Analysis of Oscillation Characteristics for Resonant-Tunneling Diode Cavity-type Terahertz Oscillator

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***Abstract*— We analyzed output power limitations and structure dependencies for RTD THz oscillator with cylindrical cavity resonator. Dependences of the output power on resonant cavity dimensions show that output power generally increases with decreasing cavity size as well as with decreasing oscillation frequency. However, we found existence of low-frequency oscillation limit where output power rapidly decreases despite of increasing RTD mesa area. Analysis of numerical calculation results has shown that output power up to -34 dBm at 2.5 THz and up to -14 dBm at 1.5THz could be expected for single RTD oscillator considered in present study.**

I. INTRODUCTION

TERAHERTZ (THz) radiation, in the range between the light waves and millimeter waves, has attracted much attention because of its applications [1-2]. Oscillators using resonant tunneling diodes (RTDs) are major candidates for THz wave sources, because of their operation at room temperature and compactness. Recently, the oscillation frequency was increased up to 1.98 THz [3]. To achieve oscillation frequencies more than 2 THz, new RTD THz oscillator structure based on low conduction loss cavity resonator was proposed. However, in the first fabrication trial, obtained oscillation frequencies were only up to 1.79 THz [3]. To optimize oscillator characteristics and reach higher frequencies, oscillation frequency limitations and structure dependences were analyzed [4]. However, for practical applications analysis and optimization of output power characteristics is also necessary. In this work output power behavior of RTD oscillator with cylindrical cavity was analyzed.

II. DEVICE STRUCTURE AND CALCULATION TECHNIQUES

Oscillator is composed of an RTD mesa structure, cylindrical cavity and a bow-tie antenna on a semi-insulating InP substrate (Fig. 1). The RTD mesa is located in the center of the cylindrical cavity. Oscillation occurs in the cavity, and output power is supplied to the bow-tie antenna and radiated into the substrate side. To obtain dependences of output power on radius and height of the resonant cavity, calculation approach similar to our previous work [3] was used. Antenna and resonant cavity admittances were obtained by 3D electromagnetic simulation and then used for solution of oscillation condition equations [5]. Oscillation condition could be written as:

$$\begin{cases} Im(Y_{ANT}) - Im(Y_{RTD}) = 0 \\ G_{RTD} - G_{ANT} > 0 \end{cases}, \quad (1)$$

where Y_{ANT} and Y_{RTD} are admittances of resonant cavity with antenna and RTD respectively. RTD conductance and conductance of resonator with antenna are represented by G_{RTD} and G_{ANT} respectively. We should mention that imaginary part of the RTD admittance is proportional to the RTD capacitance $Im(Y_{RTD}) \simeq \omega C_{RTD}$.

Fig. 2 shows RTD and antenna admittances, when RTD mesa area is 1.47 μm^2, cavity radius is 5 μm and cavity height is 4 μm. Dashed red line shows oscillation point with corresponding frequency F_{osc}, where both oscillation conditions for the real and imaginary part are satisfied and the RTD oscillator would emit high frequency energy.

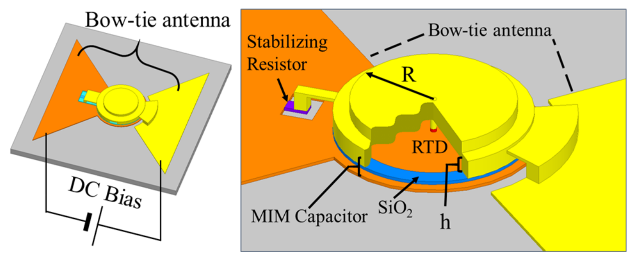

Fig. 1 RTD oscillator with cavity resonator structure

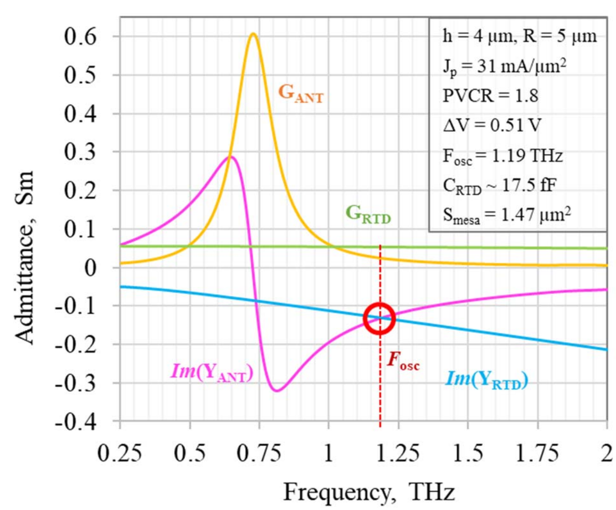

Fig. 2 Real (orange curve) and imaginary (pink curve) parts of resonant cavity and antenna admittance for cavity radius of 5 μm and cavity height of 4 μm. Green and blue curves represent respectively real and imaginary part of RTD admittance when RTD mesa area is 1.47 μm^2. Dashed red line shows oscillation point.

