A 0.2-THz Coaxial-Waveguide Gyrotron Traveling-Wave Amplifier

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Abstract—**Mode competition is a severe problem in the development of a high-power gyrotron traveling-wave-tube (gyro-TWT) amplifier in terahertz (THz) region. To improve the stability of this device, this paper investigates the possibility of using a coaxial waveguide with distributed losses as the interaction structure of a 0.2-THz gyro-TWT. Under stable operating conditions, the achieved performance of the gyro-TWT amplifier, including the output power, efficiency, gain and bandwidth, are predicted.**

I. INTRODUCTION

Recently, low power THz sources have been broadly applied to many areas. However, applications of high power THz radiation are restricted by the lack of accessible sources. Low efficiency and low power are the common disadvantages of currently available THz sources. In the past, most of the THz gyrotron studies were done on the gyromonotron [1]. The gyromonotron with an interaction structure of a cavity can generate high power THz radiation. However, its application is restricted by the narrow bandwidth. By employing a uniform waveguide, the gyrotron traveling-wave tube (gyro-TWT) amplifier features broadband amplification. For high power operation, a THz gyro-TWT must operate at a high order waveguide mode to enlarge the transverse size of the interaction waveguide. However, gyro-TWTs usually use hollow waveguides as their interaction structures. Operation at a high order waveguide mode may cause complex mode competition problems such that the gyro-TWT cannot operate stably.

Compared to the hollow waveguide, a coaxial waveguide has a center conductor as an additional means for suppressing competing modes. The losses of the inner cylinder are effective in suppressing specific competing modes which has H field near the inner cylinder. Accordingly, this study employs a coaxial waveguide as the interaction structure of a 0.2-THz gyro-TWT amplifier. The inner cylinder and the outer cylinder are individually lossy to investigate their effects on the start-oscillation current of the competing modes. After stability analysis, the performance of the gyro-TWT amplifier is predicted under stable operating conditions.

II. SIMULATION RESULTS

Figure 1 shows the interaction structure of the 0.2-THz gyro-TWT amplifier. The lossy and the copper sections form the linear and nonlinear stages of amplification [2], respectively. The parameters of the gyro-TWT are beam voltage V_b=20 kV, beam current I_b=3 A, magnetic field B_0=B_g, velocity spread 5% and velocity ratio α=1.0. The gyro-TWT is assumed to operate at the $TE_{8,2}$ waveguide mode and the fundamental cyclotron harmonic. Figure 2 plots the coupling strength as a function of the normalized guiding-center radius $\overline{r_c}$ [$=(r_c - a)/(b - a)$] for the $TE_{8,2}$ and $TE_{-8,2}$ modes (where a negative azimuthal mode number corresponds to a field counter-rotating with the electrons). Normally, the optimum guiding-center radius is selected at the maximum coupling strength of the operating mode. The optimum $\overline{r_c}$ of the $TE_{8,2}$ mode is considerably close to the inner cylinder. Considering that the electrons have sufficient space to gyrate in the nonlinear regime, the $TE_{-8,2}$ mode is selected as the operating mode for an optimum $\overline{r_c}$ of 0.46 at C = 2.0.

Figure 3 plots the $\omega - k_z$ diagram of the 0.3-THz with a coaxial interaction waveguide of outer radius b = 0.3295 cm (C = 2.0). The parabolas indicate the dispersion curves of the coaxial-waveguide modes, and the oblique lines represent the beam-wave resonance conditions. The operating point is at the intersection of the $TE_{8,2}$ dispersion curve and the fundamental cyclotron harmonic beam-wave resonance line (dot point in Fig. 3). The possible oscillating modes are $TE_{10\sim11,1}$, $TE_{0,2}$, $TE_{6\sim7,2}$, and $TE_{1\sim3,3}$ modes. From the analysis of the coupling strength, the $TE_{0,2}$, $TE_{\pm1\sim3,3}$ modes have weak coupling strength with the electrons at $\overline{r_c}$=0.46. Considering the possible oscillating modes that may co-rotate or counter-rotate with the electrons, the major competing modes are the $TE^{(1)}_{10\sim11,1}$ and $TE^{(1)}_{-6\sim-7,2}$ modes.

Because the $\mathrm{TE}_{10,1}$ and $\mathrm{TE}_{11,1}$ modes have much stronger H fields near the outer conductor, the distributed-losses of the outer conductor is mainly used to suppress the two modes. Figure 4 plots the start-oscillation currents of the $\mathrm{TE}_{10,1}$ and $\mathrm{TE}_{11,1}$ modes as functions of the resistivity ρ_b. When the resistivity ρ_b is higher than $4.3 \times 10^3 \rho_{Cu}$ (where $\rho_{Cu} = 1.72 \times 10^{-8} \Omega \cdot \mathrm{m}$), the start-oscillating currents of the two modes are raised to a value higher than the operating current. After the two modes are suppressed by the losses of the outer conductor, the distributed-losses of the center conductor is used to suppress the $TE^{(1)}_{-6,2}$ and $TE^{(1)}_{-7,2}$ modes. Figure 5 plots the start-oscillation currents of the $TE^{(1)}_{-6,2}$ and $TE^{(1)}_{-7,2}$ modes as functions of the resistivity ρ_a. When the resistivity ρ_a is higher than $6.2 \times 10^4 \rho_{Cu}$, the start-oscillating currents of the two modes are higher than the operating current.

