IEICE TRANSACTIONS

on Electronics

DOI:10.1587/transele.2021ECS6002

Publicized:2021/06/07

A PUBLICATION OF THE ELECTRONICS SOCIETY

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BRIEF PAPER

Experimental demonstration of a hard-type oscillator using a resonant tunneling diode and its comparison with a soft-type oscillator

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SUMMARY A hard-type oscillator is defined as an oscillator having stable fixed points within a stable limit cycle. For resonant tunneling diode (RTD) oscillators, using hard-type configuration has a significant advantage that it can suppress spurious oscillations in a bias line. We have fabricated hard-type oscillators using an InGaAs-based RTD, and demonstrated a proper operation. Furthermore, the oscillating properties have been compared with a soft-type oscillator having a same parameters. It has been demonstrated that the same level of the phase noise can be obtained with a much smaller power consumption of approximately 1/20.

key words: *resonant tunneling diode, oscillator, hard-type oscillator, phase noise, spurious oscillation*

1. Introduction

Recently, there has been an increasing interest in THz wave technology for various applications such as wireless communication, sensors [1]–[3], etc. This leads to attention to THz oscillators. Among them resonant tunneling diode (RTD) oscillators attract a great deal of attention as high performance signal sources [4]–[8]. The RTD's negative differential resistance (NDR) is a basis for simple oscillators. The oscillation frequency of the RTD oscillators has been continuously increasing in this decade and now it exceeds 1.9 THz [9]–[11]. Applications to wireless communication have been also investigated using RTD oscillators [12]–[14].

However, there are still some important issues for practical applications, since the RTD is a 2-terminal device. Among them spurious oscillations in the bias line is one of the most important issues [15]. We have recently proposed to use "Hard-type" oscillator concept to overcome this issue [16]–[20]. In this paper, we report on basic operation of the hard-type oscillator fabricated with an InGaAs-based RTD, and also discuss their stability compared with a soft-type oscillator fabricated with same parameters.

2. Hard-type oscillator circuit

The hard-type oscillators are defined as the oscillators having stable fixed points within a stable limit cycle [21]. This means that no self-excitation of the oscillation occurs. This is advantageous to avoid spurious oscillation if we add a trigger circuit to excite only the desired oscillation.

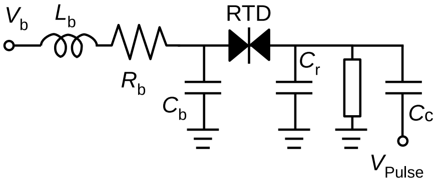

Fig. 1 Hard-type oscillator using an RTD with a capacitor-coupled trigger input.

Table 1 Circuit parameters

R_b	30Ω
C_b	10 pF
C_r	10 pF
C_c	1 pF
RTD Area	20 μm^2
RTD Peak Current Density	1×10^5 A/μm^2
Microstrip Line	50Ω, 4.5mm

Figure 1 shows the hard-type oscillator we investigate here. It is a simple RTD oscillator whose resonator is consisting of a capacitor, C_r, and a transmission line. It has a series resistor, R_b, in the bias line, which hides the NDR of the RTD from the bias line. The L_b is a parasitic inductance in the bias line.

The resistor, R_b, suppresses the spurious oscillation in the bias line, however, it also prevents the RTD being biased in the NDR region. Therefore, no oscillation begins when the voltage corresponding to the NDR region is applied. To excite oscillation a trigger pulse should be applied to the resonator. For this purpose, various types of the trigger circuit have been proposed, which use a high electron mobility transistor (HEMT) [16], a Schottky diode [18], [19], or a capacitor [20]. Here, we chose a most simple solution, the capacitor-coupled trigger.

A voltage pulse to the trigger input pushes the oscillation node voltage apart from the stable fixed points, and makes the oscillation begin. When the oscillation occurs, the capacitor, C_b, stabilizes the bias terminal.

