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# Interdigital backward-wave oscillator for 100 GHz and 1 W class
# 100 GHz帯1 W級出力を目指したインタデジタル型後進波発振管

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A backward-wave oscillator (BWO) with an interdigital slow-wave structure for 100GHz band has been developed. Simulation has shown that the BWO produces radiation at output power of 700 mW at a frequency of 102 GHz. We designed and constructed the thermionic electron gun that produces an electron-beam that has sufficient energy and emission current for the radiation. A distortion of the beam trajectory was suppressed by a strong homogeneous magnetic field and a focus electrode placed around the emitter.

## 1. Introduction

Terahertz (THz) radiation, which is located in the spectral region of 0.1-10 THz, is expected to have very wide applications. There are a number of candidates for terahertz sources, such as solid state oscillators, quantum cascade lasers, optically pumped solid state devices and novel free electron devices like Klystrons, Backward Wave Oscillators (BWO) and Gyrotrons [1]. However, it is difficult to achieve a stable and high-power oscillation in the THz frequency range.

In this paper we focused on BWO which is compact and a broadband oscillator. In general BWO covers the frequency range below 1 GHz to over 100 GHz, but the maximum output power is too small in the THz frequency range. For example, output power of continuous wave at 100 GHz is tens of milli-watt at most. So we developed the interdigital BWO with power output of about 1 Watt at 100 GHz.

## 2. Slow wave structure

The interdigital slow wave structure (SWS) is shown in Fig. 1. We designed the interdigital SWS for 100 GHz band radiation stimulated by an electron beam with energy of 10 keV, current of 100 mA, and beam radius of 1 mm. Dimensions of the interdigital SWS are as follows; L 150 um; h 440 um. We made the interdigital metallic pattern on a Teflon substrate.

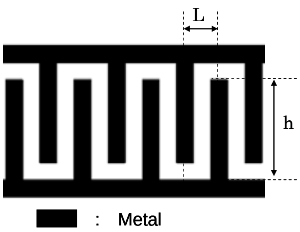

Fig.1. Interdigital

A characteristic feature of the interdigital SWS is that the ω-β diagram is shifted by π rad as compared with that of a single comb SWS as shown in Fig 2. In fact, in the range $0 < \beta L < \pi$, the wave is backward wave. The circuits are referred to as *fundamental backward wave circuits*. The opposites are referred to as *fundamental forward wave circuits*. Interaction in the fundamental backward wave structure occurs with electrons at transit angle near π/2. It should be noted that the transit angle is much smaller than for the fundamental forward wave structure (~3π/2). As a result, BWOs with fundamental backward wave structure are operated with faster and, therefore, higher voltage electron beams than fundamental forward wave BWOs, so that a high power radiation is expected.

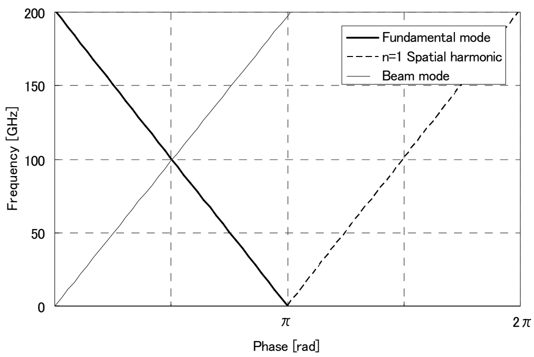

Fig. 2. Dispersion of interdigital slow-wave circuit and a beam mode at 10kV

## 3. Simulation

CST Studio software includes several solver modules applicable to vacuum electronics design. We used PARTICLE STUDIO in CST Studio which includes the capability to simultaneously model the time-dependent RF fields, magnetic focusing field, and a particle in cell (PIC) electron beam. The software is used to analyze microwave tubes [2,3].

