RF Excitation of an Oscillator with Several Tunneling Devices in Series

Olga Boric-Lubecke, *Student Member, IEEE,* Dee-Son Pan, *Member, IEEE,* and Tatsuo Itoh, *Fellow, IEEE*

Abstract—**An oscillator with several tunneling devices connected in series has a demanding excitation condition due to the DC instability of the series connection. An RF source with a frequency close to the oscillation frequency may be used to overcome this problem. The experimental demonstration of an RF source excitation of an oscillator with two tunnel diodes in series at 2 GHz is described here. The RF power necessary for the excitation is about 15 dB lower than the output power of the oscillator.**

I. Introduction

A RESONANT tunneling diode (RTD) is currently the fastest solid state source, but with a very low output power [1]. Series integration of RTD's has been proposed in order to increase the output power at millimeter-wave frequencies [2]. For ten RTD's integrated in series with the series integrated device area increased 10 times as compared to the single RTD, the total device impedance is unchanged, whereas the available RF power may be increased to up to one hundred times. The available power for the series integrated device considered in [2] is predicted to be 0.1 W at 100 GHz. Due to DC instability of the series connection when all diodes are biased in the negative differential resistance (NDR) region of the DC I-V curve, an oscillator using several RTD's connected in series has some distinct features compared to a single RTD oscillator. The oscillation amplitude has to be sufficiently large [2]–[4] to cover a considerable portion of the positive differential resistance (PDR) region of the DC I-V curve, and it is difficult to bias all RTD's simultaneously in the NDR region [3]. If the DC bias voltage—sufficient to bias all RTD's in the middle of the NDR region—is applied gradually, the DC instability will divide this voltage so that all the RTD's are biased in the PDR region. An external RF source of a frequency close to the resonant frequency of the circuit may be used to switch the bias points from the PDR region to the NDR region [4]. Simulation shows [4] that the divided DC voltage in the PDR region is DC stable but RF unstable and that the RF initialized oscillation can be maintained. Only several periods of the external RF signal are required for the switch. A device that has a heating problem, such as a pulsed IMPATT diode [4], may be used as an RF excitation source.

Manuscript received June 14, 1994. This work was supported by the Joint Services Electronics Program through AFOSR F49620-92-C-0055.
The authors are with the Department of Electrical Engineering, University of California at Los Angeles, Los Angeles, CA 90024 USA.
IEEE Log Number 9405357.

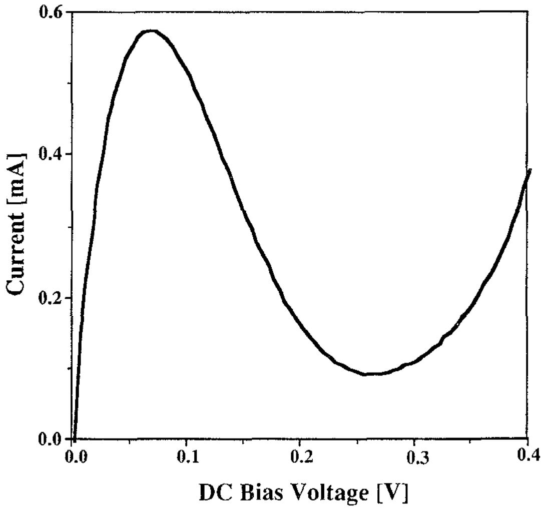

Fig. 1. DC I-V characteristics of a single tunnel diode.

The ultimate objective of this work is to build an oscillator with several RTD's integrated in series. However, due to the lack of readily available RTD's suitable for a microstrip circuit, tunnel diodes connected in series were used for this experiment. Tunnel diodes behave very similarly to RTD's and are readily available in a planar package. An oscillator with several RTD's in series is expected to behave in the same manner.

II. Oscillator Design

Back tunnel diodes manufactured by Metelics Co. were used, with a peak current of 0.55 mA, a total capacitance of 0.55 pF, and a series resistance of 6.5 Ω. The complete I-V curve was measured by placing a resistor of 184 Ω in parallel with the diode. The I-V curve was then de-embedded from the series resistance and fitted with a 5th-order polynomial for numerical calculations (Fig. 1). The large signal negative conductance and the available power (ohmic losses not included) were calculated for the DC bias voltage in the middle of the NDR region (0.160 V) as a function of the oscillation amplitude (Fig. 2), using the procedure described in [5]. For a single diode, maximum available power is 16.26 μW at oscillation amplitude 0.136 V.

