Circuit Design and Simulation of a 0.85 THz Regenerative Feedback Oscillator

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Abstract: *A 0.85 THz regenerative feedback oscillator is proposed as a compact and frequency-tunable source. The circuit design and simulation is presented including both the folded waveguide slow wave structure and the feedback circuit. The bandwidth of the circuit is over 70 GHz and the output power is over 200 mW. The circuit is being fabricated using UV-LIGA micromachining process.*

Keywords: folded waveguide, regenerative feedback oscillator, UV-LIGA, terahertz, simulation

Introduction

The outstanding potential of terahertz waves results in a significant research effort in the development of terahertz sources. As a kind of compact and frequency-tunable source, regenerative feedback oscillators (RFOs) have been widely researched in recent years. A 0.56 THz RFO was designed and simulated based on a scheme of folded waveguide and delayed feedback[1]. With the development of micromachining and integration approaches, a 0.65 THz RFO was demonstrated with an output power of 98 mW generated by the circuit and a bandwidth from 0.605 THz to 0.675 THz[2].

A 0.85 THz RFO based on folded waveguide with delayed feedback is being developed. The design and simulation results of the circuit are presented in this paper. The circuit will be fabricated using UV-LIGA process[3]because it is the most promising technique for realize a full metal microstructure.

Circuit Design and Simulation

The circuit of the 0.85 THz RFO consists of two parts: a folded waveguide slow wave structure and a feedback circuit, as shown in Figure 4. The FWG SWS amplifies the EM wave of specified frequency range and the feedback circuit couples part of the output power to the input port of FWG. Synchronization condition, amplitude condition and phase condition are three conditions for the establishment of oscillation. The synchronization condition needs the electron beam to keep a synchronous phase velocity with the electromagnetic wave propagating in SWS for the interaction of energy. Phase condition means that the phase shift of electromagnetic signal after passing through SWS, feedback circuit and T-joint should be a positive integral multiple of 2π. Amplitude condition means that the gain of slow wave structure needs to be greater than the loss of the whole circuit[1].

Design of the Folded Waveguide Slow Wave Structure: The model for dispersion and interaction impedance simulation of the folded waveguide slow wave structure is established in CST Microwave Studio (MWS)[3] as shown in Figure 1. The geometrical parameters of the model are listed in Table 1. Figure 2 shows the simulation results of the dispersion and interaction impedance. From 0.838 THz to 0.908 THz, the normalized phase velocity (v_p/c) decreases from 0.2378 to 0.2106 which means the corresponding synchronous voltage decreases from 13.1 kV to 11.7 kV and the interaction impedance is over 3.435 Ω. The CST simulation results show that the small signal gain of 75 period SWS is 17.89 dB.

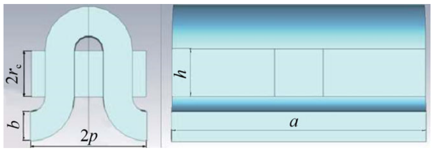

Figure 1. Model for dispersion and interaction impedance simulation of the folded waveguide slow wave structure

TABLE I. GEOMETRICAL PARAMETERS OF THE MODEL

Geometrical parameter	***a***	***b***	***h***	***p***	r_c
Value (μm)	185	22	36	44	18

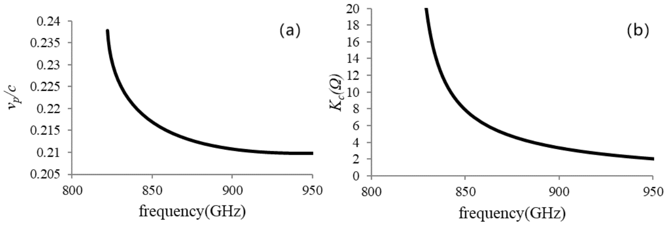

Figure 2. Simulation results of the dispersion and interaction impedance: (a) despersion; (b) interaction impedance

Design of the Feedback Circuit: A delayed feedback circuit with a standard E-T joint is simulated in MWS. The simulation model and the S-parameter results are shown in Figure 3 with the conductivity of copper set to 4.35×10^7 S/m[4]. The overall attenuation of the feedback circuit (S13 curve) is 11.23 dB at 0.85 THz including the loss of the E-T joint, which is less than the small signal gain of the FWG circuit. The amplitude condition of the starting of oscillation is met.

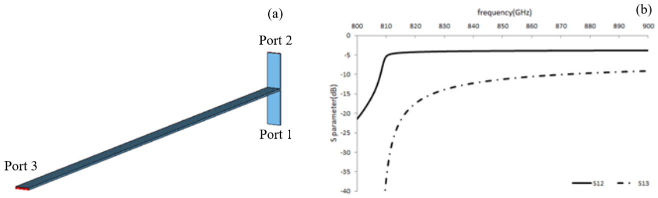

Figure 3. Simulation model and S-parameter results of the feedback circuit: (a) simulation model; (b) S-parameter results

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PIC Simulation: The circuit of the 0.85 THz RFO has been simulated by CST PIC solver[4] shown in Figure 4. A beam current of 5 mA and a beam diameter of 18 µm are assumed. The beam is confined by a 0.8 T uniform magnetic field. The length of the folded waveguide slow wave structure is set as 75 periods. The whole structure will be made of copper using UV-LIGA process and its prospective surface roughness is 30 nm, so the electrical conductivity is set as 4.35×10^{7} S/m[5]. The synchronous voltage varies from 11.7 kV to 13.1kV.

