Design and varactors:
operational considerations

A reliability study

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for robust planar GaAs
Measurements

▪ RF Input Power Burn-out Tests
  - Tests done:
    • 200mW @ 99.1GHz input with 200GHz doubler at ambient, > 2000 hours
    • 35mW input on two 400GHz doublers, 40.5 hours and 170 hours
    • 200GHz doubler at 400K and 450K with RF applied > 170mW

▪ Reverse DC Bias Current Stress Test
  - Tests done:
    • 800GHz diodes on test structure at -1µA, -5µA, -10µA at different ambient temperatures (77K, 295K, 395K)

▪ Safe Bias Range with RF input-power (10mW – 200mW)
  - Test done:
    • 200GHz doubler and 400GHz doubler

▪ Live-time measurement
  - Elevated ambient temperatures

▪ Additional measurements to determine safe bias range
  - DC Burn-out under reverse bias
  - DC Burn-out under forward bias
  - RF burn-out under high forward current
x2x2x3 Frequency chain

38mm height

Band 5
Base plate

45mm

1200 GHz tripler
WR-5 dummy isolator
WR-10 Isolator

245mm

400 GHz doubler
200 GHz doubler
45 degree twist waveguide
Power amplifier
WR-10 Isolator

94-106GHz Frequency source

- Broadband balanced design 1127 - 1242 GHz (10%)
- Reduced loss in GaAs substrate due to 3 μm thin membrane
- Beam leads for mechanical support and ground contact
- Beam leads as RF probes in the input and output waveguides
- Nominal anode size 3.0 x 12.0 μm², variations +/- 20%, 2*10¹⁷ 1/cm² doping

- Broadband balanced design 369 - 424 GHz (14%)
- Two diodes in each branch, used for impedance matching and power handling
- Nominal anode size 1.5 x 4.3 μm², variations +/- 20%, frame, and stub, 1*10¹⁷ or 2*10¹⁷ 1/cm² doping

- Beamleads as RF probes
- Reduced waveguide height in input and output waveguides (impedance matching)
- No mechanical tuning element

Precision of machining better +/-2μm

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Measured I/V curve at 300K and 100K

3E17 doping

3E17 doping 1P5x10P3 area

Reverse bias

Forward bias

Bias voltage [V]

Bias current [mA]

Limited by destructive Avalanche effect

Range of operation

Limited by dissipated power

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Chip thermal model (conduction only)

Improvements:
- Thicker metalization (1.6 um)
- wider beam leads (60 um)
- shorter beam leads (10 um)
33mW input power per diode

(a) 300K block temperature  
(b) 120K block temperature

Braun 1*10^{17}/cm^3; orange 2*10^{17}/cm^3

- Small variation of voltage and current over 1127 to 1242 GHz
- doping 5*10^{17}/cm^3
- nominal anode size is 0.4umx0.9um
- Calculated breakdown voltage: U_{br}=-9.4V

400 GHz Doubler, 300 K, 50 mW

(a) 300K block temperature  
(b) 120K block temperature

Braun 1*10^{17}/cm^3; orange 2*10^{17}/cm^3; green 3*10^{17}/cm^3

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RF Input Power Burn-out Test Setup

Test setup
RF-source: 100GHz Gun-oscillator
Hot-Plate, DUT, Power Amplifier
RF Input Power Burn-out Test on a 200GHz doubler

Reverse bias voltage at -10μA vs. Time at ambient and elevated (400K) temperature

-20
-18
-16
-14
-12
-10
-8

Reverse Voltage [V]

6mA
3mA, 295K, 200mW
at -8.5V

3mA, 400K, 173mW

Time [hours]

Output Power [mW]

0 1000 2000 3000

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RF Input Power Burn-out Test on a 200GHz doubler

Tests performed on 200GHz device shown:

(1) RF input power variations
(2) Reverse currents < -20μA
(3) Forward currents > 6mA
(4) RF Burn-out over 2000h, 200mW, 99.1GHz, 295K

Results: (a) No observable change in RF output power, (b) Reverse voltage dips then stabilizes at lower voltage

(5) RF Burn-out over 100h, 173mW, 99.1GHz at 400K

Results: (a) No observable change in RF output power, (b) Reverse voltage stabilizes further

(6) Reverse Bias Current Stress Test

Results: (a) Bias voltage settled at higher value; Impact not understood (b) RF not checked

(7) DC Burn-out under forward bias

Result: Device shorted at a bias current > 30mA
Degradation in RF output power when I/V shows marked change only

400GHz SN004 10209952
Power Degradation due to ESD damage
Pin = 150 mW, T = 295K
RHL, July 23, 2002

- severely changed I/V curve
- approx. 10% reduced RF output power
- Unknown effect on long term stability
Degradation of Reverse Bias Voltage at constant Reverse Bias Current vs. Time at different temperatures

Reverse Voltage measured at >500 min at different:

a) ambient temperatures

b) reverse currents

- Fast exponential degradation of reverse Bias Voltage within first 200 minutes
  - Expected increase in degradation with increasing temperature not consistently observed (more tests needed)
- Asymptotic convergence to reverse Bias Voltage between -4V and -7V
  - Variation in behavior observed with devices from same batch
Establishing a Safe Bias Range at high RF power

Results

- No changes in I/V parameters after testing
- Determination of a safe bias range probably possible
- Further measurements necessary and planned especially on the 400GHz doubler

- 200GHz doubler with 3.0x9.6um² anodes (M20 type)
- variable input power @295K
- Test: Bias Voltage vs. RF Input Power
  - Measured: bias voltage at -5uA, 0A, 7mA, and optimized output power
    - -5uA average current (drives the diode close to reverse breakdown)
10mW applies 0.3V shift

Reverse limit

Probably safe range

Suggested safe range with margin

Establishing a Safe Bias Range with high RF power
Preliminary Conclusions

- Limits for reverse currents cannot be set.
  Based on current data we want to avoid any reverse bias current. We know 1μA is too high.
- Leakage current gets suppressed when operated at 120K.
- Migration and verification:
  - Reverse Bias Voltage will be limited
  - Health check with I/V curve
    - Minimal reverse voltage shall be x0.75 of the calculated breakdown voltage $V_{br}$
    - Degradation of the Reverse Bias voltage at given current will be used as indication of ESD incidents or other Damages (high RF power, heat)
    - Calculation of diodes parameter to verify initial health check result in forward direction
- RF output power starts to degrade when diode I/V curve is very strongly degraded only
  - Experienced on 400GHz doubler and 200GHz doubler