

# Monolithic RTD Array Oscillators at 100 GHz and 200 GHz with On-Wafer Bias Stabilization

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We report 100 GHz and 200 GHz monolithic slot antenna coupled RTD array oscillators. The IC process for the array oscillators incorporates  $0.1\mu\text{m}$  InGaAs/AlAs Schottky-collector RTDs (SRTDs) vertically integrated above AlInGaAs Schottky-diode stabilizers which suppress parasitic oscillations in the DC bias circuit. A quasi-optical transmitter/receiver set up using the RTD oscillator as transmitter and a Schottky-diode mixer as receiver is employed for testing these oscillators. Designs above 200 GHz have shown signals on a bolometer and frequency measurements of these are currently in progress.

712 GHz wave guide RTD oscillators have been demonstrated [1]. Power levels however are low due to constraints imposed on device area for suppressing parasitic bias circuit oscillations and also due to the difficulty in integrating several discrete waveguide oscillators for power combining. Higher power levels can be obtained with monolithic RTD arrays in which parasitic oscillations in the bias circuit are suppressed by on-wafer bias stabilizers [2]. The monolithic RTD oscillator [Fig.1] consists of a low impedance Schottky-diode bias stabilizer located  $\lambda_{osc}/4$  from the SRTD. The shunt combination of SRTD and the Schottky-diode has no net negative differential resistance in its DC characteristics [Fig.4]. At the design frequency of oscillation  $f_{osc}$ , the low impedance Schottky-diode bias stabilizer is decoupled from the SRTD and the SRTD admittance is now shunted only by the slot antenna admittance. The layer structure [Fig.2] consists of a graded bandgap AlInGaAs Schottky-diode layers grown beneath the SRTD layers. The SRTDs have  $0.1\mu\text{m}$  Schottky-collectors,  $350\text{ \AA}$  space-charge layers, peak current density of  $5 \times 10^5\text{ A/cm}^2$ , and have an estimated  $f_{max}$  of  $\approx 2.2\text{ THz}$  [3]. Array fabrication demands an aggressive 8 mask IC process for monolithic integration of the SRTDs, the Schottky-diode bias stabilizers, SiN MIM capacitors, resistors and airbridges [Fig.3].

SRTD oscillators were tested with a quasi-optical transmitter/receiver set up [Fig.5]. The receiver is a broad band bowtie-antenna-coupled  $0.1\mu\text{m} \times 0.5\mu\text{m} \times 150\text{ \AA}$  Schottky-diode operated as a harmonic mixer with a 48 – 60 GHz LO for downconverting the RF oscillations to a 2 – 12 GHz span of the spectrum analyzer. Signals were detected at 100 GHz and 200 GHz [Fig.6]. The Si lens on which the oscillator array is placed forms the array's external resonant cavity, determining the oscillation frequency and the oscillator Q. The oscillation frequency was determined by shifting the LO frequency and observing the magnitude and sign of the frequency shift of the IF spectrum. The 100 GHz,  $2 \times 1$  array oscillated at 108.92 GHz with  $-34\text{ dBm}$  IF output power while the 200 GHz,  $2 \times 1$  array oscillated at 196.4 GHz with  $-44\text{ dBm}$  IF output power. The 100 GHz,  $4 \times 4$  array showed oscillations at 94.46 GHz ( $-28\text{ dBm}$ ) and at 107.48 GHz ( $-41\text{ dBm}$ ) which correspond to two cavity resonant frequencies (95% of oscillator output power in dominant mode). The measured IF power level which includes coupling losses in the quasi optical set up, conversion loss of the mixer and the preamplifier gain is roughly  $-20$  to  $-30\text{ dB}$  below the oscillator output power. The resulting  $100\mu\text{W}$  to  $1\text{mW}$  estimated oscillator output power must be verified using a calibrated bolometer. Extensive testing of higher frequency oscillators using a bolometer and a Fabry-Perot interferometer are currently in progress.

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[1] E.R. Brown et al., Appl. Phys. Lett., vol. 58, no. 20, 1991.

[2] M. Reddy et al., IEEE Microwave and Guided Lett., vol. 5, no. 7, 1995.

[3] M. Reddy et al., J. Appl. Phys., vol. 77, no. 9, 1995.

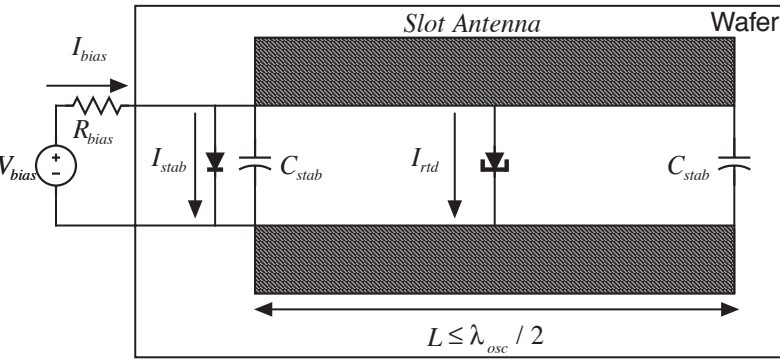


Fig.1: Circuit schematic for slot antenna coupled SRTD oscillator with on-wafer Schottky-diode bias stabilizer

