Reliability of cascaded THz frequency chains with planar GaAs circuits

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Presentation to the 15th International Symposium on Space THz Technology
April 27-29th, 2004

This Work has been made possible by the Jet Propulsion Laboratory, California Institute of Technology, under contract to the US National Air and Space Administration

Motivation

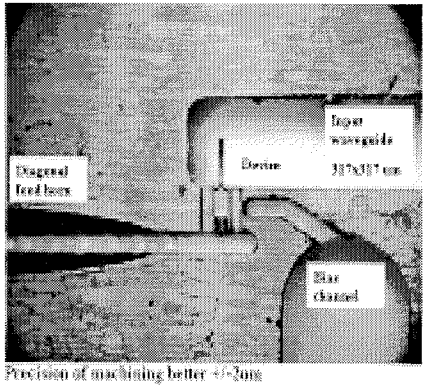
- A better understanding of device degradation mechanisms is desirable to reduce failure risks
- Environmental, Temperature and current induced failures are investigated, such as
  - ESD threshold
  - Temperature induced metal migration
  - DC currents during health check
  - RF induced currents

- Goal is to establish a procedure for determining the 'safe operating zone' for a given high power varactor diode

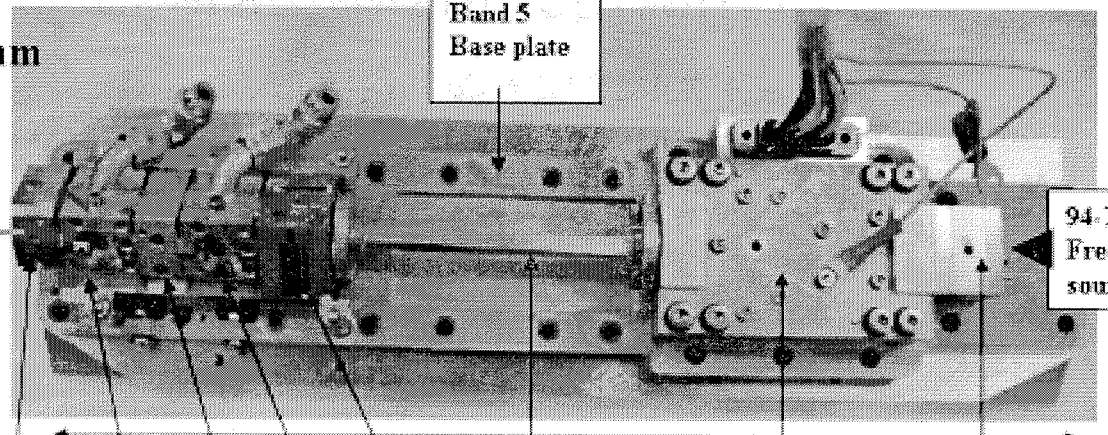
Motivation, x2x2x3 Frequency chain

38mm height

45mm



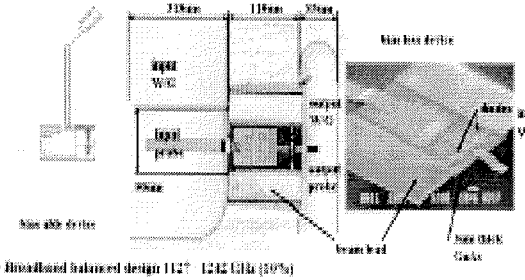
Precision of machining better +/-2um



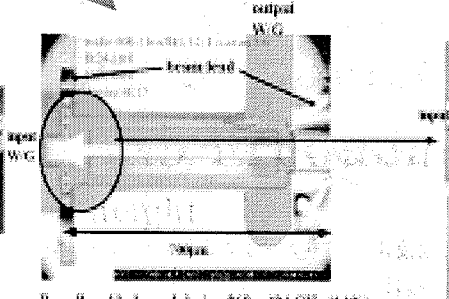
Reliability of:

1) GaAs Schottky diodes

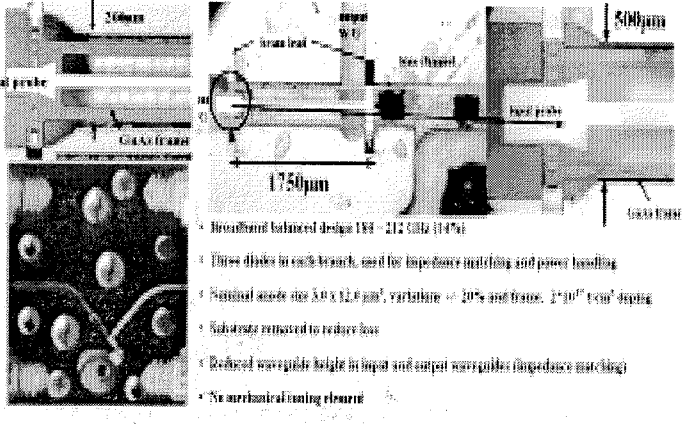
2) MMIC in PA



- 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 6.4 x 6.8µm², variations +/- 20%, 5*10¹⁷ 1/cm³ doping



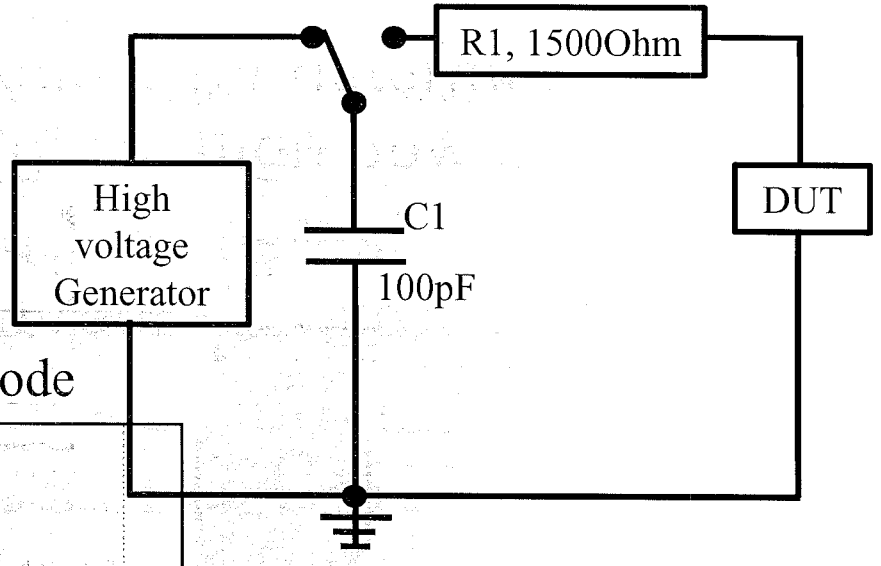
- Broadband balanced design 389 – 424 GHz (14%)
- Two diodes in each branch, used for impedance matching and power handling
- Nominal anode size 1.5 x 4.3 µm², variations +/- 20%, frame, and stub, 1*10¹⁷ or 2*10¹⁷ 1/cm³ doping



