14 GHz InP-BASED RTD MMIC VCOS WITH ULTRA LOW DC POWER CONSUMPTION

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Abstract

This paper presents the performance characteristics of 14 GHz InP-based RTD MMIC voltage-controlled oscillators with the extremely low DC power consumption. In order to further reduce the DC power consumption of RTD based VCOs, RTDs with a small emitter size, such as $1.5 \times 1\ \mu m^2$ and $1 \times 1\ \mu m^2$, are used for the negative resistance generator of the VCOs. Each VCO is implemented by using the same resonator and output buffer except the RTD size to investigate the performance of the VCOs with the variation of RTD size. The fabricated VCOs showed the sub-mW DC power consumption which is suitable for wireless sensor applications.

I. Introduction

Recently, InP-based resonant tunneling diodes (RTDs) attract a great deal of interests for implementing ultra low-power MMIC VCOs due to their properties of intrinsic negative differential resistance (NDR) characteristics at a low applied bias voltage range and high device cutoff frequency, which arise from the quantum transport phenomena in a nano scale dimension [1]. As a result, several InP-based RTD MMIC VCOs with low DC power consumption have been reported [2-4]. In order to further reduce the DC power consumption of RTD based VCOs for the wireless sensor applications requiring the sub-mW DC power consumption, the operating current of the VCOs should be decreased by the reduction of the emitter size of RTD. In this work, we report on fabrication and characterization of 14 GHz MMIC VCOs, which are implemented by using the InP RTD with the emitter size of $1.5 \times 1\ \mu m^2$ and $1 \times 1\ \mu m^2$. The emitter size of the RTD used in this work is the smallest for the RTD-based VCOs to the authors' knowledge. Consequently, the lowest power operation of the RTD-based VCOs at a target frequency range of Ku-band is expected to be obtained.

II. Oscillator Design

Fig. 1 shows the circuit topology of the RTD MMIC VCO. The balanced VCO topology is used to implement the RTD MMIC VCO. The ac virtual ground forms at the node between the two varactors. Hence the differential signals, which are essential for communication systems, are generated [5]. In this balanced topology, the phase noise can be reduced due to its immunity to the common-mode noise generated from the power supply and substrate. In the VCO, the RTD generates the negative resistance at a very low bias voltage of 0.34 V which significantly reduces the DC power consumption compared to the conventional-type VCO. The resonator determines the oscillation frequency of the VCO. By varying the tuning voltage (V_{TUNE}), the oscillation frequency of the VCO can be varied. The HBT emitter follower buffer is used to isolate the output 50 Ω load for measurement from the VCO core. In order to initiate the oscillation, the magnitude of the effective negative conductance ($|G_N|$) generated by the RTD is designed to be greater than the overall parasitic conductance (G_P) generated by the resonator and the buffer.

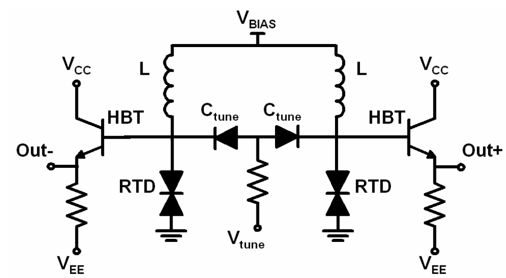

Fig. 1. Circuit topology of the RTD MMIC VCO.

III. Fabrication

The RTD MMIC VCO is fabricated by using an InP-based RTD/HBT MMIC Technology. The RTD, HBT, varactor, inductor and thin inductor and thin film resistor are monolithically integrated on the staked RTD/HBT layer structure as shown in Fig. 2. The InP-based pseudomorphic subwell RTD layers [4] are used for the required device characteristics of low

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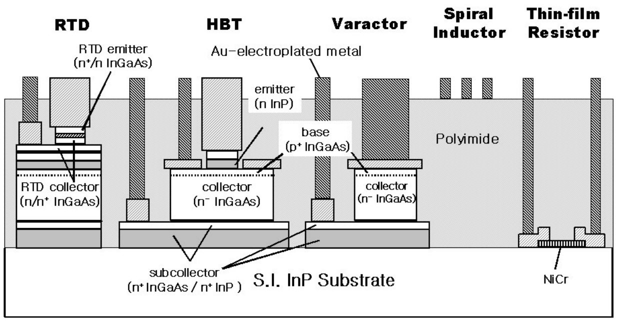


Fig. 2. Schematic cross-sectional view of an InP-based RTD/HBT Technology.

