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Low Power On-off mode RTD-based Oscillator Integrated with an HBT Switch

Jaehong Park, Kiwon Lee, Jooseok Lee, and Kyounghoon Yang
Department of Electrical Enginnering Korea Advanced Institute of Science and Technology(KAIST)
373-1, Guseong-Dong, Yuseong-Gu, daejeon, Republic of Korea.
e-mail: jhpark0226@kaist.ac.kr

***Short-Abstract*—A low power on-off mode resonant tunneling diode (RTD) based oscillator is demonstrated by using an RTD/heterojunction bipolar transistor (HBT) MMIC technology. Using the negative differential resistance (NDR) characteristics of the tunneling diode, which arise at a low applied voltage range from the quantum-effect, the low power oscillators are used for microwave on-off keying (OOK) signal modulation. The fabricated RTD-based oscillator shows low power consumption of 5 mW at an oscillation frequency of 5.2 GHz. The RTD-based oscillator operates in an on-off mode with a high data rate of 1 Gb/s from the fast switching capabilities of the RTD and HBT switch. A good energy efficiency of 5 pJ/bit has been obtained in this work.**

I. INTRODUCTION

RTDs (resonant tunneling diodes) are promising devices for applications in microwave applications, due to their properties of intrinsic NDR (negative differential resistance) at room temperature and compatibility with the conventional III-V technologies such as HBTs (heterojunction bipolar transistors) [1]. In particular, low power oscillators, utilizing InP-based RTDs as a negative resistance cell in various topologies, have been developed for very low dc power consumption in microwave applications [2]. From these results, the RTD oscillator is considered to be one of the best candidates for extremely low power applications, due to its simple topology and low applied bias voltage. Furthermore, because of the high-speed switching capability due to the fast quantum resonant tunneling phenomena and the related small parasitic capacitance [3], the on-off time of the RTD-based oscillator is very fast. Therefore, the RTD-based oscillator allows the high data-rate operation as an on-off mode oscillator for OOK (on-off keying) transmitter applications for 5 GHz UNII (unlicensed national information infrastructure) band wireless LAN (WLAN) which can provide maximum data rates of 54-Mbit/s. In the previous work, we have demonstrated the simple RTD-based OOK oscillator, operating at high data rate without an input data switch [4].

In this work, we propose a low power on-off mode oscillator by integrating an InP-based HBT into the RTD-based oscillator circuit. The HBT is used as an input data buffer as well as a switch to effectively modulate the oscillator. By switching the HBT between high and low output states, it is possible to achieve a high data rate. The proposed on-off mode oscillator has been implemented by using an RTD/HBT MMIC (monolithic microwave integrated circuit) technology.

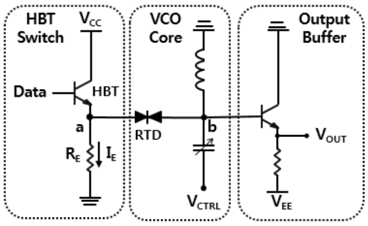


Fig.1. Schematic diagram of the RTD/HBT based on-off mode oscillator.

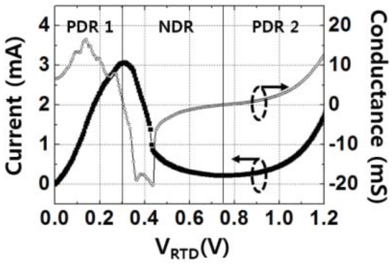


Fig.2. Measured I-V and differential conductance (g_d) characteristics of the fabricated RTD (1.8×2.3 μm^2).

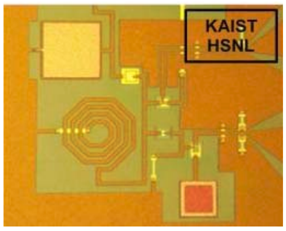


Fig.3. Microphotograph of the fabricated on-off mode RTD oscillator integrated circuit (chip size: 580×470 μm^2).

II. OPERATION PRINCIPLE AND DEVICE TECHNOLOGY

Fig. 1 shows the circuit schematic diagram of the proposed RTD-based on-off mode oscillator which consists of an RTD oscillator, an HBT input buffer switch, and an emitter follower output buffer stage. The detailed operation principle of the RTD oscillator has been described elsewhere [4]. The HBT switch is added to modulate the RTD bias current with a high switching rate and to isolate the RTD oscillator from the external input stage. When the voltage at the Data input node is 1.25 V (a logical high state “1” of the input data), the HBT switch turns on and the emitter current (I_E) flows through the resistor R_E, resulting in a supply voltage of 0.4 V at node ‘a’ for the RTD. Therefore, the RTD is biased in the NDR region and the oscillation gets started in the on-mode operation. On the other hand, when the voltage at the Data input node is 0 V

