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Proposal of Novel Terahertz Oscillators Using Resonant Tunneling Diodes and Cavity Resonators

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Abstract

Novel terahertz (THz) oscillators using resonant tunneling diodes (RTDs) and cavity resonators for high output powers are proposed, and theoretical output powers are calculated. The oscillator is composed of a line-shaped RTD mesa and a rectangular cavity resonator, which is connected to the oscillator for radiating the THz signal. The rectangle cavity is expected to reduce the conduction loss, and the large-area RTD can be used even at high frequency in this oscillator because of high resonance frequency of the cavity, which results in high output power. The highest output power of about 5 mW is expected at around 1 THz, which is a significant improvement of RTD THz oscillators which usually have a low power in the order of 10 μW.

1. Introduction

Terahertz (THz) radiation, in the range between the light waves and millimeter waves, has attracted much attention because of its applications, such as in imaging, spectroscopy, and high-capacity wireless communications [1-3]. Small-size and high-output power terahertz sources are highly desired for various applications. Quantum cascade lasers would be good candidates for sources [4-6], however, low-temperature operation (<200K) is required. The operation frequencies of electron devices are also making significant progress from the millimetre-wave side, especially in both silicon and compound semiconductor transistors [7-9]. Among the electron devices, resonant tunneling diodes (RTDs) are also major candidates for THz wave sources, because of their operation at room temperature, compactness, and undemanding system requirements [10-12].

A 1.92 THz oscillation was achieved by introducing a new fabrication process removing the n^+-InGaAs layer under the air-bridge structure with reducing in the conduction loss due to the air-bridge resistance [10]. Recently, we achieved a frequency increase in an RTD THz oscillator by reducing conduction loss in the slot antenna by the optimization of the thickness of the antenna electrode [8]. The oscillation frequency of 1.98 THz was achieved, which at present is the highest frequency of an electronic single oscillator at room temperature. However, the output power of RTD oscillators is small of about 10 μW in the 1 THz range. For practical use, it is important to increase output power, as well as to increase the frequency.

In this work, novel RTD THz oscillators are proposed, which integrate rectangular cavity resonators for high output powers by reducing conduction loss and increasing the mesa area of the RTD. The theoretical frequencies and output powers are calculated with electromagnetic simulation.

2. Device Structure and Calculation of Oscillation Characteristics

Fig. 1 shows the structure of the proposed oscillator. The oscillator is composed of a line shaped RTD mesa and a rectangular cavity resonator. The RTD has negative differential conductance in the current-to-voltage characteristics, which is utilized for THz oscillation. MIM capacitors are fabricated at the both ends of the cavity resonator. Because the capacitance is open for a direct current, a bias voltage can be applied to the RTD. THz electromagnetic wave is reflected at the capacitor because the impedance of the MIM capacitor becomes small, and a resonator is formed. A bow-tie antenna is connected to the oscillator for radiating the THz signal. The oscillator is fabricated on an InP substrate, and the THz signal is radiated into the substrate direction because of high dielectric constant of the substrate.

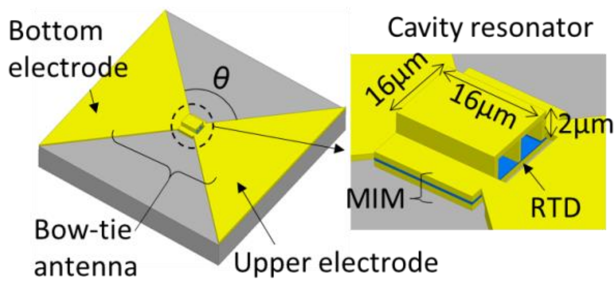

Fig. 1 Schematic illustration of the structure of the RTD THz oscillator integrated with a rectangular cavity resonator. A line-shaped RTD mesa is connected to the resonator.

The oscillation occurs if the negative differential conductance (NDC) of the RTD (G_{RTD}) exceeds the load conductance of the resonator and the antenna (G_L). The oscillation frequency is determined by the parallel resonance of the inductance of the cavity resonator and the capacitance of the RTD. In the previous slot antenna structure [11], we obtained reduced conduction loss in the slot antenna by a thick antenna electrode. Because the proposed cavity structure is equivalent to a slot antenna with very thick electrode, a very low conduction loss is obtained. The output power is proportional to the product of the current and voltage widths of the NDC region [12], and a maximum output power can be extracted from the RTD by achieving the impedance-matching condition between RTD and antenna, $G_{ANT} = G_L/2$.

The admittance of the resonator and antenna were calculated with electromagnetic simulator (HFSS, Ansys) and the oscillation characteristics were estimated taking into account all the possible parasitic elements around the RTD. The peak current density of the RTD was assumed to be 30 mA/μm^2, the peak-to-valley current ratio was around 2, and the voltage width of the NDC was about 0.28 V. The area-normalized capacitance of the RTD is 6 fF/μm^2. For bringing close to the impedance condition, we employed a sharp bow-tie angle θ of 6 degrees for an increase in the antenna conductance. Fig. 2 shows the RTD area dependence of theoretical oscillation frequency and output power. The length, width, and height of the slot resonator are 16, 16, and 2 μm, respectively. By using a large-area RTD (about 20 μm^2), a very high output power of about 5 mW is expected owing to the low conduction loss of the cavity resonator. We have investigated the fabrication process and achieved a formation of the rectangular cavity resonator using a tri-layer resist (ZEP/PMGI/PMMA) process. An oscillation frequency exceeding 2 THz is also expected when the RTD area is below 2 μm^2. Oscillation close to 3THz is also possible. However, a small RTD mesa width of ~20 nm is required in the stripe shape for ~3 THz oscillation, and investigation into the fabrication process of small mesa structure is required.

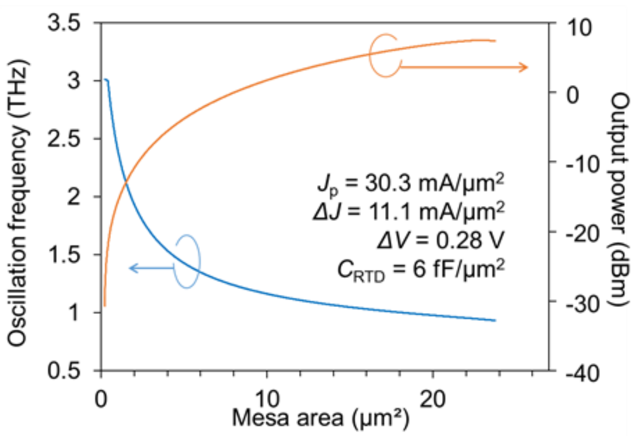

Fig. 2 The theoretically expected oscillation frequency and output power as a function of the RTD area.

3. Conclusions

Novel RTD THz oscillators were proposed which integrate rectangular cavity resonators for high output powers, and their theoretical output powers were calculated. The estimated highest output power was about 5 mW at around 1 THz by using a rectangular cavity resonator and a large area RTD which is a significant improvement of RTD THz oscillators which usually have a low power in the order of 10 μW. An oscillation frequency exceeding 2 THz is also expected with the RTD area below 2 μm^2. We have investigated the fabrication process and achieved a formation of the rectangular cavity resonator using a tri-layer resist process.

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