- Broadband balanced design 190 – 212 GHz (14%)
- Three diodes in each branch, used for impedance matching and power handling
- Nominal anode size 3.0 x 12.6 µm², variations +/- 20% and frame, 2*10¹⁷ 1/cm³ doping
- Substrate removed to reduce loss
- Reduced waveguide height in input and output waveguides (impedance matching)
- No mechanical tuning element

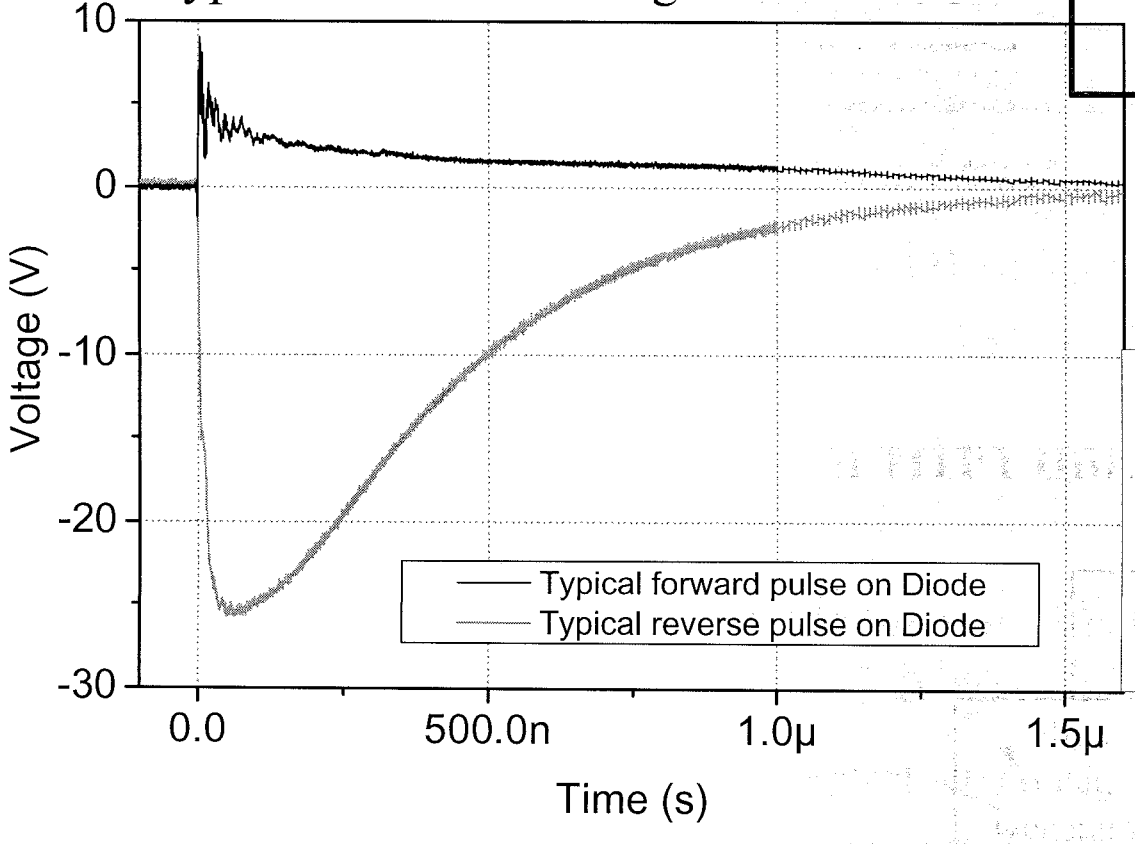
ESD limits on HIFI diodes

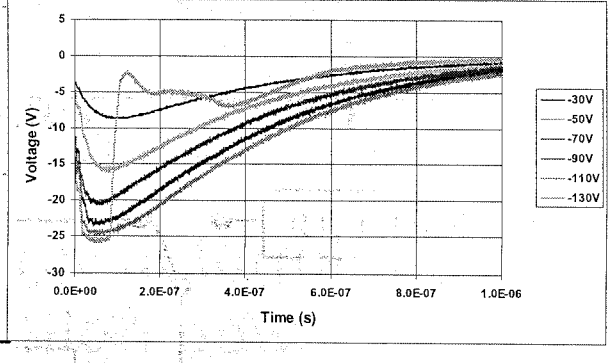
- **Human Body Model (HBM)**
  - **Variable voltage pulse**
    - **Rising time 25 nsec**
    - **Duration 250 nsec**



