Sensitive Continuous-Wave Terahertz Detection by Resonant-Tunneling-Diode Oscillators

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***Abstract*—We have characterized the sensitivity and noise equivalent power (NEP) of resonant-tunneling-diode (RTD) oscillators as terahertz (THz)-wave detectors. Using a continuous-wave (CW) frequency-tunable THz-wave photomixer source, we observed that sensitive detection was achieved by RTD oscillators around its oscillation frequencies. The quasi-optical RTD device oscillating at 0.78 THz showed a maximum current responsivity of 7.3 A/W near the peak point of the negative differential conductance (NDC) region and a minimum NEP of 7.7 pW/√Hz within the NDC region, respectively, at room temperature.**

I. INTRODUCTION

COMPACT and room-temperature devices capable of emitting and detecting terahertz (THz)-wave radiation are crucial for real-world applications such as non-destructive sensing and wireless communications. As a chip-size electronic device, resonant tunneling diode (RTD) is a promising candidate because a single RTD device can work in the THz-wave regime not only as an oscillator but also as a detector by varying its bias condition [1]. Over the last decade, the oscillation frequency and output power of RTD oscillators have been improved significantly by optimizing their structures [2]. On the other hand, it has long been known that the nonlinearity appearing in the current-voltage (*I-V*) characteristics of RTDs can be used for THz-wave detection. Recently, the coherent detection using RTD has been demonstrated [3], suggesting the possibility of superior detection performance compared with other diode-based room-temperature detectors.

Here, we report the experimental characterization of sensitivity and noise equivalent power (NEP) of RTD oscillators as THz-wave detectors [4].

II. EXPERIMENT

A schematic diagram of the experimental setup is shown in Fig. 1. In this study, a quasi-optical, slot-antenna-integrated RTD device that was mounted on a silicon lens was used. To characterize the detector performance of this RTD device, a continuous-wave (CW) frequency-tunable THz photomixer source excited by a fiber-coupled two-color laser driver was employed. The bias modulation was applied to the photomixer by a function generator (FG) at 151 kHz for lock-in detection. The modulated THz-wave radiation from the photomixer was collimated and focused onto the RTD device by a pair of polymer lenses. The thin-film attenuators were placed between the two lenses to lower the THz-wave power. The RTD device was connected to a bias tee to apply the DC bias voltage using a DC source meter and to measure the current changes induced by the modulated THz-wave radiation using a lock-in amplifier. The current sensitivities were defined as the measured signal amplitude divided by the THz-wave power incident upon the RTD device. Then, without any compensation for the optical coupling efficiency inside the RTD device or Fresnel reflection loss at the surface of Si lens, optical NEPs were derived from the noise spectral density measured using the built-in function of the lock-in amplifier. All measurements in this study were performed at room temperature.

III. RESULTS

To confirm the negative differential conductance (NDC) region of the RTD device, the DC *I-V* curve and self-oscillating THz-wave output were measured in the absence of THz-wave radiation from the photomixer source, as shown in Fig. 2(a). Note that the measured *I-V* characteristics show the total current of the device including RTD itself and the stabilization resistor. As a result, the peak and valley points of the NDC region were observed as the current kinks at approximately 1.02 and 1.33 V, respectively. The THz-wave output from the RTD device was observed between the peak and valley points, thereby visualizing the NDC region. The oscillation frequency was measured to be 0.78 THz at the bias point for maximum output power.

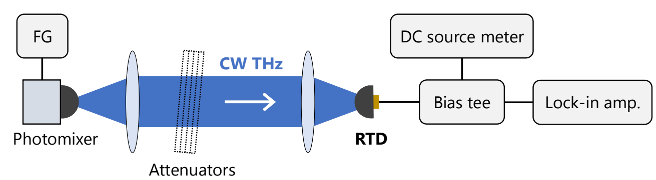

Fig. 1. Schematic experimental setup.