It could be clearly seen from Fig. 2 that solution of the oscillation condition (1) gives oscillation frequency value and allows to get corresponding values of G_{RTD} and G_{ANT}. After that, output power at obtained oscillation frequency can be estimated as [6]

$$P_{out} = \frac{1}{2} G_{rad} \cdot V_{ac}^2 \approx \frac{4}{3b} G_{rad} [G_{RTD} - G_{ANT}], \quad (2)$$

where G_{rad} is radiation conductance of the antenna and $b = 2\Delta I_{dc}/\Delta V_{dc}^3$, where ΔI_{dc} and ΔV_{dc} are height and width of the negative differential resistance (NDR) region of static I-V characteristic of the RTD. Here we use simplified equations to show main concepts of the calculation process. Detailed derivation of full equations would be presented in [6].

III. Results and discussion

Fig. 3 shows dependences of output power and mesa area on oscillation frequency for resonant cavity height of 4 μm and cavity radius values from 5 to 30 μm. Analysis of the calculation results over wider range of cavity dimensions shows that, for the RTD structure considered in present study, output power up to -34 dBm could be expected at 2.5 THz with cavity radius of 6 μm and height of 7 μm; besides that, output power up to -14 dBm could be expected at 1.5 THz with cavity radius of 5 μm and height of 4 μm.

Solution of the oscillation conditions (1) shows that RTD mesa area decreases with increasing oscillation frequency, since RTD capacitance is proportional to the mesa area, and this decrease in RTD mesa area could be clearly seen in Fig. 3. Since RTD conductance G_{RTD} is proportional to the RTD mesa area, G_{RTD} would also decrease with frequency and at some point, oscillation condition for the real part will not be satisfied. This behavior leads to existence of upper oscillation limit where output power rapidly decreases, which could be clearly seen in Fig. 3, for example, at frequency around 2.7 THz for cavity radius of 10 μm.

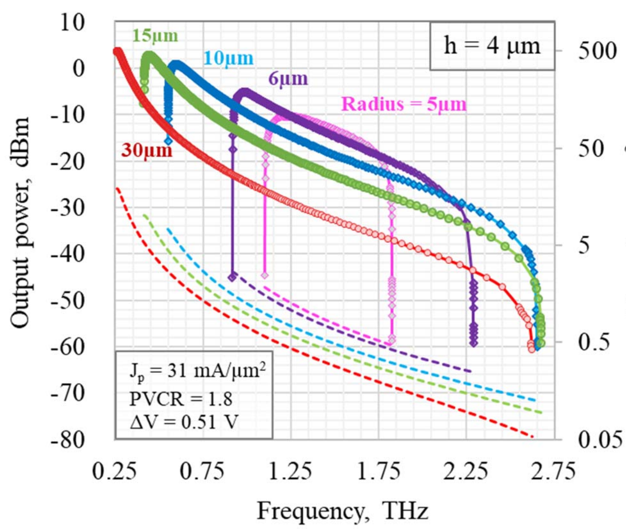

Fig. 3 Dependences of output power (line with markers) and RTD mesa area (dashed line) on oscillation frequency for resonant cavity height of 4 μm and cavity radius values from 5 to 30 μm.

With decreasing frequency, imaginary part of the Y_{ANT} increases, so RTD mesa area and output power would increase. However, calculation of output power over wide frequency range for different cavity radius values revealed decrease in output power at lower frequencies despite of increasing mesa area, leading to existence of lower oscillation limit. This behavior could be attributed to fast increase in resonant cavity conductance in the frequency region close to resonant frequency of the cavity.

Decrease in cavity dimensions would lead to decrease in cavity inductance, and hence, would lead to increase in absolute value of $Im(Y_{ANT})$. To fulfill oscillation condition (1) and balance the imaginary part of antenna admittance, $Im(Y_{RTD})$ should increase, which would require larger RTD capacitance and hence larger RTD mesa area. As a result, G_{RTD} and output power would increase with decreasing cavity radius in the region between lower and upper oscillation limits, as could be clearly seen in Fig. 3. Besides that, Fig. 3 shows decrease in frequency range between upper and lower oscillation limits with decreasing cavity dimensions, so decrease in cavity dimensions would not always lead to increase in output power at any frequency and careful analysis of output power dependences on cavity dimensions could be required to find optimum cavity radius and height for obtaining maximum output power at specific frequency.

IV. Conclusion

We analyzed output power limitations and structure dependencies for RTD THz oscillator with cylindrical cavity resonator. Dependences of the output power on resonant cavity dimensions show that output power generally increases with decreasing cavity size as well as with decreasing oscillation frequency. However, besides high-frequency oscillation limit we found existence of lower oscillation limit where output power rapidly decreases despite of increasing RTD mesa area. Discovered lower oscillation limit could lead to drop of output power even at frequencies around 1 THz, and hence this effect should be considered while designing RTD THz oscillators. Besides that, frequency range between upper and lower oscillation limits decreases with decreasing cavity dimensions, which means that decrease of cavity dimensions would not always lead to increase in output power at a specific frequency. Analysis of numerical calculation results over a wide range of cavity dimensions has shown that output power up to -34 dBm at 2.5 THz and up to -14 dBm at 1.5THz could be expected for the RTD oscillator considered in present study.

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