HBM simulator

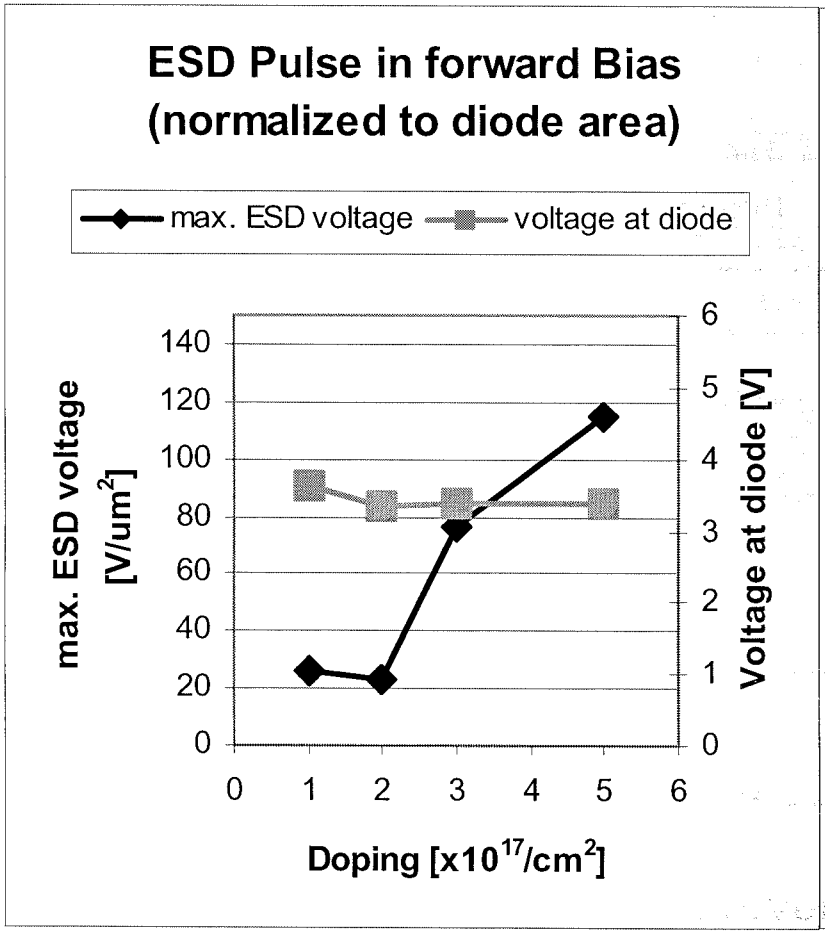
Typical measured voltage across a diode

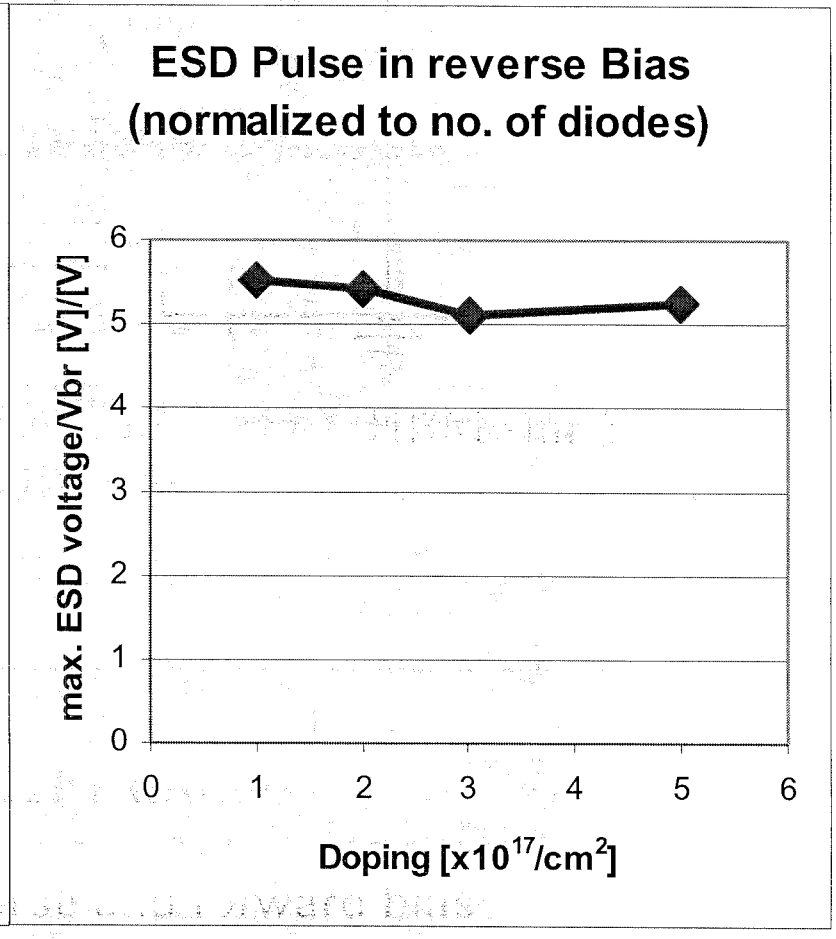




ESD limits on HIFI diodes

Measured ESD voltages in reverse and forward bias direction



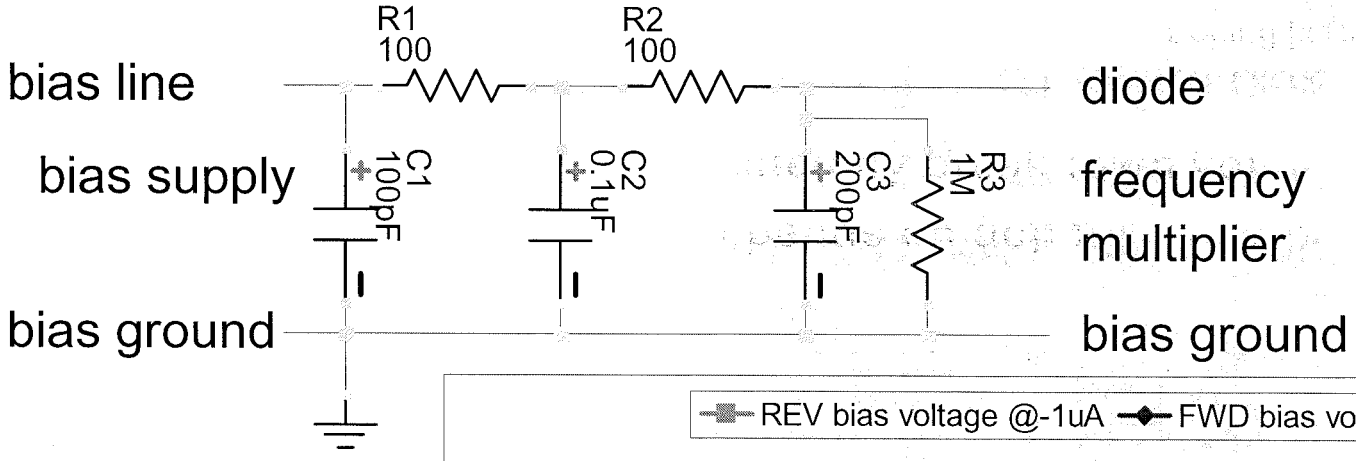