After stability analysis, the gyro-TWT can achieve stable operation by adopting the distributed-losses of the center and outer conductor. The circuit parameters used for the amplifying wave are L_1= 8.5 cm, L_2= 1.0 cm, $\rho_b = 4.5 \times 10^3 \rho_{Cu}$ and $\rho_a = 6.5 \times 10^4 \rho_{Cu}$.

III. CONCLUSIONS

Under stable operating conditions, the gyro-TWT amplifier is predicted to have an output power of 11kW (an efficiency of 18%), a saturated gain of 38 dB and a bandwidth of 1.5 %.

References

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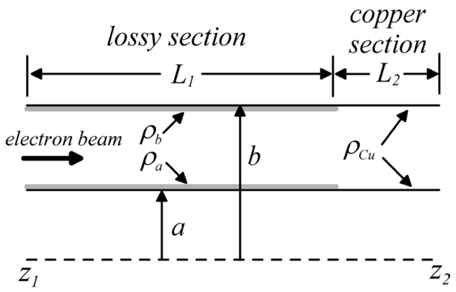

Fig. 1. Schematic drawings of the 0.2-THz coaxial gyro-TWT with distributed wall losses.

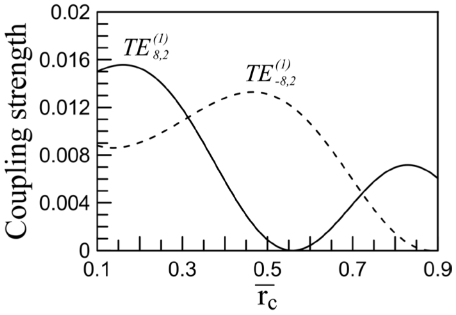

Fig. 2. Dependence of coupling strength on normalized guiding-center radius $\overline{r_c}$ for the $TE_{8,2}$ and $TE_{-8,2}$ modes.

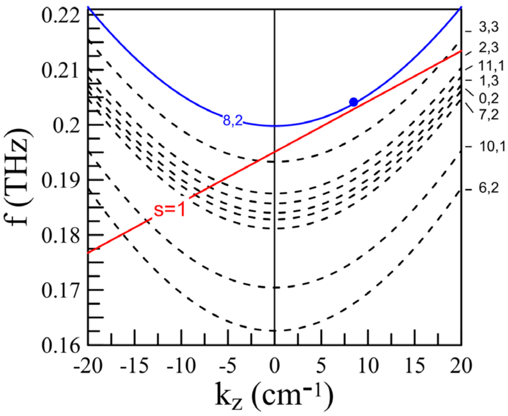

Fig. 3. $\omega - k_z$ diagrams of the transverse modes of a coaxial waveguide and the beam-wave resonance line.

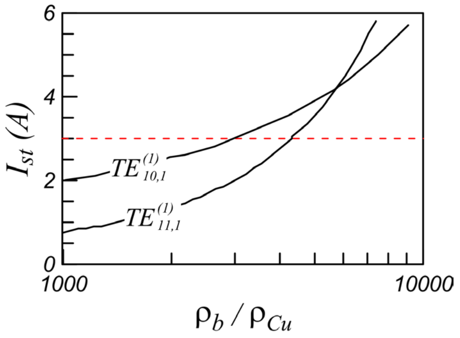

Fig. 4. The start-oscillation currents of the $TE_{10,1}$ and $TE_{11,1}$ modes as functions of the resistivity ρ_b. $\rho_a = 3.0 \times 10^4 \rho_{Cu}$.

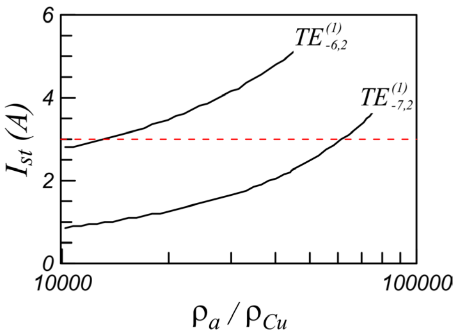

Fig. 5. The start-oscillation currents of the $T_{-6,2}$ and $TE_{-7,2}$ modes as functions of the resistivity ρ_a. $\rho_b = 4.5 \times 10^3 \rho_{Cu}$.