Wang, J., Alharbi , K., Ofiare, A., Khalid, A., Wang, L., Cumming, D., and Wasige, E. (2014) Series coupled resonant tunneling diode oscillators for terahertz applications. In: UCMMT 2014: 7 th European/UK-China Workshop on Millimeter Waves and Terahertz Technologies, Chengdu, China, 2–4 September 2014

Series Coupled Resonant Tunneling Diode Oscillators for Terahertz Applications

Jue Wang, Khalid Alharbi, Afesomeh Ofiare, Ata Khalid, Liquan Wang, David Cumming and Edward Wasige
School of Engineering, University of Glasgow
Oakfied Avenue, Glasgow, United Kindom, j.wang.2@research.gla.ac.uk

Abstract: A series of resonant tunneling diode oscillators with frequencies up to W-band and output power around one milliwatt are presented. To our knowledge, the 75.2 GHz RTD oscillator with -0.2 dBm output power is the highest power reported. The technique demonstrated here shows the great potential to scale up the design to terahertz frequencies.

Keywords: monolithic microwave integrated circuit (MMIC); resonant tunneling diode (RTD); oscillator; terahertz (THz).

Introduction

Terahertz (THz) technology can be widely utilized in varied applications such as low-visibility imaging systems, ultrafast wireless communication systems and spectroscopy systems [1]. Resonant tunneling diode (RTD) is considered to be one of the very promising solid-state THz sources which can operate at room temperature. However due to the DC instability, low frequency parasitic oscillations and poor current handling, the output power of RTD oscillators tends to be low. The published highest frequency of RTD oscillator is 1.3 THz with only 10 µW output power [2].

In this paper, we report a series of MMIC RTD oscillators operating up to W-band frequencies with around one milliwatt power. This and on-going related work is expected to lead to high power RTD oscillators operating in the 100 GHz – 1 THz range with output power of at least 1 mW [3].

RTD Layer Structure and Characteristics

The RTD layer structure was grown by molecular beam epitaxy (MBE) on a semi-insulating InP substrate. It consists of a 5.5 nm $In_{0.53}Ga_{0.47}As$ quantum well sandwiched between 1.4 nm AlAs double barriers. The collector layer and emitter layers are each 80nm thick of $In_{0.53}Ga_{0.47}As$ which are highly doped ($2\times10^{18}cm^{-3}$) with Si. The device was fabricated by optical lithography. The mesa size of the RTD device demonstrated here was 16 μm^2. A micrograph picture of the completed RTD device is shown in Fig. 1. The measured IV characteristic of the RTD is shown in Fig. 2. The peak current density was 67 kA/cm^2 and the peak to valley current ratio (PVCR) was about 2.5.

Oscillator Design and Measurement Results

The schematic oscillator circuit incorporating stabilizing resistor to suppress parasitic oscillation is shown in Fig 3 (a), where R_e denotes the stabilizing resistor to suppress the low frequency bias oscillations [4]. The decoupling capacitor C_e short-circuits the RF signal to ground. Inductance L is chosen to resonate with the RTD capacitance to obtain the desired oscillating frequency. R_L is the load resistance.

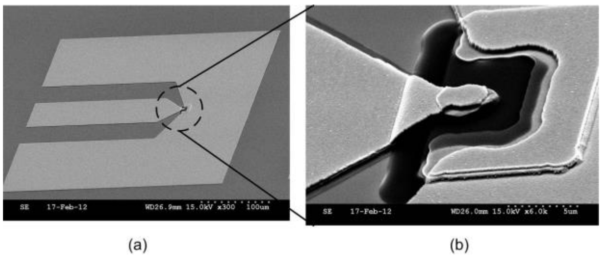

Figure 1. SEM pictures of the fabricated device. The RTD mesa size was 16 μm^2.

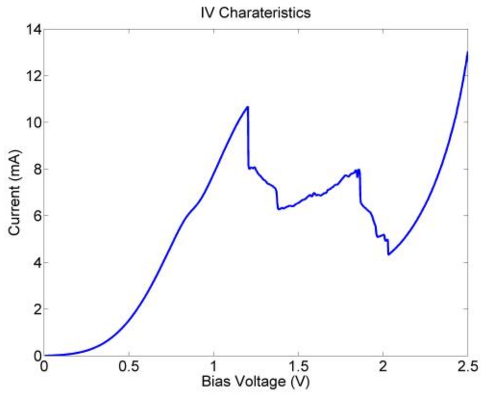

Figure 2. Measured IV characteristics of the single RTD device (16 μm^2).

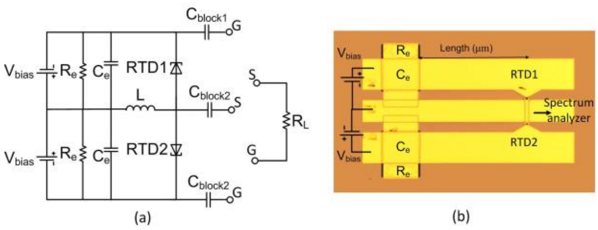

Figure 3. (a) The schematic circuit of double RTD oscillator and (b) Fabricated double RTD oscillator layout with schematic measurement setup.