Reverse ESD voltage pulse limited by breakdown voltage Vbr

Forward ESD voltage pulse depends on doping, 3.2V per diode

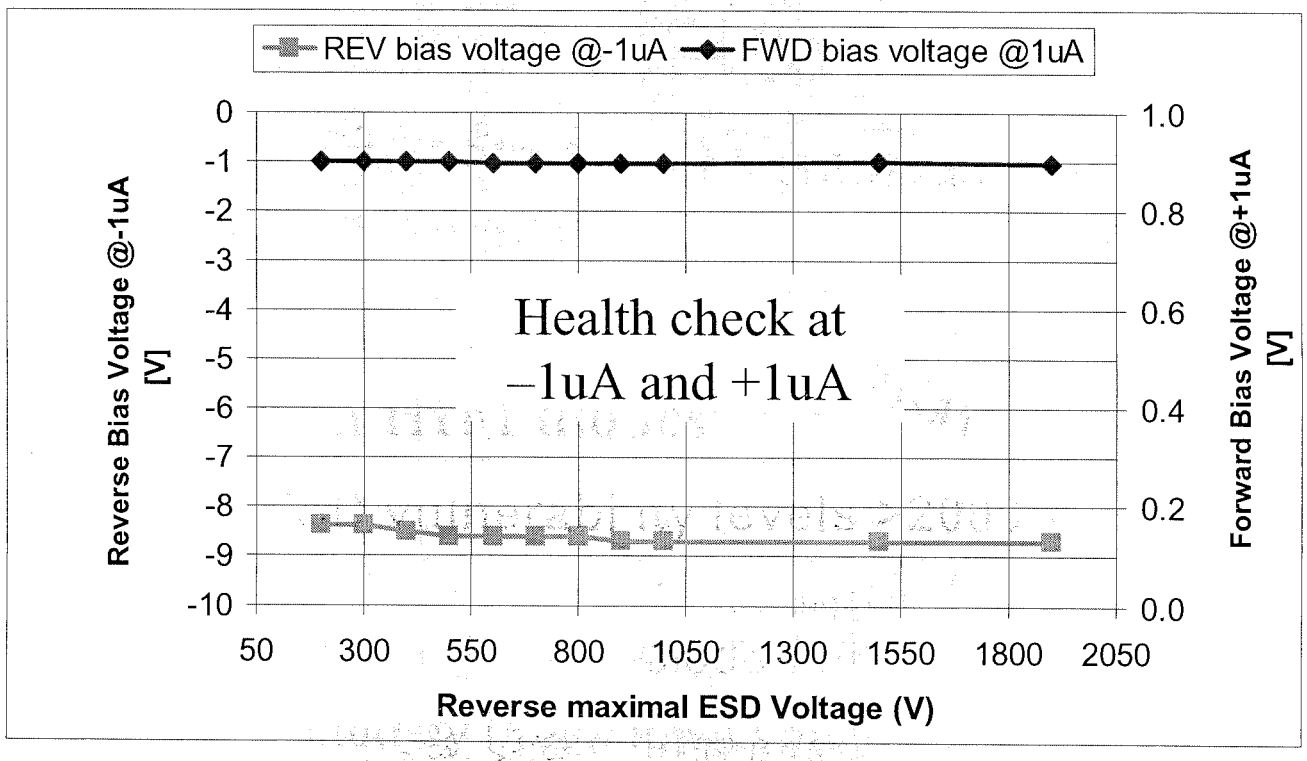
ESD limits on HIFI diodes

- **Filter circuit increases ESD vulnerability levels >2000 V**



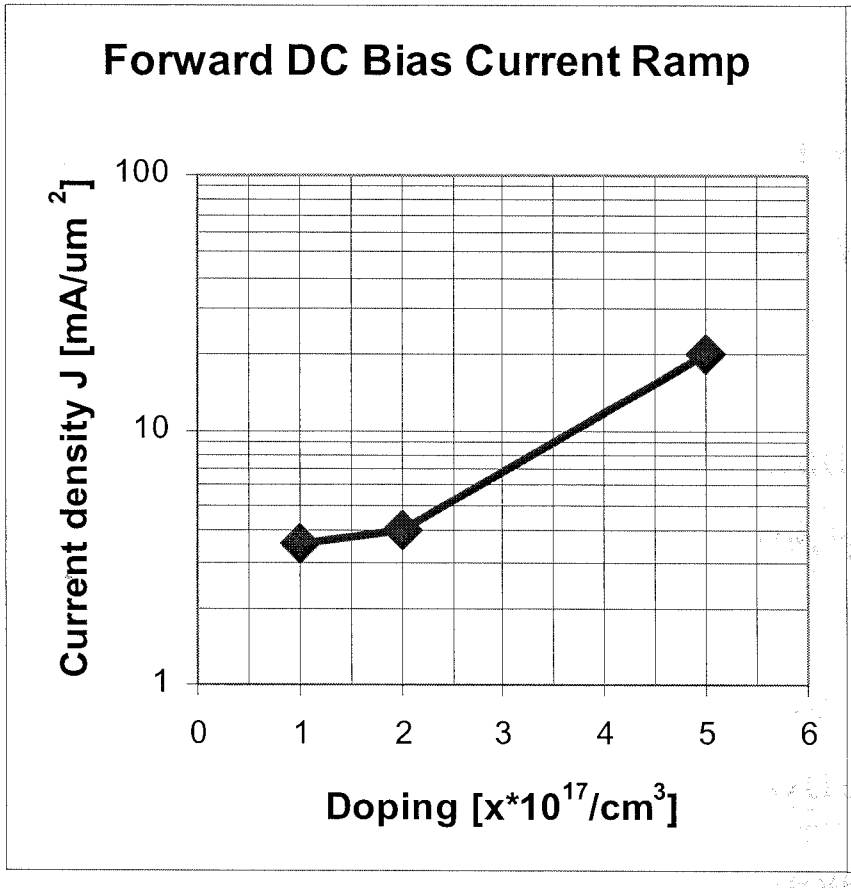