Several oscillators with two diodes in series were tested, each designed at 2 GHz for different oscillation amplitude. The minimum oscillation amplitude was experimentally determined to be 0.140 V, slightly higher than the amplitude

1051-8207/94$04.00 © 1994 IEEE

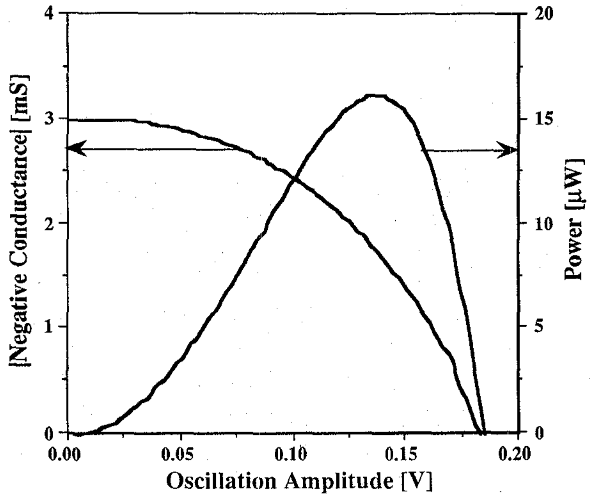

Fig. 2. Large signal negative conductance and the available power versus oscillation amplitude for a single tunnel diode.

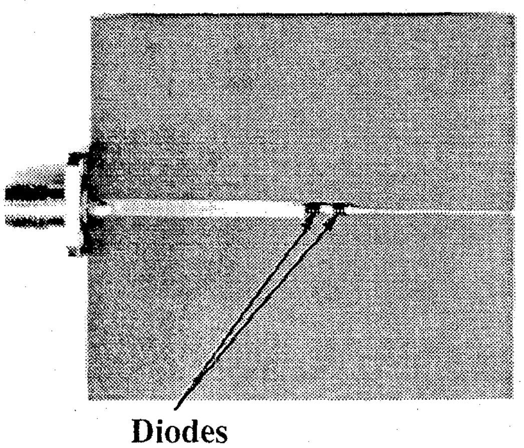

Fig. 3. Oscillator circuit with two tunnel diodes in series.

for which the maximum available power is predicted. For oscillation amplitude 0.140 V, the available power is 16.19 μW, which gives 13.30 μW or -18.76 dBm of output power after ohmic losses are accounted for. One- and two-diode oscillators were designed in the same configuration for oscillation amplitude of 0.140 V, with a corresponding negative conductance of 1.7 mS per diode. A shorted stub was used to cancel the device reactance and a quarter-wave transformer to transform the large signal negative resistance into $-50\ \Omega$. Each circuit was about a half wavelength long at the oscillation frequency (Fig. 3).

III. Experimental Results

An HP 8350B sweep oscillator was used as an external RF source. The RF signal was applied to the oscillator circuit through a circulator. The oscillation signal was detected by an HP 8562A spectrum analyzer. The DC bias voltage was applied through a bias-T network, and the current through the device was monitored during the experiment. The total loss in the experimental setup was about 3 dB. A single diode oscillator was tested as a reference in the same setup, and

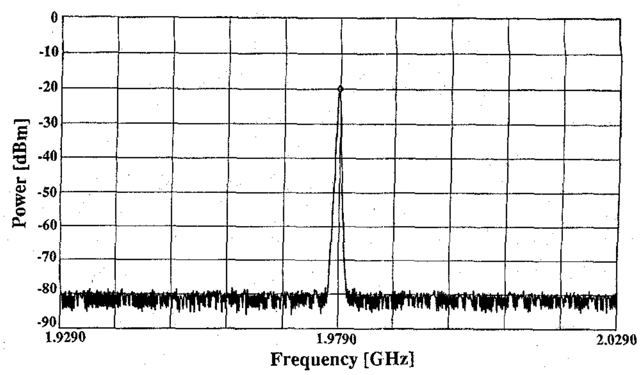

Fig. 4. Oscillation spectrum. Actual output power is 3 dB higher, due to the losses in the measurement setup.

it had output power -20 dBm, slightly lower than predicted -18.76 dBm, at 2.1 GHz.

