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High Tuning-Range VCO Using a Gated Tunnel Diode

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1. Introduction

The resonant tunneling diode (RTD) has been investigated in many high frequency applications, including 712 GHz oscillators [1], voltage controlled oscillators (VCOs) with low power consumption [2], high output power oscillators [3], and also analog-to-digital converters [4]. We report on a VCO with 30 percent tuning range, using a gated tunnel diode in an oscillator tank circuit. The main feature of the VCO is the isolation between input and output that is provided by the GaAs gated tunnel diode (GTD). The GTD is a two port RTD device with tuneable capacitances and high transconductance [5, 6]. The separate gate terminal allows for new circuit design and implementations. The oscillator is a tank circuit with the GTD in parallel with a short circuited coplanar waveguide (CPW) acting as an inductor.

2. Fabrication and circuit layout

The GTD is a 2x10 μm^2 double barrier resonant tunneling diode grown on a Semi-Insulating GaAs substrate. The diode consists of AlGaAs/GaAs/InGaAs/GaAs/AlGaAs (1.7/1/2/1/1.7 nm) double barriers, which offers a current density of 70 kA/cm^2. The diode was grown by molecular-beam epitaxi. In the direct vicinity of the diode, an array of tungsten wires was overgrown with 700 nm GaAs by metallorganic vapor phase epitaxi technique. The period of the tungsten wires is 250 nm and the tungsten grating forms a Schottky contact to the GaAs, which makes it possible to control the conducting area of the tunnel diode and hence to modulate the tunneling current directly [7].

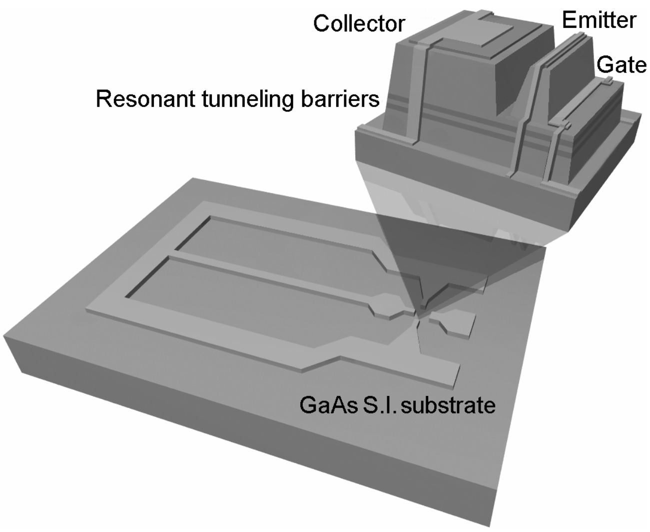

Fig. 1 Mesa etched gated tunnel diode on a Semi-Insulating GaAs substrate (upper right corner). The tank circuit is a gold structure on the substrate implemented as a coplanar waveguide.

The GTD is formed in a mesa structure, Fig. 1. The alloyed ohmic contacts were fabricated with Ge/Au/Ni/Au. The complete circuit design is shown in Fig. 1, including the GTD, the tank circuit, and the RF probe pads for contacting the circuit. CPWs have been designed with different lengths and spacing between signal and ground, and experiments show that the corresponding resonance frequency is altered by the CPW design. The DC path through the CPW warrants a stabilization network for the oscillator. Since the negative differential resistance of the GTD exists from DC to frequencies well above the circuit resonance frequency, it is critical to suppress spurious oscillations.

3. Characterization

Measurements where carried out with Infinity probes from Cascade Microtech and a spectrum analyzer FSU50 from Rohde and Schwarz. The bias voltage for the GTD was supplied by a bias-Tee as described in Fig. 2, together with the circuit configuration of the VCO. The waveguide can be represented by an inductance with a series resistance and a parallel capacitance. This capacitance includes the contribution of the RF probe pad. In this configuration, the oscillator drives the 50 Ω spectrum analyzer input without any buffer.

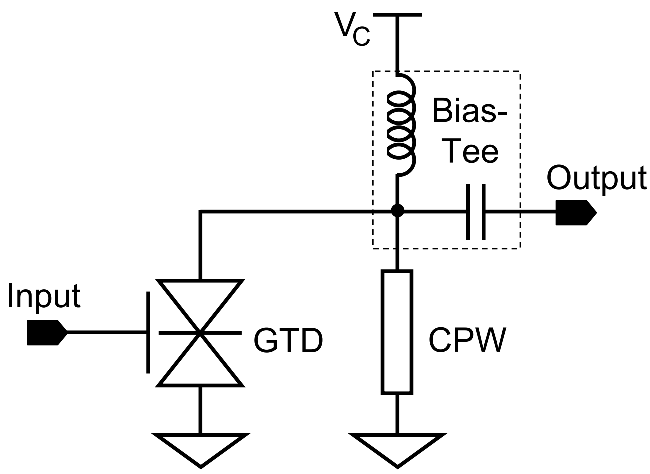

Fig. 2 Voltage controlled oscillator with GTD in parallel with a coplanar waveguide. A bias-Tee is connected to the output in order to isolate the spectrum analyzer from the collector DC bias.