In the simulation the electron beam has cylindrical shape of radius 1 mm, beam voltage of 10kV, beam current of 50–100 mA, and the magnetic field is applied by a stack of daughnut type magnets. The distance between SWS and the bottom of the electron beam is 0.1 mm.

Figure 3 shows that the time dependence of radiation and Fourier analysis of the signal. The radiation has a strong peak at a frequency of 102 GHz, which is in good agreement with the design goal of 100 GHz. The output power is estimated at 700 mW in the beam condition of 10 kV and 100 mA. The output power as a function of a beam current is shown in Fig. 4. A start current for the radiation is 60 mA (7.6 A/cm$^2$).

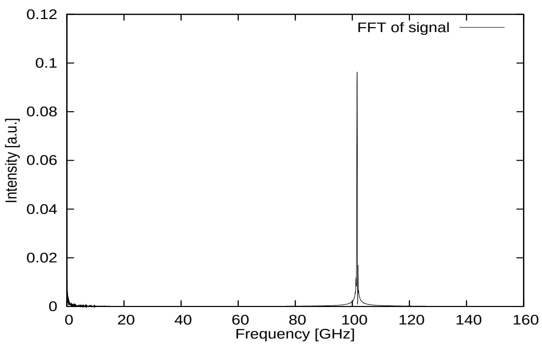


Fig.3. FFT analysis of the signal

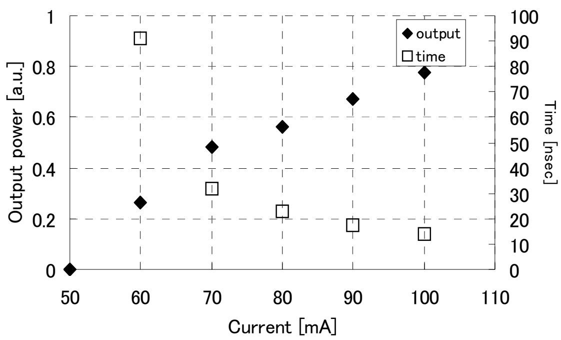


Fig.4 Current vs output power and start time

## 4. Design of electron gun

We developed an electron gun for the 100GHz band interdigital BWO. The electron gun has been designed for the generation of the cylindrical beam with beam radius 1 mm, beam voltage 10 kV, beam current 100 mA and 3 mm cathode-anode distance. The electron emitter which consists of the Ir-coated dispenser cathode is capable of generating current of over 100 mA [4]. A focus electrode placed at adjacent to the emitter and tipped toward the anode straightens the equipotential profile between the cathode and the anode. The trajectory simulation of the electron-beam emitted form the gun containing the focus electrode shows a rectilinear electron flow as shown in Fig.5. The special variation of the beam radius is less than 6%.

In a preliminary experiment of the electron gun, the beam current of 60 mA is observed at acceleration energy 10 keV in the test chamber.

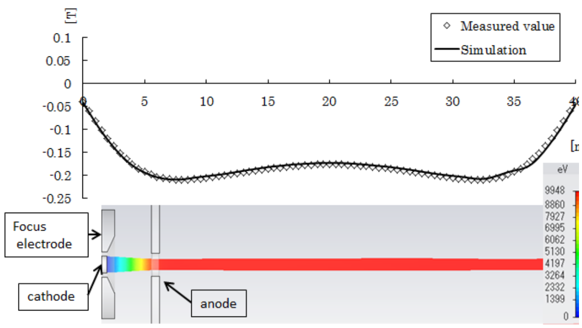


Fig. 5 Axial magnetic field of cylindrical magnet and trajectory of electron beam at 10 kV

## 5. Summary

We designed the interdigital SWS for 100 GHz band radiation stimulated by an electron beam with energy of 10 keV. In the simulation of the BWO, we observed the radiation which is in good agreement with the design.

The electron gun for the BWO has been designed for the generation of the cylindrical beam with beam radius 1 mm, beam voltage 10 kV. A low variation of beam radius less than 6% is obtained by the trajectory simulation.

## References

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