the microwave tube.

CST Studio Suite integrates vary studios, such as MWS, EM, Particle studio and so on, which can be used to compute the cold-test parameter of the slow-wave structures (SWS), magnetic field distribution of focusing system, electron trajectory and beam-wave interaction respectively. But the beam-wave interaction of the microwave tube is carried out in the time domain by using CST PIC solver. The particle information of the spent electron beam is incompatible with CST Particle Tracking, which is used to design the MDC, because the collector design belongs to DC steady state calculation. Therefore, it will cause an interface problem between the interaction calculation and the collector. In order to solve this problem, in this paper the particle data obtained from the interaction calculation is processed and introduced into the collector for the three-stage depressed collector design. Finally, a three-stage depressed collector suitable for 220GHz extended interaction klystron is designed in this paper. Its recycling efficiency is up to 90% and the returning electron is zero. It can be seen from the electron trajectory that the electrons uniformly hit on the different electrodes' surfaces of the collector.

Docking of Beam-wave Interactions with Collector

Designing the multi-stage depressed collector should be based on the results of interaction between the electron beam and the electromagnetic field in the high frequency structure. In this paper, the beam-wave interaction result of a 220 GHz EIK is used for the MDC simulation calculation. Under the condition of electron beam channel filling ratio of 0.67, working voltage of 18 KV, current of 0.22 A and axial magnetic field of 0.8 T, the output power of the device is greater than 100W and the gain is greater than 30 dB in the range of 218.3 GHz-218.5 GHz[2] .

Considering the beam-wave interaction, when the output signal is stable, the modulated electron beam has a specified period in time domain at the end of the interaction structure. In order to obtain the currents of vary macro particles, a particle monitoring surface is set at the end of the circuit, the time interval is set to the 1/20 period of the electromagnetic wave. After the beam-wave interaction calculation, the electron data of different time slices on the monitoring surface is exported and processed into the current, which can be adopted to design the MDC using CST Particle Tracking Solver.

Analysis of the Imported Data at the Depressed Collector Entrance

The position distribution of the spent particles at the end of the interaction circuit is shown in Figure 1. It can be seen that the cross-sectional size of the particle trajectory is about 0.15mm*0.15mm. Figure 2 shows the cross-sectional structure of a three-stage depressed collector.

After the beam-wave interaction of the electron injection, most of the electrons transfer energy to the high-frequency field. And the electron energy is reduced, but the energy loss of the electrons to the high-frequency field is not the same. So the energy of the electron at the entrance of the collector is different. There is also a small portion of electrons that gain energy from the high frequency field. Figure 3 and figure 4 are the energy distribution diagramand the current distribution diagram at the entrance respectively.

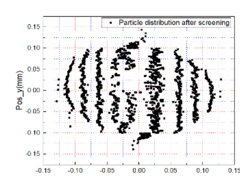

Figure 1. Particle position distribution at the entrance of the MDC

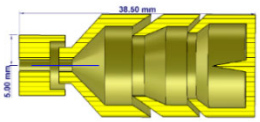

Figure 2. Section diagram of three-stage depressed collector

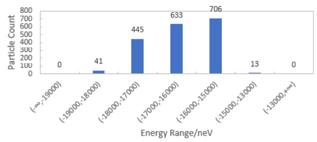

Figure 3. The energy distribution of outlet particles after screening

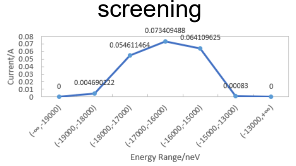

Figure 4. The current distribution of the screened outlet particles in each energy interval

From the energy distribution diagram and the current distribution diagram above, the voltage of the three-stage depressed collector should be set within the range from -19000 V to -13000 V.

Optimize the Three-Stage Depressed Collector Based on the Spent Electron Trajectory

To improve the overall efficiency of the EIK, a three-stage depressed collector has been designed and optimized. During the simulation and optimization, it is found that the position and voltage of the electrodes have a great influence on the collector efficiency and the return current[3]. In addition, the SEE of the collector material is also a significant factor affecting the collector efficiency. The commonly used collector electrode material is oxygen-free copper with excellent thermal and electrical conductivity. But the oxygen-free copper shows a high SEY in a wide range of electron energy. The collector must be applied with a high voltage to hold back the returning electron. Therefore, when a single electron reaches the collector, a large amount of secondary electrons are inevitably generated. When these secondary electrons hit the electrodes again, it causes considerable energy loss, which causes the decrease of the collector efficiency, the rise of the tube's temperature, the increase of the return current, even the heat dissipation power and form noise. Therefore, it is important to suppress SEE[4][5].

In order to weaken the influence of SEE and obtain the highest recovery efficiency of the collector. In this paper, the oxygen-free copper after ion beam surface treatment is selected as the collector electrode, and the maximum SEY is only 0.65[5]. According to the simulation results, when the three-stage depressed collector's opening radius is 1 mm, the overall size is 17mm*17mm*38.5mm, and the voltages of electrodes respectively are -13500V, -14500V, -15500V, the recovery efficiency of the three-stage depressed collector is up to 90% and the returning electron is zero. The simulation results by CST Particle Tracking Solver are shown in Table 1 below. The electron trajectory is shown in Figure 5. The electrons are collected by the electrode without returning electron.

Table 1. Recovery current at all levels

	First Stage (-13500V)	Second Stage (-14500V)	Third Stage (-15500V)
Collision Current(A)	0.036	0.168	0.164
Emission Current(A)	0.016	0.078	0.0766
Collect Power(W)	270	1305	1354.7
Efficiency	2929 W /3258 W=90%		

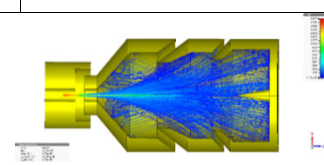

Figure 5. Electron track simulation results of three-stage depressed collector

Summary

The beam-wave interaction simulation in frequency domain and the data interface of the collector time domain simulation are used to design the three-stage depressed collector of the 220 GHz extended interaction klystron, and the shapes and voltages of electrodes are optimized by CST Particle Tracking Solver. The collector of the final design has an efficiency of 90% and the returning electron is zero. It can be seen from the electron trajectory that the electrons uniformly hit on the different electrodes' surfaces of the collector, so that the collector can dissipate the waste heat without hot spots.

Acknowledgements

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