A Low-Voltage Backward Wave Oscillator Operating at THz Band

Wei Shao, Duo Xu, Zhanliang Wang, Huarong Gong, Tao Tang, Zhaoyun Duan, Zhigang Lu, Yanyu Wei, Yubin Gong*

National Key Laboratory of Science and Technology on Vacuum Electronics

University of Electronic Science and Technology of China

Chengdu, China, 610054

*email: ybgong@uestc.edu.cn

Jinjun Feng

Vacuum Electronics National Laboratory

Beijing Vacuum Electronics Research Institute

Beijing, China, 100016

Abstract: *A low-voltage backward wave oscillator based on staggered double vane structure is designed in this paper and a novel straight-waveguide input/output coupler is also proposed. The high-frequency characteristics and transmission characteristics of the structure are calculated and the results of the circuit show that the reflection coefficient is below -10dB in the frequency range of 250-300GHz. The beam-wave interaction is also carried out and the output power is greater than 20mW within the frequency range of 290GHz to 300GHz, which the corresponding operating voltage is 3800V to 4500V. And a maximum output power of 2W is reached at 300GHz.*

Keywords: backward wave oscillator; low voltage; terahertz band; beam-wave interaction.

Introduction

Vacuum electron devices (VEDs) have been attracted a lot of attentions in recent years. Backward wave oscillators (BWOs) as one of the VEDs, can achieve a rapidly voltage tuning over a wide frequency range without a RF input signal. A lot of research on BWOs has been carried out and many significance conclusions are reported [1, 2], which presents a potential application in high frequency and high power THz sources.

In this paper, a THz backward wave oscillator is designed with a low-voltage tuning based on the staggered double vane slow wave structure (SWS). The high-frequency characteristics and the transmission characteristics of the structure are shown in section II and III respectively. The beam-wave interaction of the BWO with a relatively lower voltage is also mentioned in section IV. Finally, section V shows some conclusions about the design.

The High-frequency Characteristics

The design goal of the frequency range is 250GHz to 300GHz and the corresponding voltage tuning is 3500V to 5000V. Staggered double vane structure is selected as the SWS to achieve a relatively wider bandwidth. The optimized structural parameters are shown in Table 1, where *w*, *h*, *g* and *p* are the width, height, thickness and period length of the vane, and *t* is the height of the beam tunnel.

Table 1. The geometric parameters of the structure

Parameters	Value(mm)
w	0.65
h	0.3
g	0.12
p	0.32
t	0.12

Figure 1 is the dispersion curves of the BWO, the frequency range of backward wave region is 230GHz to 315GHz. To satisfy the low-voltage operation, the backward wave region with the phase of 2π to 3π is selected as the operating frequency range.

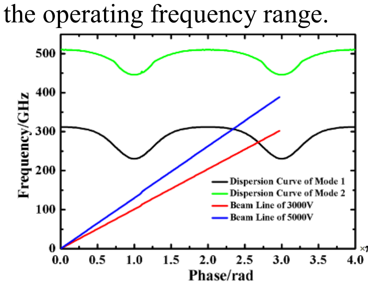

Figure 1. The dispersion curves of the structure

The red and blue curves in Fig. 1 represent the voltage line of 3000V and 5000V respectively, which meet at the frequency points of 270GHz and 305GHz. The bandwidth of the structure can be achieved by adjusting the operating voltage. The interaction impedance curve within the range of corresponding phase 2π-3π is plotted in Fig. 2. The value of the impedance is little small because of the operating region is the higher harmonic of the fundamental mode.

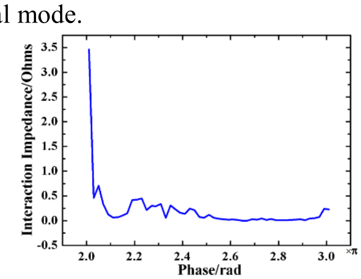

Figure 2. The impedance curve of the structure

The Transmission characteristics

The simulation model of the high frequency structure is shown in Fig. 3. The loss of the structure will be much higher at THz band because of the smaller skin depth, which will influence the start-oscillating and the output power of the BWO. So, in this paper, a novel input/output coupler is selected to reduce the length of whole structure. And the attenuator is put at one of the ports to absorb the signal which can be seen in Fig. 3.

