Design and Simulation of a 140GHz Gyro-TW with Dielectric Loaded Waveguide

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Abstract: *In this paper, a 140GHz gyro-TWT uniform dielectric loaded waveguide operating in the low loss TE_{01} mode is presented. By adopting a low DC driver of 50kV, 1A to satisfy the power capacity of small dimension structure. The loaded dielectric is used to suppress the potential backward wave oscillation. This gyro-TWT is designed and simulated by a particle-in-cell (PIC) software. The optimized simulation results indicate the designed gyro-TWT can operate at the desired mode TE_{01} with the output power of 12.85kW, the corresponding saturated gain and -3dB bandwidth are 39.3dB and 7.5GHz, respectively.*

Keywords: Gyro-TWT, Parasitic oscillation, Dielectric loaded, PIC simulation

Introduction

Gyrotron devices as a fast wave devices works on the principle of electron cyclotron resonance maser (ECRM). In particular, Gyro-TWT with high power and wideband of frequency characteristics have broad application prospects in high resolution imaging radar, electronic countermeasure and high data communication system. In recent years, surrounding on the stability problem of gyro-TWT, extensive theoretical and experimental research have developing. As the critical obstacle, stability problem seriously restrict the development of gyro-TWT. Related research find that properly introduce loss mechanism into interaction circuit, not only can guarantee the operating mode amplified stably, but also can absorb the ineffective power of self-excited oscillation [1], [2]. In 1990s, K.R Chu *et al*, successfully designed and tested a ka-band gyro-TWT with the waveguide walls more resistive. An output power of 93kW was developed with 3GHz bandwidth and 70dB saturated gain, operating in TE_{11} mode [3]. In 2002, David B. McDermott *et al*, experimentally designed a w-band gyro-TWT with uniform dielectric loaded. The amplifier presented an output power of 140kW at 92GHz with 28% efficiency, 50dB saturated gain and 5% bandwidth [4]. Meantime, NRL developed a periodically dielectric loaded gyro-TWT with the output power 137kW, the saturated gain and bandwidth are 47dB and 8.6%, respectively [5]. In 2003, MIT adopted a new type structure-confocal waveguide as the interaction circuit of gyro-TWT. This device operating in HE_{06} mode. At 140GHz, this device produced up to 30kW of peak power with saturated gain of 29dB, bandwidth of 2.3GHz [6]. Currently, heavily loaded waveguide operated at lower order mode has demonstrated to be a good approach to control these problems. Although in the higher frequency regime, to maintain enough dimensions of the reasonable cavity at the operating frequency, it is unavoidable for gyro-TWT to operate at high-order mode, which means extreme mode competition. To solve this problem, the structure have mode selection characteristics is developed, such as confocal waveguide. Apart from this scheme, in this paper, in order to overcome the problem of small power capacity in interaction circuit, a low DC driver has been adopted while guaranteeing the desired power requirements, at the same time, it can use the dielectric loaded method to suppress the parasitic oscillation problem.

Design and Simulation

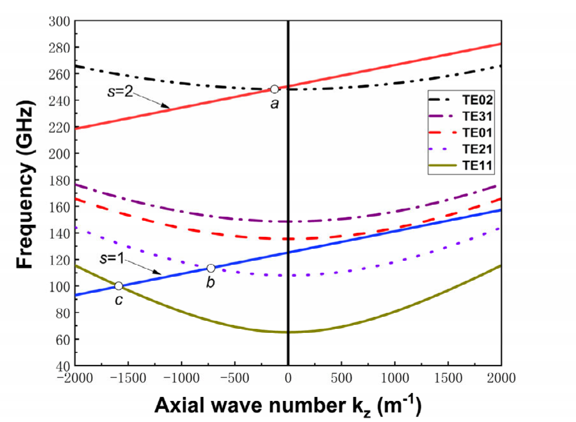

Figure 1. Dispersion diagram of the operating mode TE_{01} and possible oscillating modes (point a, TE_{02} mode, absolute instability oscillation; point b, c, TE_{21}, TE_{11} mode, backward wave oscillation)

The Figure 1 shows the dispersion diagram of the interaction system, which clearly manifests that the fundamental harmonic electron beam ($s = 1$) bears broad-band synchronization with the TE_{01} mode in the interaction waveguide. The potential backward wave oscillation, TE_{21}, TE_{11} mode and absolute instability oscillation, TE_{02} mode are also presented in Figure 1. By adjusting the length of linear part and improving wall loss to reduce the operating current of absolute instability oscillation mode, could efficiently suppress this parasitic oscillation. Moreover, through the analysis of the backward wave oscillation linear theory. The start-up threshold corresponding to the oscillation mode has been calculated. In the process of our design, the parameters of structure and electron are far below the start threshold. Figure 2 demonstrates the interaction system. Which comparatively shows the interaction circuit profile, and relative location of the electron beam. Operational parameters of this gyro-TWT interaction circuit are listed in Table 1.