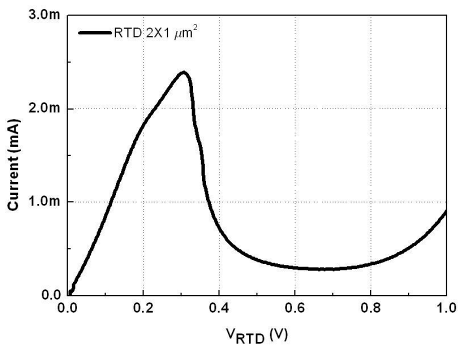


Fig. 3. Current versus voltage characteristics of the RTD at room temperature.

peak voltage and high peak current. Fig. 3 shows the DC I-V characteristics of the InP RTD. In order to obtain the stable DC I-V characteristics, the parallel resistance is integrated with the RTD. The fabricated RTD shows a peak voltage (V_P) of 0.31 V, a peak current density of 120 kA/cm^2 (J_P) and a peak-to-valley current ratio (PVCR) of 10 at room temperature. The HBT with an emitter size of 0.4×4.2 μm^2 was used in the buffer. The fabricated HBT shows a maximum cutoff frequency of 90 GHz and a maximum oscillation frequency of 65 GHz. The size of the varactor is 22×22 μm^2 and the capacitance value varies from 120 fF to 250 fF with the corresponding quality factor varying from 22 to 16 at 14 GHz under a tuning voltage (V_{tune}) range from -3 V to 0 V. The spiral inductor was formed by using a gold interconnection metal. The inductance of the spiral inductor is 0.525 nH with the quality factor of 25 at 14 GHz. Fig. 4 shows the microphotograph of the fabricated 14 GHz RTD MMIC VCO. The area of both the fabricated VCO circuits excluding the pads is about 540×340 μm^2.

IV. Measurement Results

The characteristics of the fabricated 14 GHz VCOs were measured by using an HP8764E spectrum analyzer. As shown in Figs. 5(a) and (b), the output spectrum of the fabricated VCO using 1.5×1 μm^2 RTDs (VCO-I) shows an RF output power of -12.2 dBm and the DC power consumption of 0.91 mW, and the

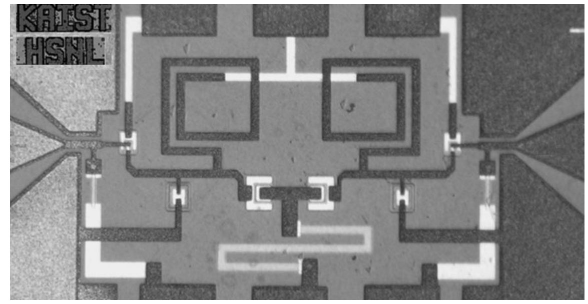
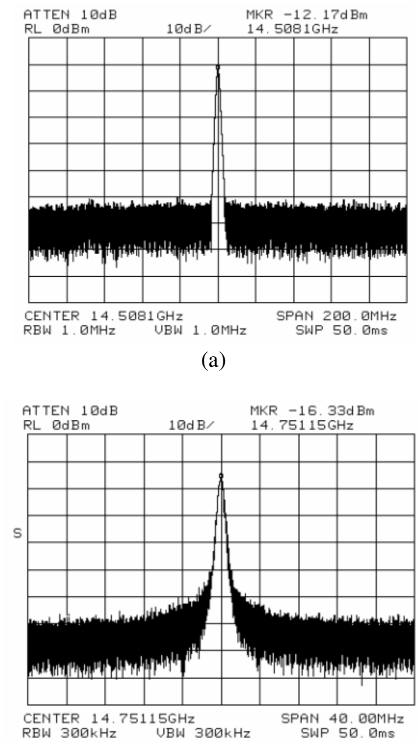


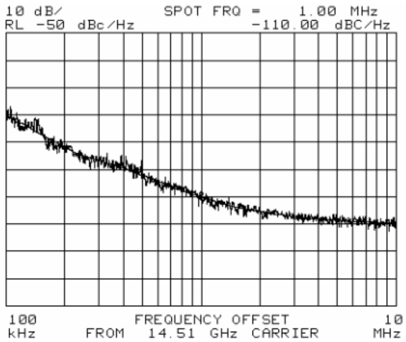
Fig. 4. Microphotograph of the fabricated RTD MMIC VCO.



