Impedance matching method in high-power RTD THz oscillator integrated with rectangular-cavity resonator

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***Abstract*— We propose an impedance matching method to increase the output power of novel resonant tunneling diode (RTD) terahertz oscillator. An equivalent circuit model and analysis method for the oscillation characteristics were established. A matching point for output power was found by changing MIM capacitor, and the simulation results show that high output power, like 5 mw, is possible to be achieved at around 1 THz.**

I. Introduction

Oscillators using resonant tunneling diodes (RTDs) are major candidates for THz wave sources, because of their operation at room temperature and compactness. Although we achieved a high power oscillation of around 0.7 mW by an arrayed RTD oscillator [1], the output power of single RTD oscillator is relatively small, in the order of 10 μW around 1 THz. An increase in the output power of single oscillators is required. Novel RTD THz oscillators with cavity resonators and bow-tie antennas for high output power were proposed [2, 3]. In this work, we propose and simulate an impedance matching method between RTD and antenna in the novel oscillator to extract maximum output power from RTD. The impedance matching is realized through an optimum MIM capacitor in the resonator. Simulation results show that high output power is possible by long cavity. For example, a high output power of 5 mW is expected at 1 THz.

II. Device Structure And Equivalent Circuit

Fig. 1 shows the structure of the proposed RTD oscillator. A rectangular RTD mesa is integrated at the center of a gold-metal rectangular cavity resonator. An InGaAs/AlAs double barrier RTD and a semi-insulating (SI)-InP substrate are employed. The RTD has a negative differential conductance (NDC) in the current-to-voltage characteristics, which is utilized for THz oscillation. Two metal-insulator-metal (MIM) capacitors are fabricated at the both ends of the cavity resonator. Because the capacitors are open at DC, a bias voltage can be applied to the RTD. THz electromagnetic waves are reflected at the MIM capacitor because its impedance is small, and a resonator is formed. A bow-tie antenna is connected to the cavity via the right-hand side MIM capacitor. The generated THz signal passes through the MIM capacitor and is radiated by the antenna. The THz radiation is obtained to the substrate direction because of high dielectric constant of the substrate. An n^+InGaAs resistor for the suppression of low-frequency parasitic oscillation is fabricated near the left-hand side MIM capacitor. The output power of the RTD oscillator is proportional to the product of current and voltage width of the NDC region [4]. Therefore, an increase in the RTD area is effective for high output power operation. The resonator inductance should be reduced to maintain the oscillation frequency because the RTD capacitance becomes large with increasing area. By reducing the inductance, the conduction loss in the resonator rapidly increases. However, the resistance of the cavity resonator is very small [3]. Thus, the conduction loss becomes small.

Fig. 2 depicts the equivalent circuit of the proposed RTD oscillator. R_r and L_r denote the resonator resistance and inductance, respectively. The resonator capacitance is small compared to the RTD capacitance and can be neglected. C_{m1} and C_{m2} denote the right- and left-side MIM capacitances. The bow-tie antenna demonstrates broadband characteristics, and it can be expressed as a single conductor G_b connected in parallel with C_{m1}. A stabilization resistor R_{stab} was connected in parallel with C_{m2} to suppress parasitic oscillations caused by the external circuits including bias lines. A three-dimensional electromagnetic simulator (Ansys HFSS) was employed in this study for resonator analysis. In the simulation, RTD was substituted with a port. The admittance pertaining to resonator and antenna was calculated as viewed from the port. The values of the circuit elements in Fig. 2 were obtained by fitting the frequency dependence of the admittance to that obtained by the simulator [3].

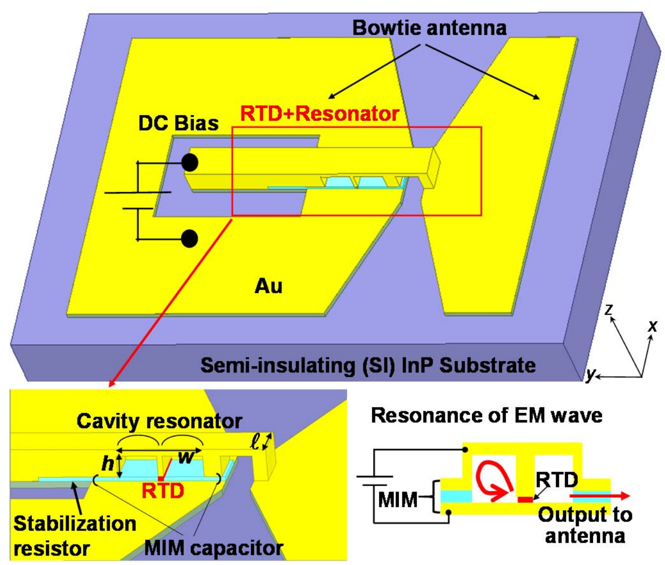

Fig. 1. Schematic structure of RTD oscillator with rectangular cavity resonator.