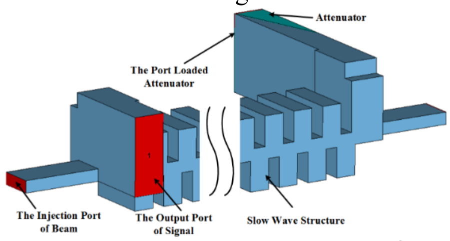

Figure 3. The three-dimensional model of the high frequency structure.

The material properties of the attenuator in the simulation is set with a relative dielectric constant of 6.5 and a loss tangent of 0.5. And copper is applied as the outer wall of the model and the corrected conductivity of the copper is set as 2×10^7S/m considered the actual conditions [3].

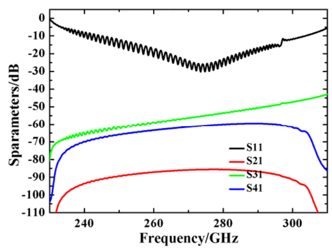

Figure 4. The transmission characteristics of the structure.

In the process of calculation, the period number of the structure is 60 and the results of the transmission characteristics are drawn in Fig. 4. Port 1 is the output port of signal and port 2 is the port loaded attenuator. Ports 3, 4 are the ports of beam tunnel. It can be seen that S_{11} is below -10dB within the frequency range of 250-300GHz.

The Beam-wave Interaction

Here, the operating current is set as 100mA in the simulation of beam-wave interaction. The focusing magnetic field of 0.8T is applied and the corrected conductivity of 2×10^7S/m is also considered.

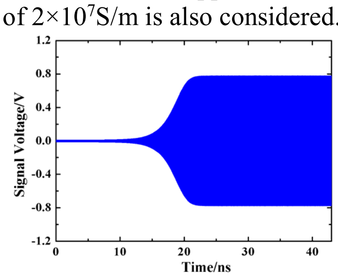

Figure 5. The output signal with 4000V operating voltage.

The results of output signal when the operating voltage is 4000V are given in Fig. 5, the start-oscillating time is about 20ns and a stable output signal can be obtained with 0.27W output power. Figure 6 is the corresponding spectrum of output signal, which is quite pure and is mainly concentrated at the frequency point of 292.6GHz.

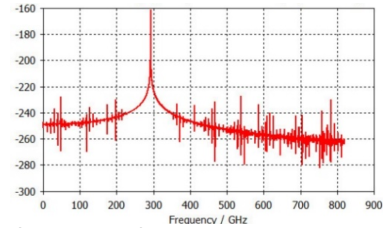

Figure 6. Spectrum of output signal (magnitude in dB).

The results of output power versus frequency are given in Fig. 7, which the operating voltage is swept from 3800V to 4500V. The output power is greater than 20mW in the frequency range of 290GHz-300GHz. And the maximum output power is about 2W at 300GHz.

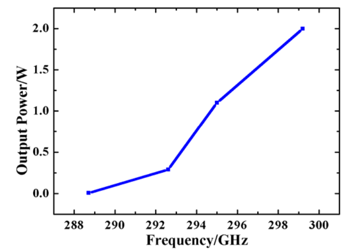

Figure 7. The results of output power versus frequency.

Conclusion

In this paper, a low-voltage THz backward wave oscillator is designed with the staggered double vane SWS. The results of dispersion characteristics and transmission characteristics of the structure show a good performance in the frequency range of 250GHz to 300GHz. And the results of beam-wave interaction present a greater than 20mW output power in the frequency range of 290GHz-300GHz.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (Grant Nos. 61531010 and 61921002).

References

1. M. Mineo, C. Paoloni. Double-corrugated rectangular waveguide slow-wave structure for terahertz vacuum devices. IEEE Transactions on Electron Devices, vol. 57, no. 11, pp.3169-3175, 2010.
2. C. Paoloni, A. D. Carlo, F. Brunetti, et al. Design and realization aspects of 1-THz cascade backward wave amplifier based on double corrugated waveguide. IEEE Transactions on Electron Devices, vol. 60, no. 3, pp.1236-1243, 2013.
3. B. B. Yang, M. P. Kirley, and John H. Booske, Theoretical and Empirical Evaluation of Surface Roughness Effects on Conductivity in the Terahertz Regime, IEEE Transactions on Terahertz Science and Technology, vol. 4, no. 3, pp. 368-375, 2014.