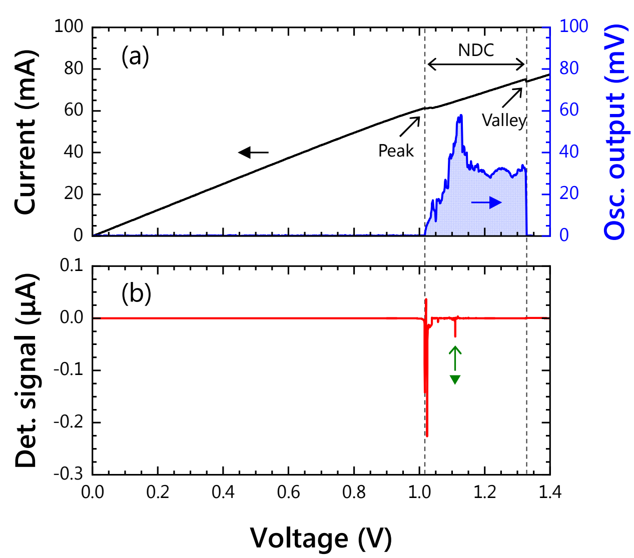

Fig. 2. (a) Measured DC *I-V* curve (left) and bias-dependent THz-wave output (right) of a 0.78-THz RTD device. (b) Detected signal current as a function of bias voltage with input 0.78-THz power of 21 nW.

Figure 2(b) shows the measured detection signal as a function of bias voltage. The frequency and average power of the input THz radiation were 0.78 THz and 21 nW, respectively. The detected signal in this RTD device reached a maximum near the peak point of the NDC region, corresponding to the peak current responsivity of 7.3 A/W. At this bias point, however, the RTD became unstable with a high noise floor because the peak is the initial point of oscillation by itself, resulting in a NEP of 0.74 nW/√Hz.

The signal with significant amplitude was also observed within the NDC region, as indicated by the green inverted triangle in Fig. 2(b), where the frequency of the THz-wave radiation to be detected was coincident with the oscillation frequency of the RTD itself.

Figure 3 shows the measured input-output characteristic at 0.78 THz for this bias voltage of 1.11 V. A significant current sensitivity of 3.0 A/W was obtained below the input THz-wave power of 10 nW. As the observed noise floor was as low as that outside the NDC region, the NEP at 1.11 V was measured to be 7.7 pW/√Hz, which is the lowest result for this RTD device. Above the input power of 10 nW, the signal amplitude was observed to show the relation proportional to the square root of the input THz-wave power with a slope of 0.5, as represented by the dashed line in Fig. 3. By tuning the THz-wave frequency of the photomixer source, we concluded that this sensitive detection mechanism is based on the injection locking phenomenon in the RTD device [4].

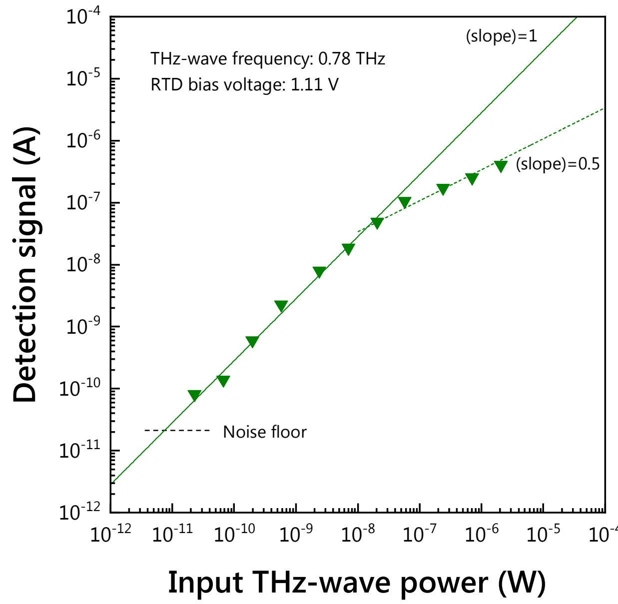

Fig. 3. Measured input-output characteristic at 0.78 THz for the bias voltage of 1.11 V. The horizontal broken line indicates the noise floor.

IV. SUMMARY

We experimentally characterized the sensitivity and NEP of quasi-optical, slot-antenna-integrated RTD oscillators as THz-wave detectors. The minimum NEP for the 0.78-THz RTD device was measured to be 7.7 pW/√Hz at 0.78 THz within the NDC region. Our result demonstrates that RTD THz-wave oscillators can be used as sensitive THz-wave detectors.

ACKNOWLEDGMENT

This work was supported in part by JST ACCEL (No. JPMJMI17F2), Terahertz Technology Platform of JST Collaborative Research Based on Industrial Demand "Terahertz-wave: Towards Innovative Development of Terahertz-wave Technologies and Applications", JST CREST (No. JPMJCR1534), JSPS KAKENHI (Nos. JP17H01282 and JP16H06292), and SCOPE (No. 175003003) from the Ministry of Internal Affairs and Communications, Japan.

The authors would like to thank Prof. H. Ito of RIKEN/Tohoku Univ. and Prof. M. Kumano of Tohoku Univ. for fruitful discussions.

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