Design of a Planar Sheet-Beam Magnetron Injection Gun

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Abstract: *A planar sheet-beam magnetron injection gun for the 94GHz sheet beam metallic grating waveguide amplifier based on combined resonance has been designed in this paper. The planar sheet-beam magnetron injection gun has two anodes which can optimize velocity ratio and transverse velocity spread conveniently. The electron beam produced by the planar sheet-beam magnetron injection gun can operate at accelerating voltage 34kV and current 1.7A. The guiding center of the electron beam at the region of interaction is 0.525mm and the magnetic field at interaction region is 2.8T. The simulation result of Opera indicate that the velocity ratio is 1.16 and transverse velocity spread is 3.5%.*

Keywords: Planar sheet-beam magnetron injection gun; cyclotron sheet electron beam; sheet beam metallic grating waveguide amplifier; Opera software

Introduction

The traveling wave tubes have a lot of advantages such as high power, wide frequency band, low noise, high gain and so on, which have wide applications in satellite communications, modern radar system and so many other fields. With the development of modern radar and satellite communications, higher requirements are put forward to vacuum devices. The sheet electron beam has become a future development trend because of its high power and high frequency. The sheet beam metallic grating waveguide amplifier can perfectly match with the sheet electron beam. It can improve the performances of vacuum devices such as power efficiency and gain. Improving the interaction efficiency between the metallic grating waveguide and the sheet electron beam is a problem that needs research scholars to pay more attention on it when the beam intensity has been determined. According to the research, the cyclotron sheet electron beam with a certain velocity ratio will obviously increase the gain and bandwidth of the sheet beam metallic grating amplifier interaction system. The traditional magnetron injection gun cannot provide cyclotron sheet electron beam. Therefore, the development of planar sheet-beam magnetron injection gun has become an urgent technical problem to be solved [1-2].

The main structure of this paper is organized into two major parts as follows. On the one hand, the paper has introduced the calculation formulas of basic parameters and the design steps of planar sheet-beam magnetron injection gun. On the other hand, the simulation result of Opera is shown in the paper. A cyclotron sheet electron beam with a velocity ratio of 1.16 and a transverse velocity spread of 3.5% was obtained through the simulation.

Design and Simulation

The basic parameters of planar sheet-beam magnetic injection gun are determined by the following formulas.

$$B_c Y_c = B_0 \left(Y_g - R_L \right) \tag{1}$$

$$l_c = \left(Y_2 - Y_1 \right) / \tan \theta_c \tag{2}$$

$$f_m = \frac{B_0}{B_c} \tag{3}$$

$$L_x = l_x f_m^{\,1/2} \tag{4}$$

$$J_0 = \frac{I_0}{\pi \left(Y_2^{\,2} - Y_1^{\,2} \right) / \sin \theta_c} \tag{5}$$

In these equations, B_0 and B_c are the magnetic field at cathode and interaction region, respectively. R_L is Larmor radius. Y_g is the thickness of sheet electron beam and Y_c is the cathode radius. Y_1 and Y_2 are the boundaries of the cathode emitter region. θ_c is the slope angle of emitter. l_x is the width of sheet electron beam and L_x is the width of cathode in x-axis. J_0 is the current density of cathode emitter. Basic parameters required for the sheet beam metallic grating waveguide amplifier are given in Table 1.

Table 1. Parameters of the sheet beam metallic grating waveguide amplifier

Parameter	Value
Frequency	94GHz
Beam voltage	34 kV
Beam current	~2A
Magnetic field at resonator	2.8T
Velocity ratio	1
Transverse velocity spread	<5%
Beam cross section	1.2mm×0.3mm

Although many factors should be considered when designing a planar sheet-beam magnetic injection gun, the cathode structure parameters can be determined by the above formulas. The detail design steps are introduced as follow. First of all, f_m can be defined by B_0 and B_c. Secondly, according to the formulas (1) (2) (4), The length, width and height of the cathode can be obtained simultaneously. Finally, the slope angle of emitter will be chosen which can produce a laminar flow electron beam. Generally speaking, when the slope angle of emitter is greater than 24°, the sheet electron beam has perfect laminar flow. In this paper, the Larmor radius is determined to be 0.15mm by calculation. The thickness and width of cyclotron sheet electron beam is required to be 0.3mm and 1.2mm, respectively. The magnetic field which was produced by a superconducting solenoid is postulated to be 2.8T at interaction region. Fig.1 shows the axis magnetic field which is designed and simulated by Opera software. The particular parameters of planar sheet-beam magnetic injection gun are determined by the steps mentioned above. The parameters are given in Table 2.

Table 2. Parameters of planar sheet-beam MIG

Parameter	Value
Main anode voltage	34 kV
Modulating anode voltage	7 kV
Beam current	1.7A
Current density	14.7A/cm^2
Pitch angle	40°
Magnetic field at resonator	2.8T
Average guiding center radius	0.525mm
Emitter length	0.47mm
Velocity ratio	1.16
Transverse velocity spread	3.5%

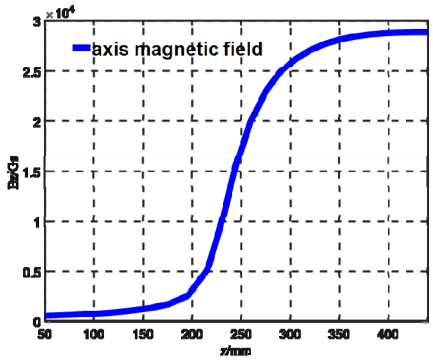

Figure 1. The distribution of magnetic field B_c

After considering all factors, the planar sheet-beam magnetic injection gun is modeled and simulated by Opera software. In order to obtain more accurate results, the grid of planar sheet-beam magnetic injection gun, cathode surface temperature and work function were chosen appropriately. Fig.2 shows the structure of designed planar sheet-beam magnetic injection gun. The cross section of cyclotron sheet electron beam at the position of interaction region entrance is shown in Fig.3.

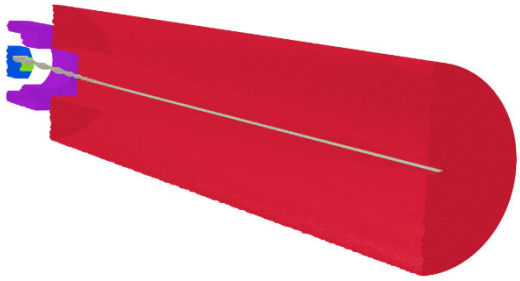

Figure 2. Structure of planar sheet-beam MIG

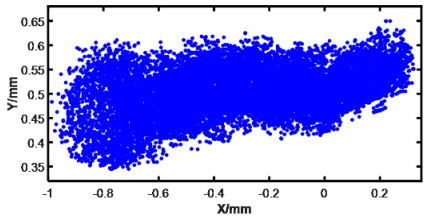

Figure 3. Cross section of cyclotron sheet electron beam at interaction region entrance

Conclusion

A planar sheet-beam magnetic injection gun with two anodes for the sheet beam metallic grating waveguide amplifier has been designed by using a series of equations and Opera software in this paper. The design has good parameters for cyclotron sheet electron beam with a suitable velocity ratio (α=1.16) and low transverse velocity spread (3.5%).

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