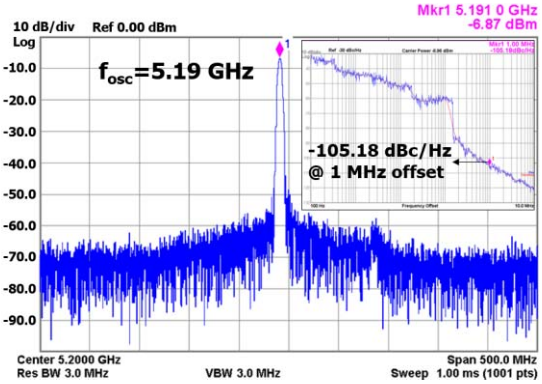
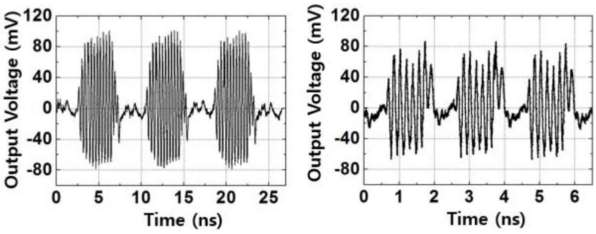


Fig.4. Measured output spectrum of the fabricated RTD oscillator (inset: phase noise at a 1-MHz offset)



(a) (b)

Fig.5. Measured time-domain waveforms at the output of the fabricated RTD on-off mode oscillator with an on-off modulation data rate of (a) 250 Mb/s and (b) 1 Gb/s.

TABLE I

PERFORMANCE COMPARISON WITH OTHER LOW-POWER OSCILLATOR ICS.

	[6]	[7]	This work
Technology	180 nm CMOS	250 nm CMOS	**1.8 µm RTD**
f_{osc} (GHz)	2.46	5.73	5.2
Data Rate (Mb/s)	136	100	**1000**
Energy efficiency (pJ/bit)	22	50	**5**

(a logical low state "0" of the input data), the HBT switch turns off and the RTD is biased in the PDR 1 (positive resistance region 1). As a result, the oscillation gets into under the off mode condition. An InP-based RTD/HBT MMIC technology has been used to fabricate the proposed RTD oscillator. The epitaxial layer structure of a pseudomorphic InP-based RTD used in this work has been described elsewhere [2]. The fabricated RTD exhibits a peak-to-valley current ratio (PVCR) of 13.6 with a peak voltage (V_P) of 0.31 V and a peak current (I_P) of 3.07 mA. The RTD exhibits the negative resistance characteristics in a voltage range from 0.31 to 0.74 V as shown in Fig. 2. The fabricated 1.5×4.0 μm^2 HBT has a peak current gain cutoff frequency (f_T) of 100 GHz and a peak maximum oscillation frequency (f_{max}) of 100 GHz. As for the LC resonator, the inductance of the used spiral inductor is 2.0 nH. Fig. 3 shows the microphotograph of the fabricated oscillator with a chip area of 580×470 μm^2 excluding the pads.

III. MEAUREMENT AND DISCUSSION

In order to confirm the fundamental performances of the fabricated RTD single-mode oscillator, the fully on-mode operation of the oscillator biased at the HBT collector voltage (V_{CC}) of 1.5 V and base voltage (Data node) of 1.25 V was measured on wafer using a N9030A PXA signal analyzer with a system impedance of 50 Ω at room temperature. At the oscillation condition, the collector current of the HBT is measured 2 mA and the voltage of the node 'a' is 0.4 V. As shown in Fig. 4, the output spectrum of the oscillator operating at the on-state DC bias condition shows an oscillation frequency of 5.2 GHz. The measured phase noise of the oscillator was obtained to be -105.2 dBc/Hz at a 1 MHz offset. The RF power of -6.87 dBm was obtained at the output port of the oscillator with an RTD bias current of 1.93 mA. Fig. 5 shows the measured time-domain waveforms from the output of the RTD on-off mode integrated oscillator at OOK data rates of 250 Mb/s and 1 Gb/s. The corresponding power consumption of the oscillator was 3 mW excluding the output buffer. The total power consumption of the RTD/HBT based oscillator including the emitter follower output buffer was measured to be about 5 mW.

Table I shows the performance comparison of the fabricated on-off mode RTD oscillator with the previously published low-power OOK transmitter ICs reported in the related frequency range. The fabricated RTD on-off mode integrated oscillator demonstrates an energy efficiency better than 4~10 times, compared to the previously reported other conventional OOK transmitters.

IV. CONCLUSION

In order to obtain a low power RTD on-off mode oscillator for OOK transmitter applications, the quantum-effect RTD oscillator has been fabricated with monolithic integration of an HBT switch. The proposed integrated oscillator showed a low power consumption of 5 mW at an oscillation frequency of 5.2 GHz. In addition, the high energy efficiency of 5 pJ/bit at a 1 Gb/s data rate was achieved. According to the results, the quantum-effect RTD-based oscillator is very promising for the low-power/low-energy wireless transmitter applications.

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