We used a voltage source to bias the collector of the GTD in the negative differential region and then by applying a DC voltage to the input node (gate), the oscillator was tuned over a wide range. The tunneling current through the GTD was about 6 mA at V_G=0 V, depending on the exact bias in the NDR region. The applied collector bias was V_C= 2.4 V which is substantially higher than the peak voltage of the GTD (V_C= 0.5 V). This voltage difference is originating from a parasitic series resistance in combination with the direct current path in the CPW. The current through the input node was measured to a maximum absolute value of 180 μA, which demonstrates a good isolation between the input and output. Fig. 3 shows the measured frequency spectrum of the oscillator (V_G=0 V), where the main peak at 23 GHz corresponds to the ground frequency of the oscillator. In particular, we note a large spur free dynamic range of 53.9 dBc around the main resonance.

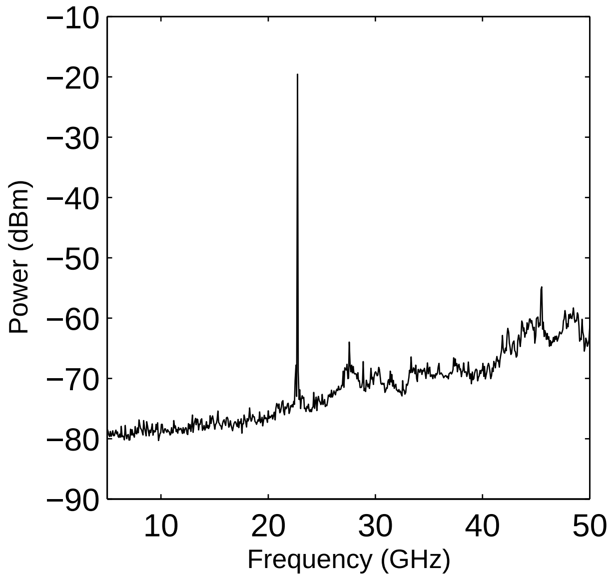

Fig. 3 Room temperature frequency spectrum of a voltage controlled oscillator driving a 50 Ω spectrum analyzer. The DC bias conditions are V_C=2.4 V and V_G=0 V.

Next we applied a DC bias to the gate and studied the oscillator tuning range for different voltages on the gate, Fig. 4. Measurements where made in both positive and negative direction in order to see any hysteresis in the frequency behaviour. We observed a total frequency modulation of about 7 GHz as the gate was changed from -1.91 V to 0.27 V in this VCO, which corresponds to a 30 % modulation. The output power remained fairly constant about -20 dBm over a wide range with a larger drop in the forward bias direction. The VCO measurements were confirmed by measuring on several circuits with the same CPW design, as well as for different designs. The identical circuits showed a good reproducibility, while VCOs with different CPWs showed a systematic change in oscillation frequency as expected. Table I shows the influence of the configuration of the CPW on the tuning range as well as fir the centre frequency of the VCO.

Table I VCO dependence on CPW configuration

Configuration Length/space/width (μm)	Tuning range (GHz)	Centre frequency (GHz)
174/118/8	5.5	15.8
270/107/30	5.5	18.8
174/107/30	7	23

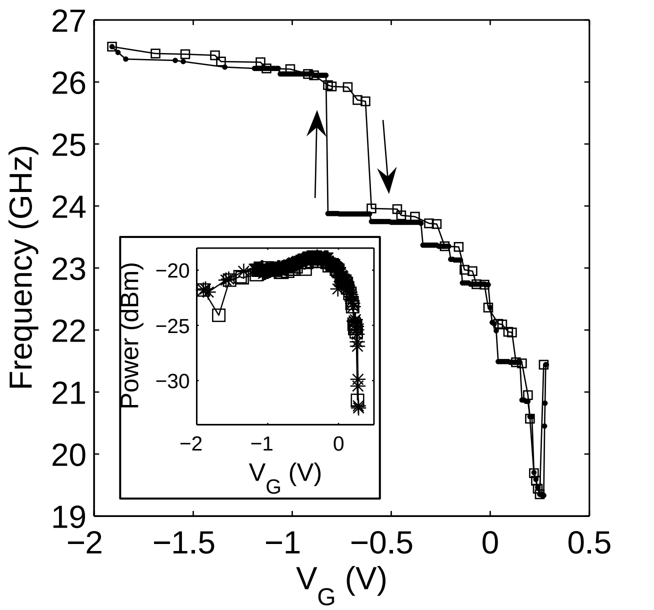

Fig. 4 Frequency dependence of the VCO, measured in both negative and positive direction. Figure also contains the output power.

4. Conclusions

We report on the experimental realization and the performance of a VCO consisting only of a gated tunnel diode and a coplanar waveguide. The VCO covers a tuning range of 7 GHz with a centre frequency at 23 GHz, thereby a 30% frequency modulation is performed by a single VCO circuit. The output power is steady over a wide range around -20 dBm. The result is consistent for several circuits with diverse waveguides.

Acknowledgements

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