SRTD Space-charge Region and Double Barrier Structure 420Å	SRTD
SRTD LT Spacer 100Å	
SRTD Emitter N=1·10 <sup>19</sup> /cm <sup>3</sup> , 500Å	
SRTD Buried N++ layer N=5·10 <sup>19</sup> /cm <sup>3</sup> , 5000Å	Selective Etch
Al <sub>0.48</sub> In <sub>0.52</sub> As Undoped, 1000Å	
Undoped In <sub>0.53</sub> Ga <sub>0.47</sub> As, 100Å	Schottky-Diode
Al <sub>0.48</sub> In <sub>0.52</sub> As (TOP) Undoped, 900Å	
In <sub>0.53</sub> Ga <sub>0.47</sub> As (BOTTOM)	
Diode Emitter N=1·10 <sup>19</sup> /cm <sup>3</sup> , 500Å	
Diode Buried N++ layer N=5·10 <sup>19</sup> /cm <sup>3</sup> , 5000Å	
Semi-insulating InP	
Substrate	

Fig.2: MBE layer structure for fabricating SRTD oscillator arrays with on-wafer Schottky-diode bias stabilizer

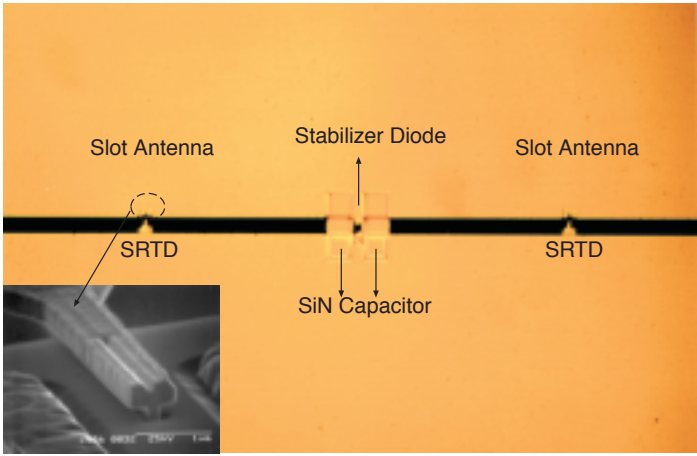


Fig.3: Photograph of a section of a fabricated IC in a 8 mask layer process including e-beam lithography (also shown is a SEM micrograph of airbridge 0.1x1.0 μm² SRTD)

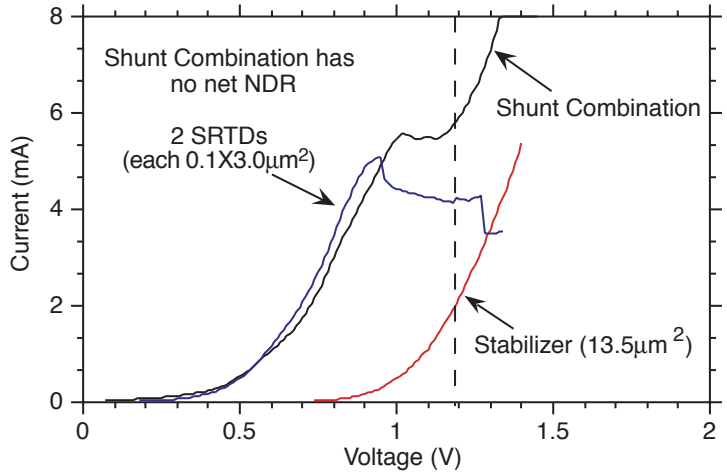


Fig.4: DC characteristics of SRTDs, on-wafer Schottky-diode bias stabilizer, and their shunt combination showing no net NDR characteristics, thereby eliminating DC bistability

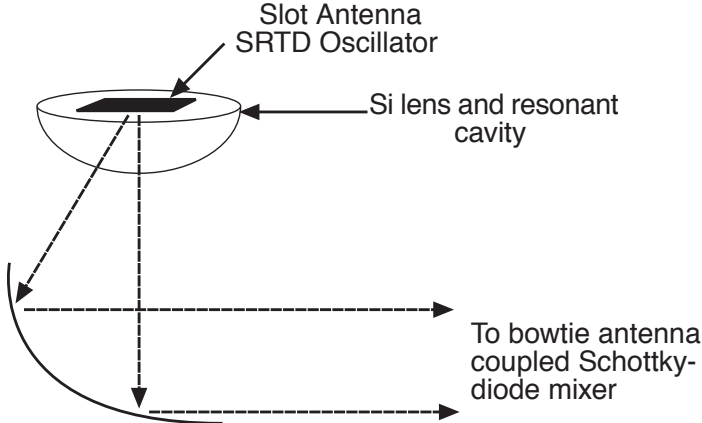


Fig.5: Set up for testing quasi-optical slot antenna SRTD oscillator array

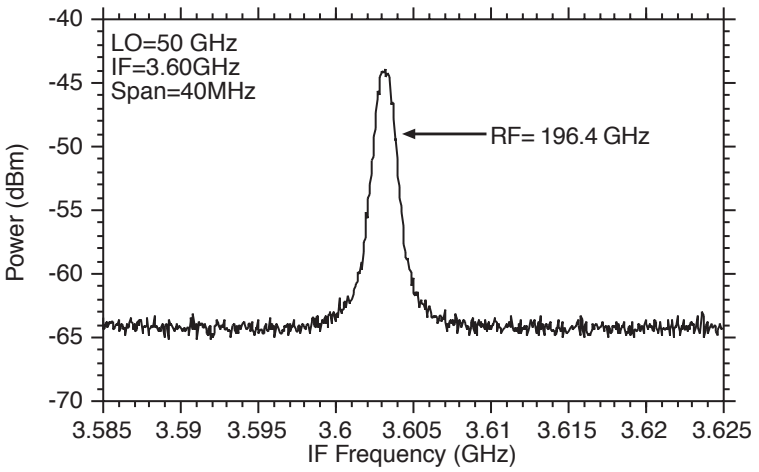


Fig.6: Observed IF spectrum of a 200 GHz, 2x1 SRTD oscillator array after downconverting with 4th harmonic of 50 GHz