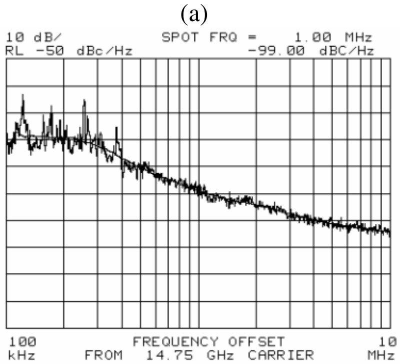
(b)

Fig. 5. Measured output spectrum of the MMIC: (a) VCO-I and (b) VCO-II.

VCO with 1×1 μm^2 RTDs (VCO-II) shows an RF output power of -16.3 dBm at the DC power consumption of 0.62 mW. The obtained DC power value of 0.62 mW is the lowest value among those of Ku-band differential VCOs to the authors' knowledge. The measured phase noise of the VCO-I was obtained to be -110 dBc/Hz at 1 MHz offset at an operating frequency of 14.51 GHz and that of the VCO-II was obtained to be -99 dBc/Hz at 1 MHz offset at an operating frequency of 14.75 GHz as shown in Figs. 6(a) and (b). With the size reduction of the RTDs, the higher oscillation frequency, lower RF output power and worse phase noise performance are obtained due to the reduction of the capacitance and negative conductance ($|G_N|$) of the RTDs. Fig. 7(a) shows the measured oscillation frequency and Fig. 7(b) shows the output power with respect to the tuning voltage. The detailed measurement results of the fabricated MMIC VCOs are summarized in Table I.

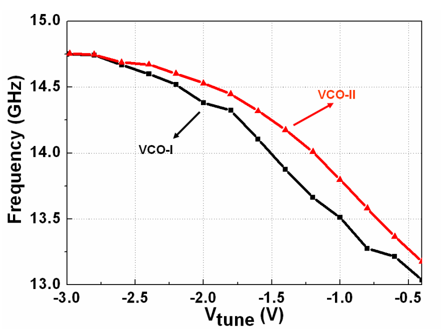


(a)

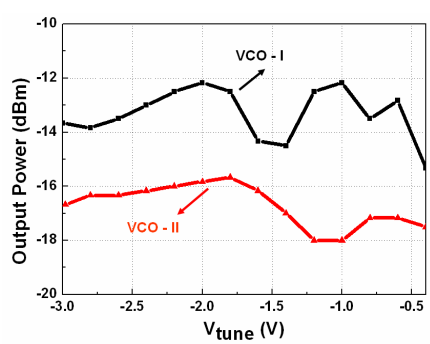


(b)

Fig. 6. Measured phase noise versus offset frequency of (a) VCO-I and (b) VCO-II.



(a)



(b)

Fig. 7. Measured (a) oscillation frequency and (b) output power versus the V_{tune} of the RTD MMIC VCO-I and II.

TABLE I

Summary of performance characteristics for the fabricated Ku-band RTD MMIC VCOs.

Performance	VCO-I	VCO-II
Emitter size of RTD	1.5×1 μm^2	1×1 μm^2
F_{OSC}	13.9 GHz	14.0 GHz
Tuning Freq.	1.7 GHz	1.6 GHz
Best PN @ 1MHz	-110 dBc/Hz	-99 dBc/Hz
Maximum P_{RF}	-12.2 dBm	-15.7 dBm
DC power of VCO core	0.91 mW	0.62 mW
F.O.M of VCO core	194 dBc/Hz	185 dBc/Hz

V. Conclusion

14 GHz VCOs with the RTD size of 1.5×1 μm^2 and 1×1 μm^2 have been fabricated and characterized using an InP-based MMIC technology. Both the fabricated MMIC VCOs showed the extremely low DC power consumption compared to the conventional VCOs. The VCO-I implemented using the 1.5×1 μm^2 RTD showed DC power consumption of 0.91 mW and the VCO-II implemented by the 1×1 μm^2 RTD showed that of 0.62 mW. These results demonstrate the potential of the RTD based MMIC VCOs with low DC power consumption for wireless sensor applications.

Acknowledgement

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