Design of a Terahertz Wire-wrap Backward Wave Oscillator

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Abstract— **In this paper, an innovative slow-wave circuit, applied the wire-wrap structure, is proposed for the design of backward-wave oscillator (BWO) operating in terahertz band. Compared with the conventional BWO, the novel BWO has the relatively low accelerating voltage around 1 kV and low beam current of 0.1 A (the current density is 188 A/cm^2). The Particle-in-cell (PIC) results predict that this BWO is capable of producing the output power over 400 mW at 324GHz and the range of 3dB voltage tuning bandwidth is from 311 GHz to 338 GHz. Moreover, the advantage that the wire-wrap SWS is constructed by wrapping the fine copper wire avoids the difficulty caused by conventional micro-fabrication technology. The simulation results presented by various parameters demonstrate that the novel wire-wrap structure can be applied as a promising slow-wave structure for terahertz radiation source application.**

INTRODUCTION

Recent years, the research of the terahertz (THz) wave has been considerable interest in radio astrophysics and astronomy, security inspection, radar applications, imaging, biology and materials science [1]-[3]. The availability of the terahertz wave is consequently become the precondition to terahertz development. The generation of THz wave is mostly depended on vacuum electron devices (VEDs) with slow-wave structure (SWS). Backward-wave oscillator (BWO), a typical vacuum electron device, is considered as the most promising device to product THz radiation signal and SWS is the pivotal component using to exchange energy between electron beam and the electromagnetic field

The conventional SWS, such as corrugated waveguide, sinusoidal waveguide and the folded waveguide were introduced as the popular structure for the realization of BWO [4]-[6]. But all the SWSs mentioned above used modern micro-fabrication technology, such as deep reactive ion etching, deep X-ray LIGA process and UV/SU-8 lithography to process [7]. Unfortunately, the machine accuracy including the accuracy on the dimensions and the surface roughness of the metal walls bring great adverse influence on the device performance. It is hard to process non-destructive SWS. So a novel wire-wrap SWS and fabrication method are put forward and apply to design BWO to get over this challenge.

MODEL AND DESIGN

A. Slow-wave Structure Design

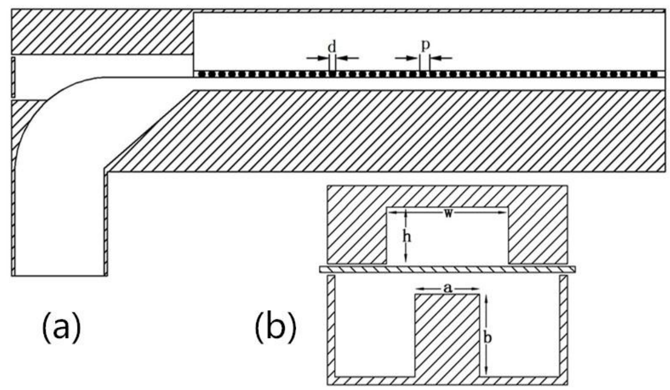

Fig. 1 Schematic configuration of the novel wire-wrap BWO: (a) the sectional view under the vertical axis direction and (b) the front view of the whole tube.

TABLE I
THE DIMENSIONS OF BACKWARD WAVE OSCILLATOR

G	Geometrical parameter	Quantitative Value and Units
d	Copper diameter	25 μm
p	Period length	50 μm
w	Cavity width	0.4 mm
h	Cavity height	0.3 mm
a	Ridge width	0.2 mm
b	Ridge height	0.37 mm

The specific structure of wire-wrap slow wave circuit is shown in Fig. 1 and the dimensions are listed in Table II. This structure features a rectangular cavity, periodic fine copper wire and a rectangular ridged waveguide. The ridge on the bottom of waveguide is used to increase the z-component electric field when electron beam interact with the z-component electric field. The physical realization of this structure was accomplished with two component parts. The fine copper wire twines around the upper cover plate to construct the slow wave circuit. Before that, the fine copper wire is firstly stretched to the diameter of 25 μm. In the progress of machining SWS, the fine copper wire keeps smooth. So the problem caused by the conventional micro-fabrication can be avoided because the fine copper wire is extremely uniform and smooth.

On the contrary of forward wave devices which output its energy at the end of collector, the backward wave devices output its energy at the end of electron gun. Based on this principle, a standard rectangular output waveguide is designed at the end of electron gun to output signal. In addition, a slope is added to match the coupling impedance of the interaction chamber and output waveguide.