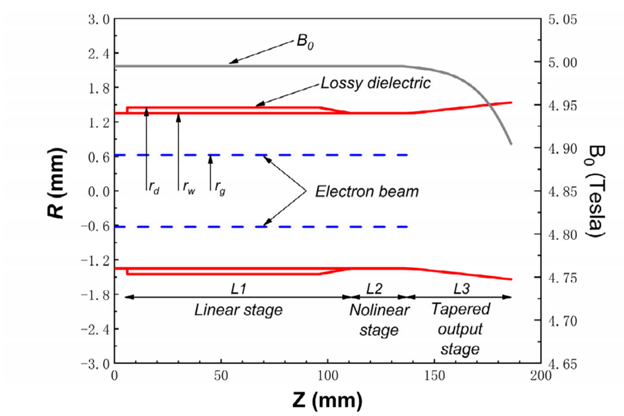

Figure 2. 2-D configurations of 140GHz gyro-TWT.

Table 1. Design parameters of the 140GHz gyro-TWT

Voltage	Current	Alpha	B_0	Wall resistivity
50kV	1A	1	4.995T	2.8e5 ρ_{Cu}
r_w	r_d	r_g	L_1	L_2
1.35mm	1.45mm	0.63mm	111.5mm	25mm

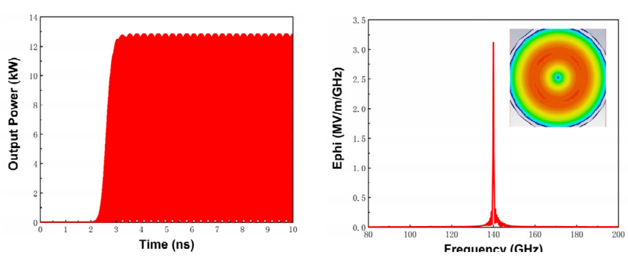

Figure 3. The temporal response of peak power developed at the output port of waveguide. And the Fourier transform and contour plot of output E-field signal.

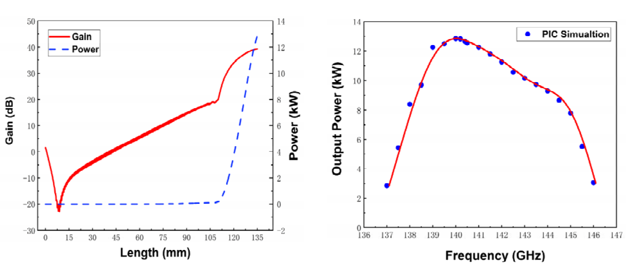

Figure 4. Axial power and gain growth of 140GHz *TE_{01}* wave. And saturated output power versus frequency

Conclusion

The total length of RF interaction structure is 136.5mm. The modeling of 140GHz gyro-TWT and the beam-wave interaction study are done using a commercially available 3D PIC code. A gyrating electron beam of 50kV, 1A with a guiding center radius of 0.47 times waveguide radius r_w is used. The RF signal interacts with the helically gyrating beam in the presence of static magnetic field B_0 of 4.995T. After the beam-wave interaction process, an RF output power of 12.85kW is observed, which is shown in Figure 3. The saturated gain and electronic efficiency of the present 140GHz uniform dielectric loaded gyro-TWT amplifier is calculated as 39.3 dB and 25.7% respectively. The Fourier transform of the amplified output signal and the contour plot of TE02 mode at the output port are shown in Figure 3. Figure 4 shows the axial power and gain growth. There is an inflection point near the beginning of the unloaded region where the electron stop absorb energy and the growth rate increases. Theory indicates that a gyro-TWTs gain will decrease by one third of the added loss. Although the loss reduces the growth rate, it was found to have little effect on the efficiency. The right diagram of figure 4, demonstrates that the 3-dB bandwidth is calculated as ~7.5GHz. Thus, the proposed uniform dielectric loaded interaction structure for 140GHz gyro-TWT effectively suppressed the potential BWOs causes the instability. The proposed structure is also improved the bandwidth of the device by changing the dispersion characteristics and maintaining the beam wave synchronism for a wide range of frequency.

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