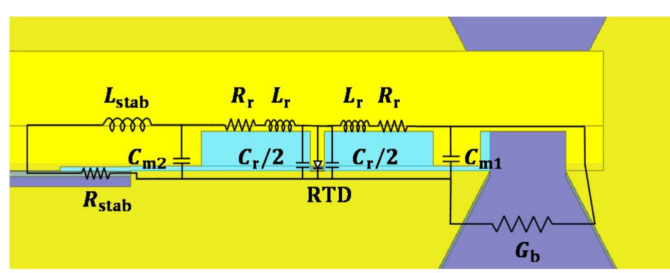

Fig. 2. Equivalent circuit of RTD oscillator with rectangular-cavity resonator and bow-tie antenna

III. Impedance Matching with MIM Capacitor for High Output Power

The oscillation frequency and output power of the proposed structure were estimated using the detailed RTD model and equivalent circuit model. The RTD parameters used for the calculation are current density of 8 mA/µm^2; peak-to-valley current ratio of 4; NDC voltage width of 0.4 V; and area normalized capacity of 6 fF/µm^2. These parameters were estimated with the same manner as [4, 5]. The cavity parameters used for the calculation are width of 22 µm; height of 2 µm; and mesa width of 2 µm. Oscillation occurs when the absolute value of the RTD NDC exceeds the real part of the admittance of the cavity resonator and antenna. The oscillation frequency is the point at which the imaginary admittance of the resonator and RTD crosses zero. The oscillation frequency is dominantly determined by the parallel resonance between L_r and C_{rtd}. However, its value is slightly affected by the right-hand side MIM capacitor C_{m1}, because C_{m1} is connected in series with L_r. The oscillation frequency increases with reduction in C_{m1}, because the apparent inductance viewed from RTD decreases.

The output power can be estimated by calculating power consumption on G_b in the equivalent circuit in Fig. 2. As shown in Fig. 3, with each specific cavity length, the shape of output power is an upward convex function with respect to C_{m1}. The maximum point is where the impedance matching point of the RTD oscillators. Therefore, MIM capacitor C_{m1} can be used to satisfy the impedance matching condition and extract the maximum output power from RTD.

Because the value of L_r decreases with increase in ℓ, the RTD area can be increased and high output power can be obtained at nearly constant oscillation frequency. However, G_{rtd} is proportional to RTD area, and thus, the optimum C_{m1} value also changes with ℓ. Fig. 3 depicts dependence of output power on both the MIM capacitance and cavity length ℓ for 1-THz oscillator. As can be observed in Fig. 3, the optimum C_{m1} and the maximum output power increase with increasing ℓ. High output power is possible by long cavity. For example, a very high output power of 5 mW can be realized with C_{m1} = 90 fF at ℓ = 90 µm. This output power is two orders of magnitude higher than conventional slot resonators [6]. This is because, the conduction loss of the cavity resonator is smaller than that of the slot, and RTD area is much larger than that of the slot [3]. However, large drive current is required to large-area RTD in a long cavity, and heating may be a problem.

IV. Conclusion

This work theoretically presents that RTD THz oscillators integrated with a rectangular cavity can radiate high output power by the impedance matching between RTD and antenna load through MIM capacitors. The circuit parameters were obtained for the equivalent circuit of the resonator by fitting the frequency dependence of the admittance, and the oscillation frequency and output power were analyzed with the equivalent circuit. By changing the MIM capacitance, the output power was maximized due to the impedance-matching for various sizes of the resonator. Simulation results show that high output power is possible by long cavity. For example, a high output power of 5 mW is expected at 1 THz, which is very useful for various THz applications such as imaging, spectroscopy, and high-capacity wireless communications.

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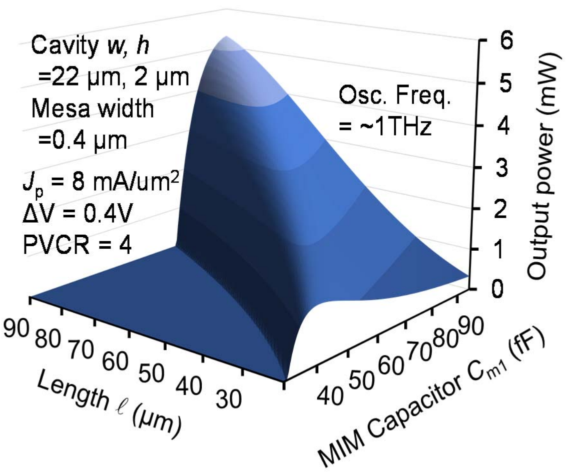

Fig. 3. Theoretically expected output power as function of MIM capacitance and cavity length

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