Filtering noise -3dB point at 30 kHz

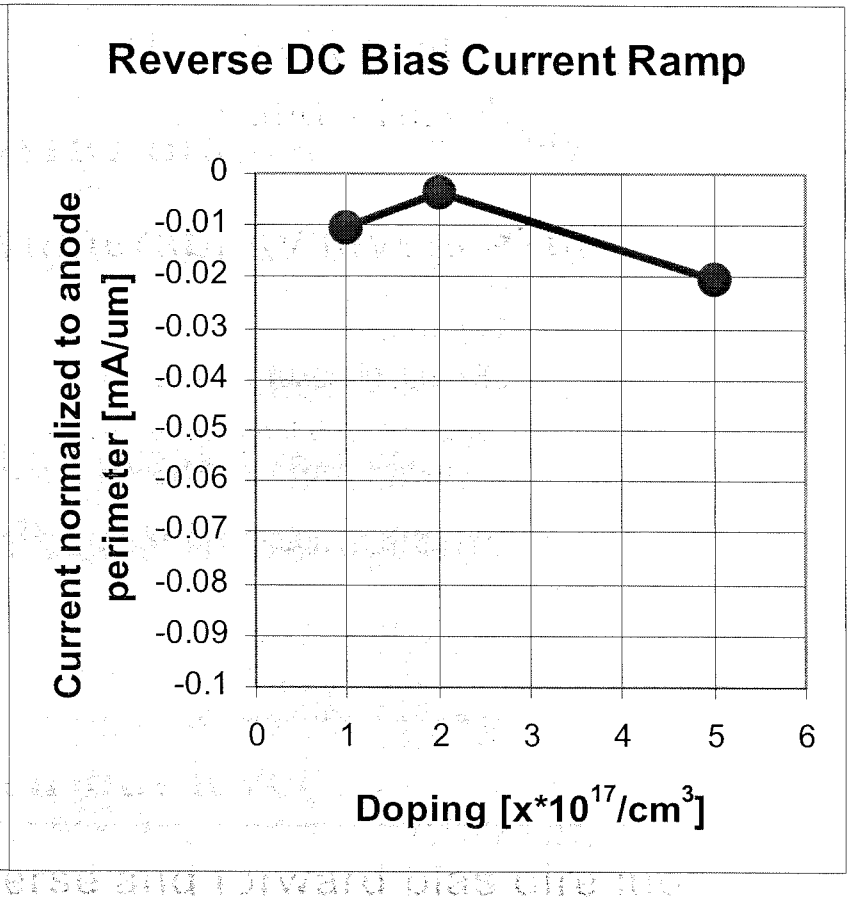
No change after thermal stress test 10x 300K - 77K LN_2



DC current burn-out level

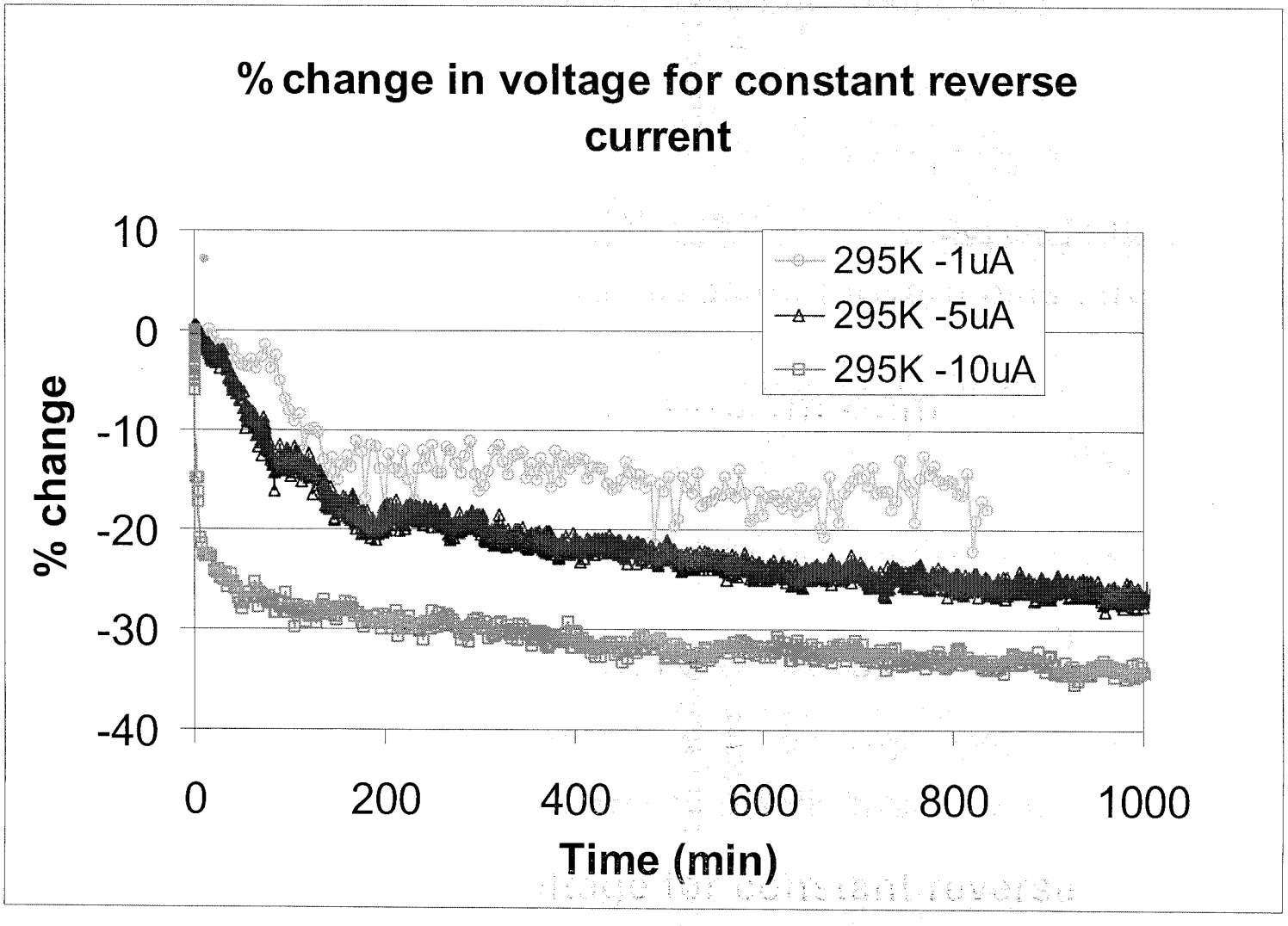
Measured current levels in reverse and forward bias direction