Simple circuits were fabricated using an InGaAs-based RTD on a printed circuit board (PCB) to demonstrate the basic operation. The RTD was fabricated with standard photo lithography and liftoff process. The details were shown in the reference [22]. The RTD was connected by wire bond-

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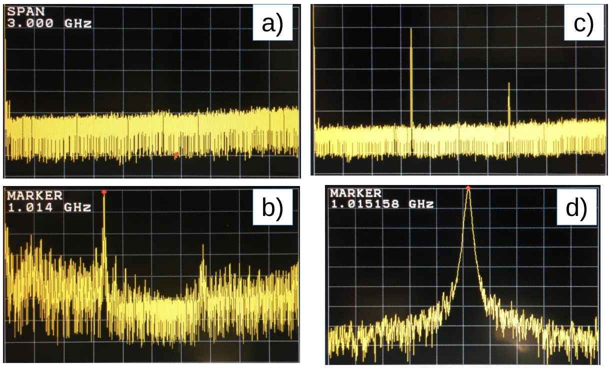

Fig. 2 Output spectra of the hard-type oscillator. a) Before triggering, b) Under periodic pulse application, c) After triggering, d) Magnified view of the oscillation peak. x-axis: a), b), c) 0 to 3GHz with 300MHz/div, d) 100 kHz/div, y-axis: 10 dB/div.

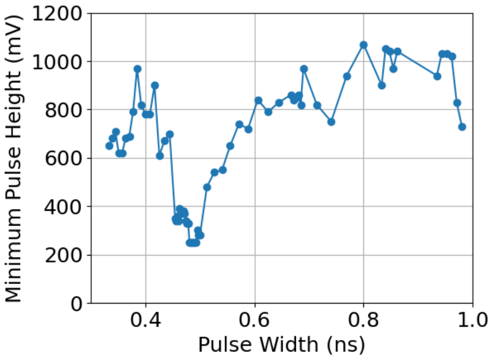

Fig. 3 Minimum trigger pulse height required for oscillator excitation as a function of the pulse width.

ing, and 1005-type (mm) chip devices were used for the capacitors and resistors. To eliminate the effects of bonding wires and for ease of the measurement, relatively low resonant frequency of 1 GHz was chosen. Circuit parameters are shown in Table 1. We think that the results discussed in this paper is also valid for higher frequency oscillators, because the same equivalent circuit well describes the operation of the oscillators at THz frequency range [10]. For the circuit configuration, we employed a microstrip transmission line instead of an inductor for future higher frequency experiments. The equivalent inductance was about 1.4 nH at 1 GHz. From this value the characteristic impedance of the resonator is calculated to be 12 Ω, which is defined as $\sqrt{(L/C)}$. This small impedance value ensures harmonic oscillation [23], and it is similar to those calculated from the parameters reported for THz oscillators [24], [25]. A soft-type oscillator having a parallel stabilizing resistor of 5Ω in place of the series resistor was also fabricated with the same parameters for comparison.

3. Results and discussion

First, we tested the basic operation of the hard-type oscillator. The current-voltage characteristics of the bias terminal show a large hysteresis due to the series connected bias line resistor of 30 Ω. This hysteresis disables the RTD to be biased in the NDR region.

The measured spectra of the hard-type oscillator are shown in Fig. 2. As shown in a), no oscillation was observed even though the bias voltage corresponding to the hysteresis region was applied to the circuit.

Then we applied periodic pulse signal to the circuit. The pulse height and width were 800 mV and 1 ns respectively, with 35 ps rise and fall times. The repetition rate was set to 100 MHz. Fig. b) shows the spectrum while the pulses are fed. A strong peak at the resonant frequency was observed among broad and noisy signals. This peak remains after the pulse signal input was stopped as shown in Fig. c), which indicates the circuit is in the oscillation state. Once the oscillation begins, stable oscillation persists while the bias voltage is in the hysteresis region. Figure 2 d) shows the magnified view of the spectrum. The oscillation peak is sharp, and no spurious oscillation was observed. This stable oscillation can be obtained with a small current of approximately 10 mA, which corresponds to the power consumption of 12 to 13 mW. It is noted here that the periodic pulses in Fig. 2 (b) are not necessary and a single-pulse can excite the oscillator. The oscillation spectrum is the same for both conditions. This is a natural consequence of the fact that there is only one limit cycle in this system.