A photograph of the fabricated circuit is shown in Fig. 3 (b), where R_e was realized as thin film NiCr resistor. The decoupling capacitor C_e was realized as metal-insulator-metal (MIM) capacitor (C_e = 87.1pF). R_L was introduced by the impedance of spectrum analyzer which is usually 50Ω. The MMIC RTD oscillator frequency was measured on wafer by using

an Agilent E4448A spectrum analyzer in combination with Agilent 11970W mixer. As the mixer loss was not calibrated, for frequency over 50 GHz, the actual power was measured by Agilent 437B power meter.
The spectrum of the best results is shown in Fig. 4. The oscillating frequency was 75.2 GHz. After compensating the mixer, cable and RF probes loss, the actual output power is about -0.2 dBm, which is the highest power reported for W-band RTD oscillator.

The summary of double RTD oscillator aiming at different frequencies is tabulated in Table 1. As the resonator L in Fig. 3 (a) is related to the CPW length [3], the designed frequency f_o versus CPW length l is plotted in Fig. 5, where the solide line presents the osicllator employing two 4×4 μm^2 RTDs while the dash line presents the osicllator employing two 5×5 μm^2 RTDs. It indicated that with reducing the CPW length, the oscillator employing two 4×4 μm^2 sized RTDs frequency can reach up to 200 GHz. These frequencies can be further increased by reducing device sizes.

Conclution and discusstion

The MMIC RTD oscillator which combined two large RTD devices for high output power has been described here. The results demonstrate the potential of this technology for higher power (>1 mW) and frequency (>100 GHz) by proper circuit design [3]. RTD-based MMIC oscillators with improved circuit design are expected to be useful in terahertz applications.

Acknowledgements

The authors would like to thank the staff of the James Watt Nanofabrication Centre (JWNC) at the University of Glasgow. This work was supported by the Engineering and Physical Sciences Research Council (EPSRC), grant number EP/J019747/1.

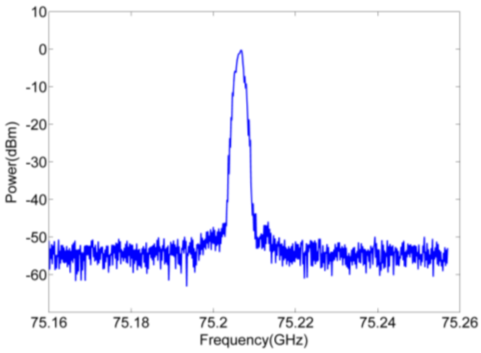

Figure 4. Measured spectrum of the 75.2 GHz RTD oscillator. VBW=150 kHz, RBW=2 MHz.

Table 1. Measurement Results

Size (μm^2)	Designed freq. (GHz)	CPW Length (μm)	Measured freq. (GHz)	Power (dBm)
4×4	28	620	33.7	-5.5
4×4	43	320	39.6	-0.1
4×4	74	120	75.2	-0.2
5×5	75	60	86.5	-5.6

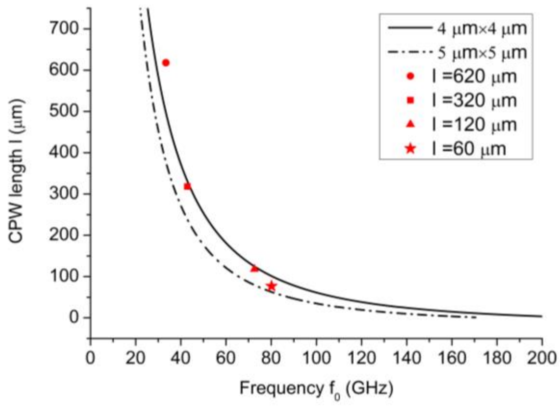

Figure 5. The calculated CPW length l versus frequency f_o, compared with the measurement results.

References

1. Rostami, A., Rasooli, H. and Baghban, H. 'Terahertz Technology: Fundamentals and Applications', *Springer*, 2010.
2. Asada, M. and Suzuki, S., "Compact THz oscillators with resonant tunnelling diodes and application to high-capacity wireless communications," *21st International Conference on Applied Electromagnetics and Communicaitons*, pp. 14-16, Oct. 2013.
3. Wang, J., "Monolithic Microwave/Millimetrewave Integrated Circuit Resonant Tunnelling Diode Sources with around a Milliwatt Output Power," *Ph.D. Thesis*, University of Glasgow, 2014.
4. Wang, L. and Wasige, E. : 'Tunnel diode microwave oscillators employing a novel power combining circuit topology', *European Microwave Conference* , pp. 1154-1157, Sep. 2010.