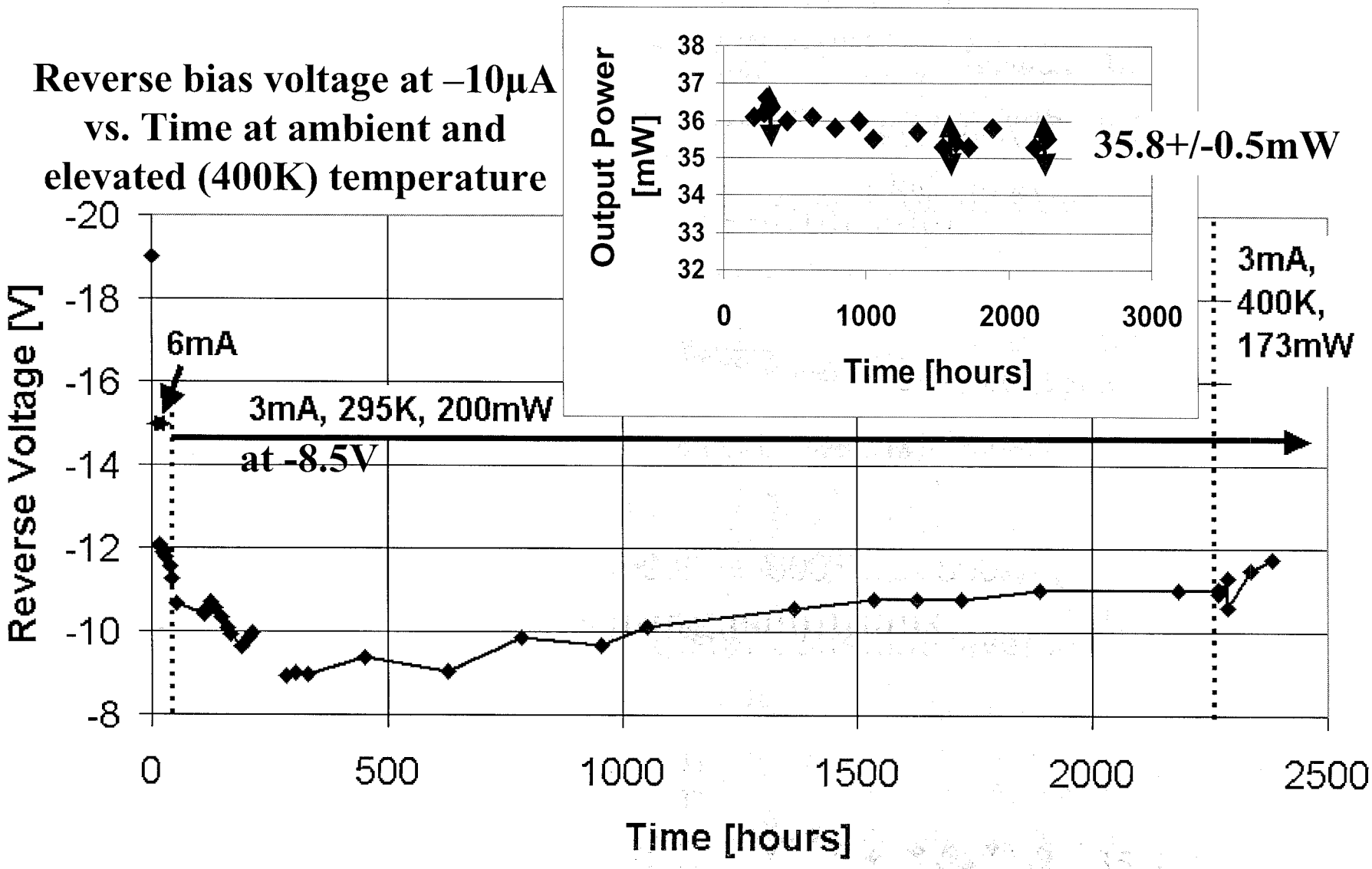


- Current limit in forward ~doping
- Normalized current in reverse <=-0.1mA/um

DC reverse current stress

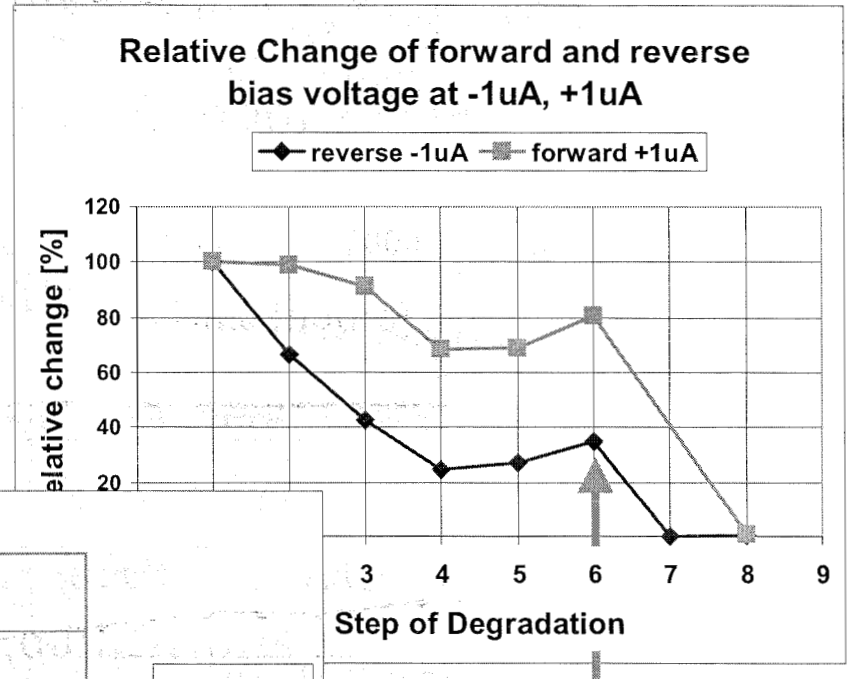


RF/DC operating conditions