Next, we investigated the trigger pulse condition for proper operation. Figure 3 shows the minimum pulse height required for triggering the oscillation as a function of the pulse width. It has an interesting dependence showing a valley at about 0.5 ns. This pulse width corresponds to the half period of the oscillation. This dependence can be explained as follows. First, current pulse is induced when the pulse voltage rises. This excites the circuit to begin oscillation. Next, when the pulse voltage falls, the current pulse with opposite direction flows. This enhances the excitation if it occurs at the opposite phase of the oscillation, while it suppress the excitation if the phase of the oscillation is the same as the first current pulse. Consequently, the minimum pulse height can be obtained when the pulse width equals to half the oscillation period.

Finally, we compared the properties of the hard-type oscillator with a soft-type oscillator fabricated with the same parameters. The fabricated soft-type oscillator shows stable oscillations at around 0.99 GHz. It consumes much larger power, approximately 210mW. About 95 % of this power was consumed at the stabilization resistor.

Regarding the stability of the oscillators, one of the most important properties is a phase noise [26]–[28], which governs the performance of the communication systems, sensors [29]–[31], etc., using the oscillators. Figure 4 shows the oscillation frequency and the phase noise at the offset frequency of 100 kHz as a function of the bias voltage. The bias voltage region for oscillation are 0.86 to 1.09 V, and 1.16 to 1.31 V for soft- and hard-type oscillators, respectively. Due to the series resistor, the voltage region of the hard-type

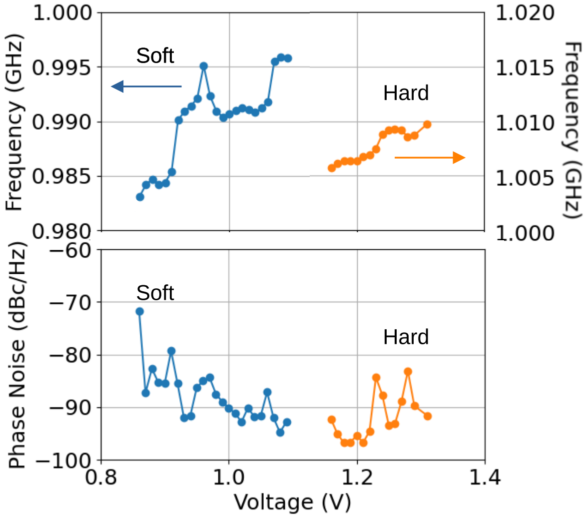

Fig. 4 Oscillation frequency and phase noise of the soft- and hard-type oscillators having the same circuit parameters. The offset frequency of the phase noise is 100 kHz.

oscillator shifts to higher voltages. Both oscillators show relatively small dependence of the oscillation frequency on the bias voltage, which indicates the oscillation is not relaxation mode but harmonic mode [23], [32].

For the soft-type oscillator the phase noise is large at around the smallest voltage, where the oscillator shows slightly unstable behavior with spurious oscillations. This is due to a large negative differential conductance (small NDR) just above the peak voltage, because 5Ω stabilization resistance is not enough to compensate NDR here. Decreasing the resistance can suppress this instability, however, it increases the power consumption. Except above region, soft- and hard-type oscillators show almost the same phase noise. It should be noted that the same level of frequency stability can be obtained for the hard-type oscillator even though the power consumption is approximately 1/20.

4. Conclusion

A hard-type oscillator was fabricated with an InGaAs-based RTD. It has a capacitor-coupled trigger input for excite oscillation. Proper triggering and stable oscillation were demonstrated with this circuit. Next, details of triggering operation were investigated, and it was found that the minimum pulse height required for exciting the oscillation can be obtained when the pulse width equals to half the oscillation period. Finally, phase noise property was compared to that of the soft-type oscillator having the same circuit parameters. It was demonstrated that the same phase noise can be obtained with a much smaller power consumption of approximately 1/20.

Acknowledgments

The authors thank Mr. Kazuhiko Ueda for his help in fabricating the devices. This work was supported by JSPS KAKENHI Grant Number 18H01495, and the VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Keysight Technologies Japan, Ltd. A part of this work was carried out under Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University.

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