A DC voltage sufficient to have both diodes biased in the middle of the NDR region was applied to the two-diode oscillator. Due to the DC instability, one diode was initially biased on the first rising branch of the DC I-V curve, whereas the other diode was biased on the second rising branch. The RF signal was applied for several seconds. While the external RF signal was on, a significant change in current was observed, and the signal was clearly amplified. After turning the RF signal off, an oscillation was present. The output power was -18 dBm at 1.9790 GHz (Fig. 4), 2 dB higher than for a single-diode oscillator. Due to the diode package, there is a phase shift between the diodes, which degrades output power, and hence a full 3-dB increase in power cannot be achieved. It is expected that this problem would be resolved in the series integrated device, where the distance between the diodes would be negligible. Minimum RF power for which excitation was observed was -33 dBm, which is 15 dB lower than the oscillator output power. In [4], minimum excitation power for RTD devices at 90 GHz was reported to be 3 dB higher than the oscillator output power. However, a comprehensive investigation of the minimum excitation power was not carried out in [4]. Discrepancy between predicted and observed minimum excitation power may be due to the different device (shape of the DC I-V curve), and oscillator configuration used in the experiment. Excitation with -33 dBm power was possible in the frequency range 1.964 to 1.990 GHz, for a DC bias voltage between 0.25 and 0.38 V. With -13 dBm, excitation was observed from 1.940 to 2.019 GHz. The rectified I-V curves for one- and two-diode oscillators are very similar, with the voltage twice as large for the two-diode oscillator. This confirms that two diodes are oscillating simultaneously.

IV. Conclusion

The RF source excitation of an oscillator with two-tunnel diodes in series was demonstrated experimentally at 2 GHz. The output power was close to the predicted value, with two diodes producing 2 dB higher power than one diode. The power required for excitation was about 15 dB lower than the oscillator output power. The external RF signal was only applied for a couple of seconds. The turn-off time of the RF signal is not critical, because the circuit is only switching from the amplifier to the oscillator mode. This kind of excitation is easy to implement experimentally. An extension to more diodes in series is straight forward, with the required RF power increased with the number of diodes. A similar behavior is expected from RTD's connected in series. A device that has a heating problem, such as a pulsed IMPATT, or a low power device such as single RTD, may be used for excitation.

ACKNOWLEDGMENT

This letter was guest-edited by Dr. Steve Maas of Nonlinear Technologies, Inc. We would like to thank Prof. M. Rodwell of the University of California at Santa Barbara for helpful discussions.

REFERENCES

[1] E. R. Brown, J. R. Soderstrom, C. D. Parker, L. J. Mahoney, K. M. Molvar, and T. C. McGill, "Oscillations up to 712 GHz in InAs/AlSb resonant-tunneling-diodes," *Appl. Phys. Lett.*, vol. 58, pp. 2291–2293, May 1991.

[2] C. C. Yang and D. S. Pan, "Theoretical investigations of a proposed series integration of resonant tunneling diodes for millimeter-wave power generation," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 434–441, Mar. 1992.

[3] Y. I. Vorontsov and I. V. Polyakov, "Study of oscillatory processes in circuits with several series-connected tunnel diodes," *Radio Eng. Electron. Phys.*, vol. 10, pp. 758–763, May 1965.

[4] C. C. Yang and D. S. Pan, "A theoretical study of an integrated quantum-well resonant tunneling oscillator initiated by an IMPATT diode," accepted for publication in *IEEE Trans. Microwave Theory Tech.*

[5] O. Boric-Lubecke, D. S. Pan, and T. Itoh, "Large signal quantum-well oscillator design," in *Proc. 23rd European Microwave Conf.*, Madrid, Spain, Sept. 1993, pp. 817–818.