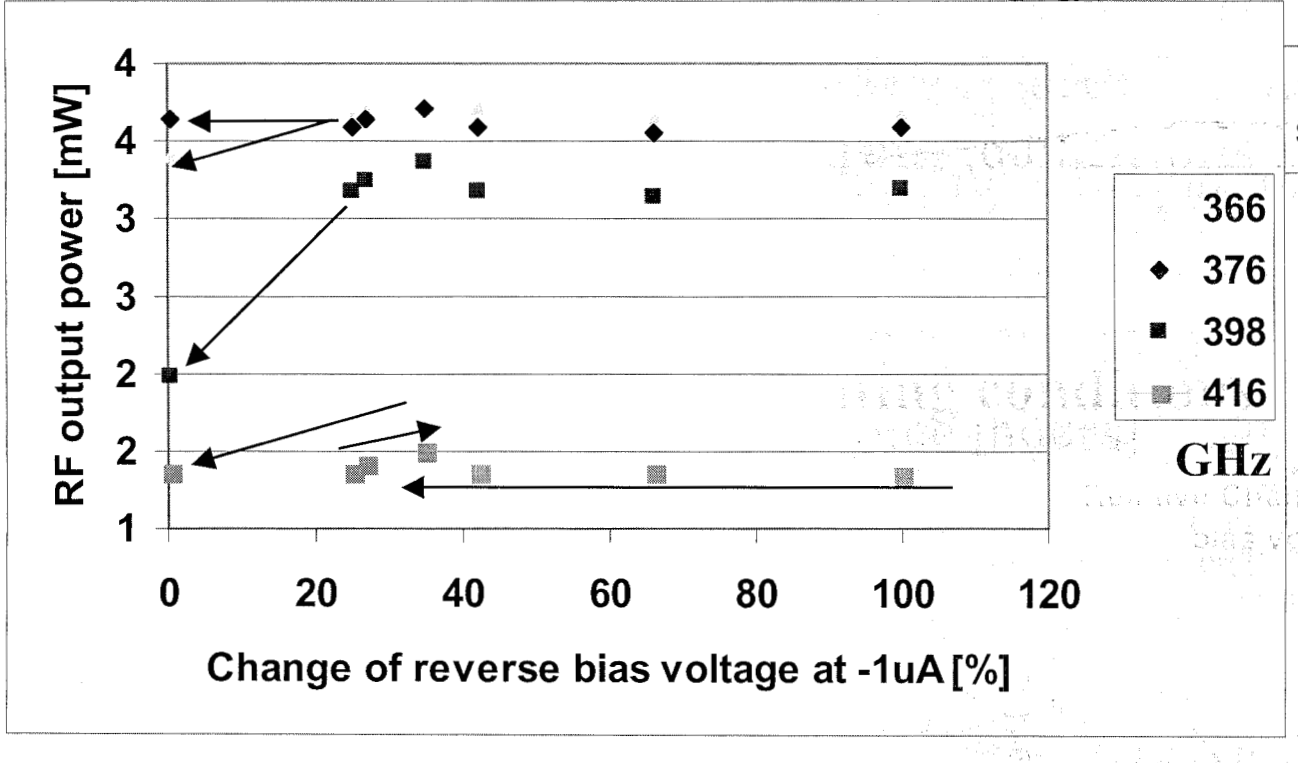


RF/DC operating conditions

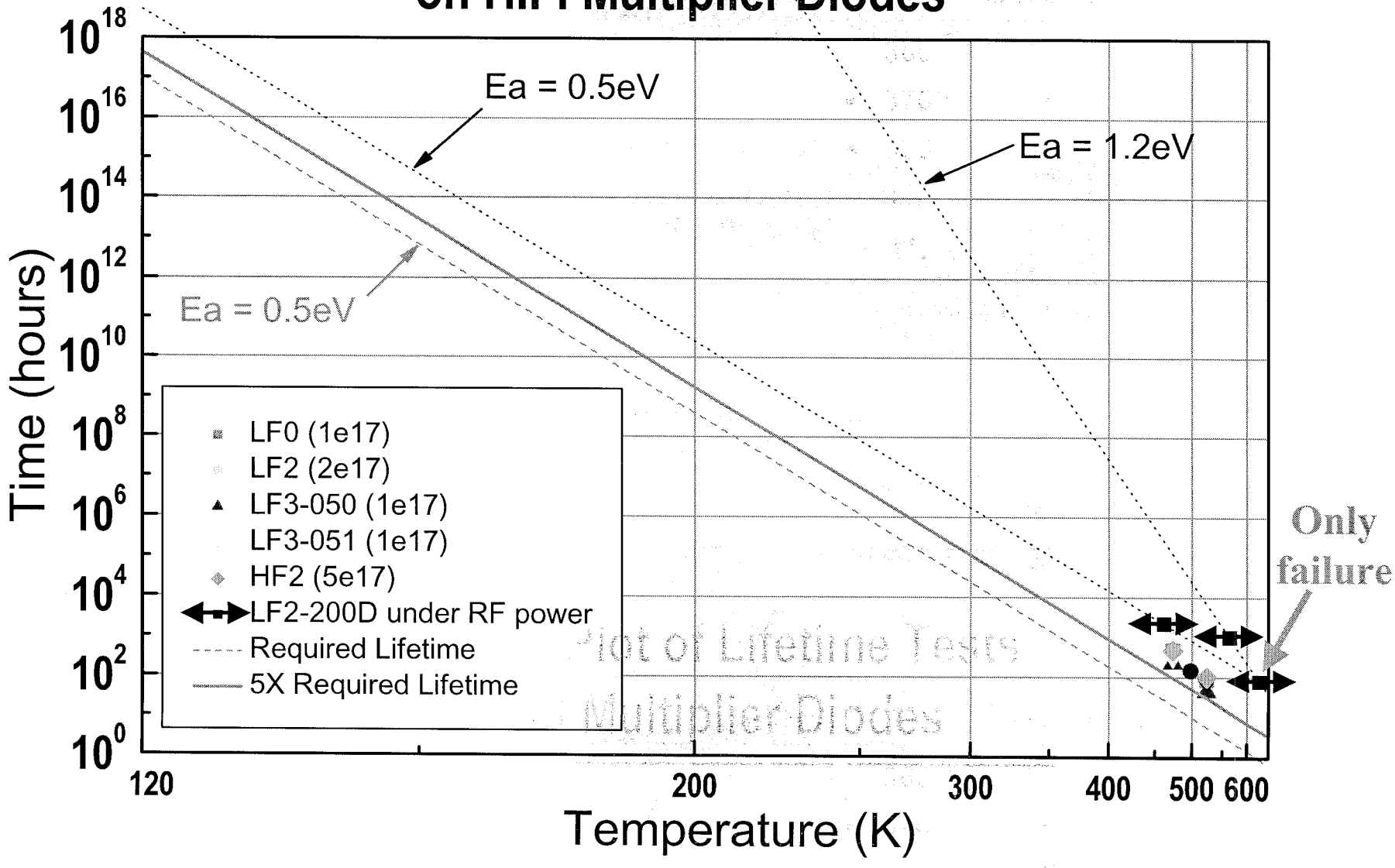
- Change of RF characteristic
- I/V curve severe damaged
- Reverse current not stable
- More interaction between 200/400GHz doubler (impedance)