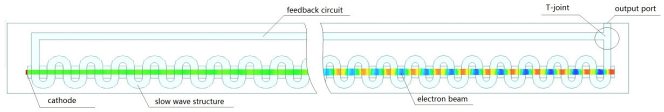

Figure 4. Model for PIC simulation of the RFO

The simulation results of the output power and frequency of the circuit are shown in Figure 5. As the beam voltage increases from 11.8 kV to 13.1 kV, the frequency decreases from 908.96 GHz to 838.4 GHz. The output power is over 200 mW at most voltages. Figure 6 shows the voltage amplitudes and frequency spectrums of the oscillation at two different beam voltages. Figure 6 (a) shows the stable voltage amplitude of the oscillation at 12.9 kV is 0.8 V, and the power is 320 mW. Figure 6 (b) indicates the frequency of the oscillation is 841.09 GHz at 12.9 kV. Figure 6 (c) shows an unstable voltage amplitude of the oscillation at 12.1 kV which implies the oscillation has multiple frequencies. Figure 6 (d) indicates there are three oscillation frequencies at 12.1kV because they all meet the phase condition and broadband synchronization condition.

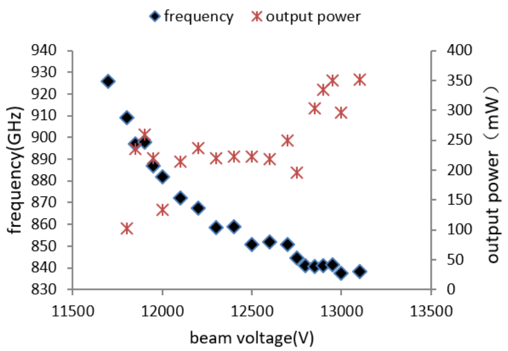

Figure 5. Simulation results of the output power and frequency of the circuit

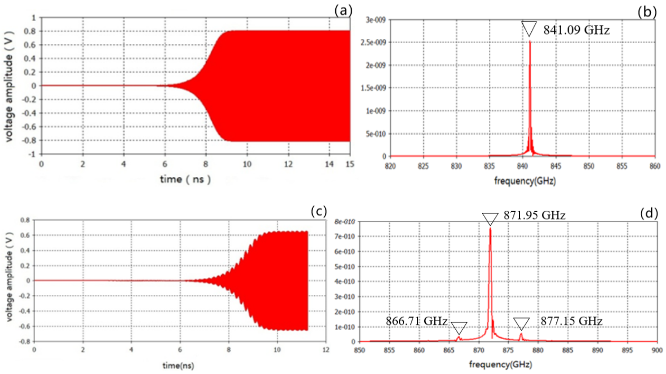

Figure 6. Voltage amplitudes and frequency spectrums of the oscillation at two different beam voltages: (a) voltage amplitude at 12.9 kV; (b) frequency spectrum at 12.9kV; (c) voltage amplitude at 12.1 kV; (d) frequency spectrum at 12.1 kV

Circuit Fabrication

The circuit is being fabricated using UV-LIGA process. Figure 7 (a) shows the photo image of the photoresist film structure. Figure 7 (b) shows the folded waveguides on the substrate after electroplating and polishing. The removing of photoresist and bonding processes are being developed.

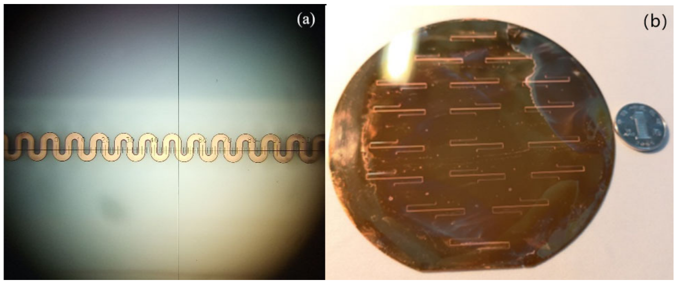

Figure 7. Photo images of (a) the photoresist film structure and (b) the folded waveguides on the substrate

Conclusions

A 0.85 THz RFO based on a folded waveguide slow wave structure with delayed feedback are designed and simulated. The beam voltage of the RFO varies from 11.8 kV to 13.1 kV and its frequency range is from 0.838 THz to 0.908 THz with a output power of over 200 mW. The circuit is being fabricated using UV-LIGA process.

References

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