Vacuum Electron Beam based THz Devices and Continuous-Wave THz Imaging

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Abstract
Terahertz vacuum electron devices (VEDs) employing the silicon based MEMS circuits such as photonic crystals and grating structure are studied to increase the radiation intensity. And, terahertz antenna with the dual-mode structure at both sides is proposed to enhance the spatial resolution in the continuous-wave terahertz imaging.

Keywords: Terahertz Vacuum electron devices Photonic crystals Backward-wave oscillator Continuous-wave terahertz imaging

1. Introduction
In recent years, terahertz (THz) imaging technology has been developed for numerous applications in bio-medical imaging, security screening, and quality control. For the real-time and the high resolution THz imaging, THz radiation sources using electronic and photonic technology and the THz imaging techniques have been studied [1-2]. In particular, with the advent of MEMS technology and high current density cathodes, the VEDs have been investigated as efficient THz sources. In this paper, THz VEDs employing photonic crystals resonator and grating structure fabricated by wet etching are studied to increase the radiation intensity. And, THz antenna is proposed to enhance the spatial resolution in the CW THz imaging [3-4].

2. Results
Two-dimensional (2D) photonic crystals (PCs) are fabricated by wet chemical etching of the high-resistivity (HR) silicon used for the mode selective resonator in the THz VEDs. The HR silicon wafer with an index of refraction of 3.4 is used to form the 2D PCs, and the wet chemical etching of silicon is characterized by the anisotropic etching indicating the sloped sidewall with an angle of 54.7°. For the formation of the photonic band gap (PBG) at the frequency of about 0.1 THz, the PCs with the radius at the top (R_t) of 350 μm, the height (H) of 150 μm, and the period (a) of 1430 μm is fabricated as shown in the Fig. 1 (a). The PBG with the transmittance less than about -60 dB is experimentally measured from the frequency of 94 GHz to 108 GHz.

Figure 1: (a) Two-dimensional 0.1 THz photonic crystals fabricated by wet chemical etching and (b) 0.66 THz Smith-Purcell backward-wave oscillator with an inverse wet-etched grating.
An inverse wet-etched grating based on silicon is adopted in the 0.66 THz Smith-Purcell backward-wave oscillator (BWO) to enhance the radiation intensity as shown in the Fig. 1 (b). The inverse wet-etched grating has an inversely triangular shape to enhance the intensity of the evanescent wave used for the interaction with the electron beam, and the grating is described by a wet-etched angle in the parcel-in-cell (PIC) simulation. In case of a beam current of 500 A/m, the radiated power is $7 \times 10^3$ W/m and $20 \times 10^3$ W/m for the rectangular grating and the inverse wet-etched grating, respectively, and the enhancement of the radiated power is more than two times higher than the conventional rectangular grating.

![Image](image.png)

Figure 2: (a) Optical image, (b) CW terahertz image obtained by using 0.2 THz wave, and (c) X-ray image of hidden insects inside the wheat flour.

THz antenna is used in the continuous-wave (CW) THz imaging system to enhance the spatial resolution. THz antenna with the dual-mode structure at both sides has a role to focus the THz wave effectively into the sample without the power loss located at the front part of sample. To demonstrate the enhancement of spatial resolution, the transmission CW THz imaging system is used with the 0.2 THz source. From the phantom imaging, the spatial resolution is reached less than 500 μm, and the resolution is enhanced more than eight times higher than the conventional CW imaging system. The THz imaging of hidden insects inside the wheat flour using the THz antenna is shown in the Fig. 2 to apply in food inspections. The CW THz image obtained by 0.2 THz wave and X-ray image are shown in the Fig. 2 (b) and 2 (c). From the comparison, the low density matters are clearly identified in the CW THz image due to the amplitude and phase variation.

3. Conclusions

The silicon based wet-etched MEMS circuits of 0.1 THz two-dimensional photonic crystals and 0.66 THz grating structure are studied for high power compact THz VEDs. And, the spatial resolution in the CW THz imaging is enhanced by using the THz antenna with the dual-mode structure at both sides.

References