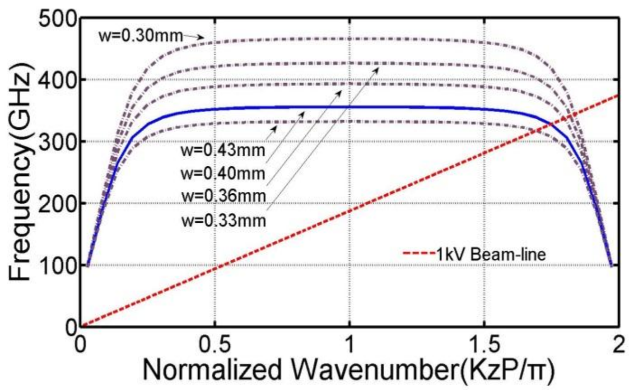

Fig. 2 Dispersion curves with different cavity widths *w*.

B. *High Frequency Characteristics*

The dispersion properties of the fundamental mode obtained by the eigenmode calculation with CST are plotted in Fig. 2. In this structure, the dispersion behaviour is mainly determined by the cavity width *w* on the upper cover plate. Except the dispersion for the nominal dimensions in Table III, the curves for different values of cavity width *w* are plotted for the purpose of providing flexibility in choosing dimension of device. The beam line of 1 kV intersects the dispersion curve at the operating frequency about 324 GHz. At this intersection, the velocity of electrons is almost synchronous with the phase velocity of the backward wave which is equal to the slope of the beam line.

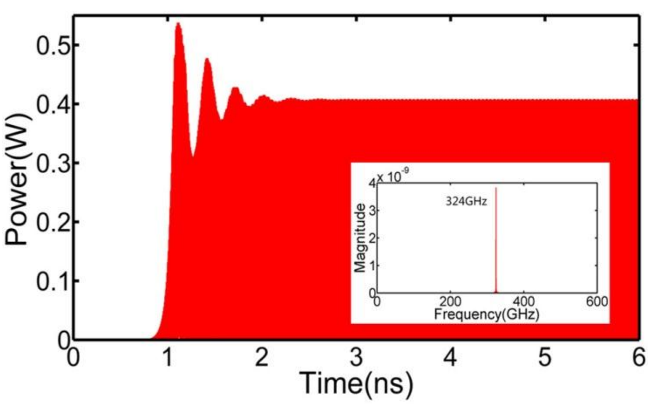

Fig. 3 Time plot of the output power with a inset of its frequency spectrum.

Performance Simulation and Result Analysis

In order to test the performance of the wire-wrap BWO, the necessary simulations are performed by particle-in-cell (PIC). The initial pencil electron beam with a diameter of 0.26mm has a relatively low introducing voltage about 1 kV and low beam current of 0.1 A, thus the current density is 188 A/cm^2. The BWO structure has 46 periods and the longitudinal distance between two centres of copper wire is 50 μm. A series of typical parameters, such as power, frequency and 3dB voltage tuning bandwidth are obtained.

As is clear from Fig. 3, the wire-wrap backward wave oscillator is capable of producing stable output peak power of 400 mW with the start oscillator time about 1.2 ns. The inset shows a pure frequency spectrum operating at 324GHz. At this operating point, the interaction chamber has the strongest interaction impedance. When the electrons travel along the SWS, the electrons gradually bunch and give its kinetic energy to the electromagnetic field. Fig. 4 shows the variation trend of output power as a function of introduced voltage. As can be seen, this BWO can get a 3dB voltage tuning bandwidth of 27GHz range from 311 GHz to 338 GHz. There exists a fluctuant phenomenon between 1 and 1.1 kV due to mode competition. Given that the operation voltage is under the low condition and the current density is small, the BWO with wire-wrap SWS is considered as an effective solution for BWO application.

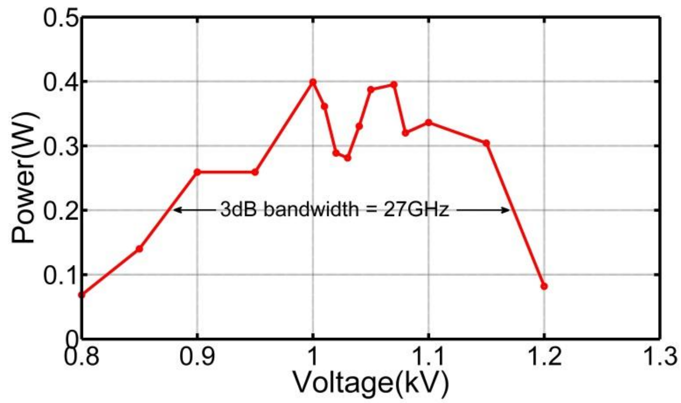

Fig. 4 Output power as a function of introducing voltage

Conclusions

In conclusion, a novel wire-wrap SWS for backward wave oscillator has been designed. The BWO has the relatively low operating voltage of 1kV and low current density of 188 A/cm^2. Based on these conditions, the device can produce the output peak power over 400 mW operating at THz band. Moreover, the processing method is another original advantage in the processing progress. The experiment of BWO with the proposed wire-wrap SWS is in plan.

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