ESD pulse –130V

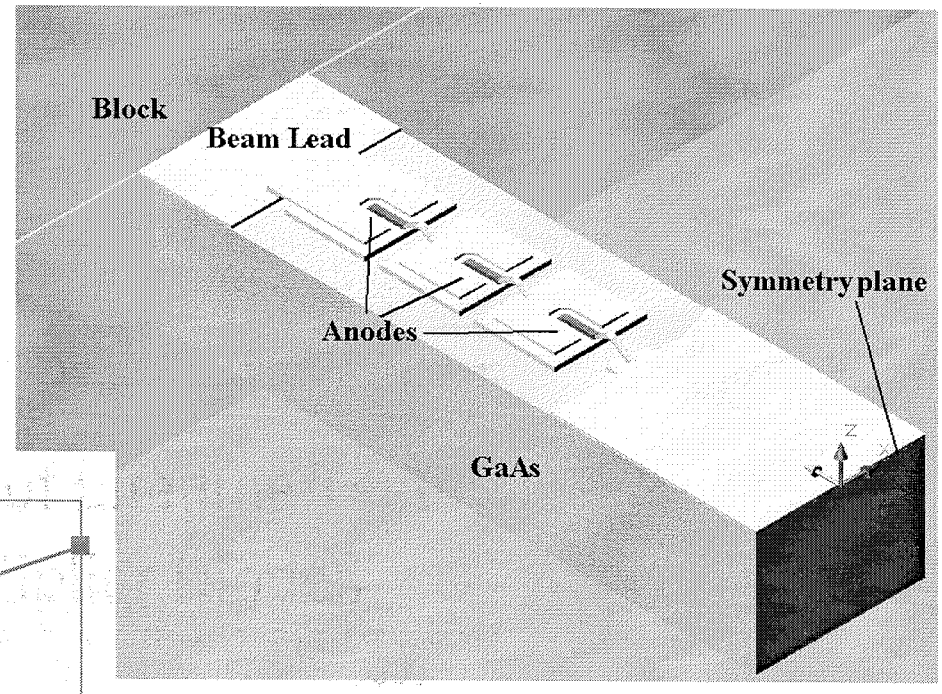


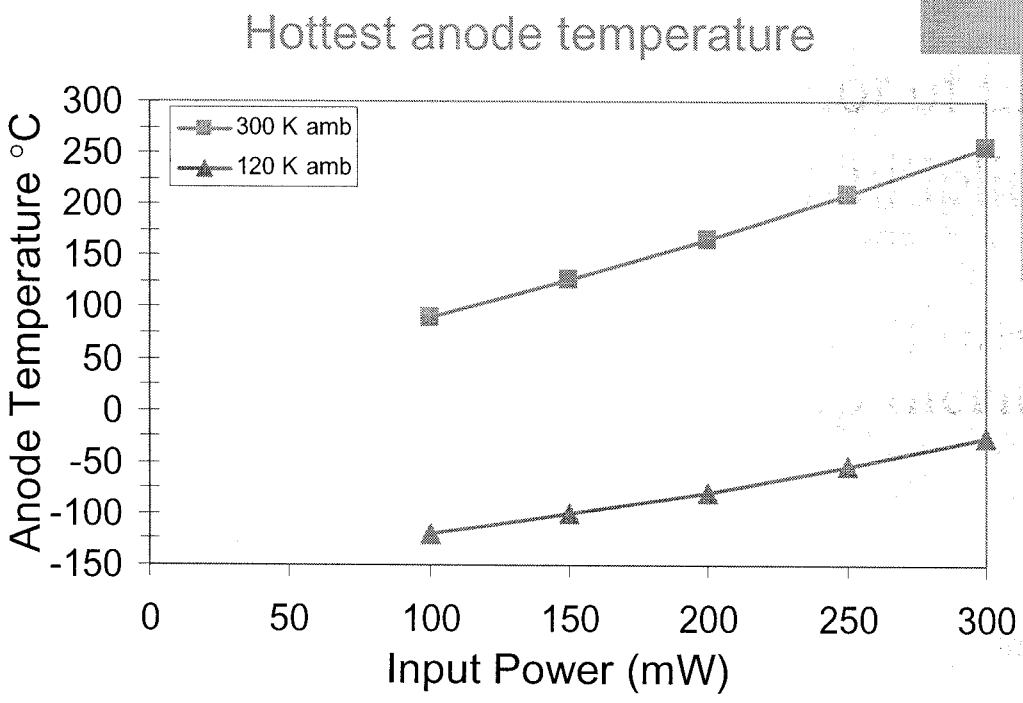
Arrhenius Plot of Lifetime Tests on HIFI Multiplier Diodes



GaAs Diode Chip thermal Model

$$T = T_{BLOCK} + R_{T1}P_{DISS} + R_{T2}P_{DISS}^2$$





Modeled system has:

1. No convection, heat escapes through beam leads only.
2. Temperature dependent GaAs thermal conductivity.
3. Assumes dissipated power is 75% of input power.

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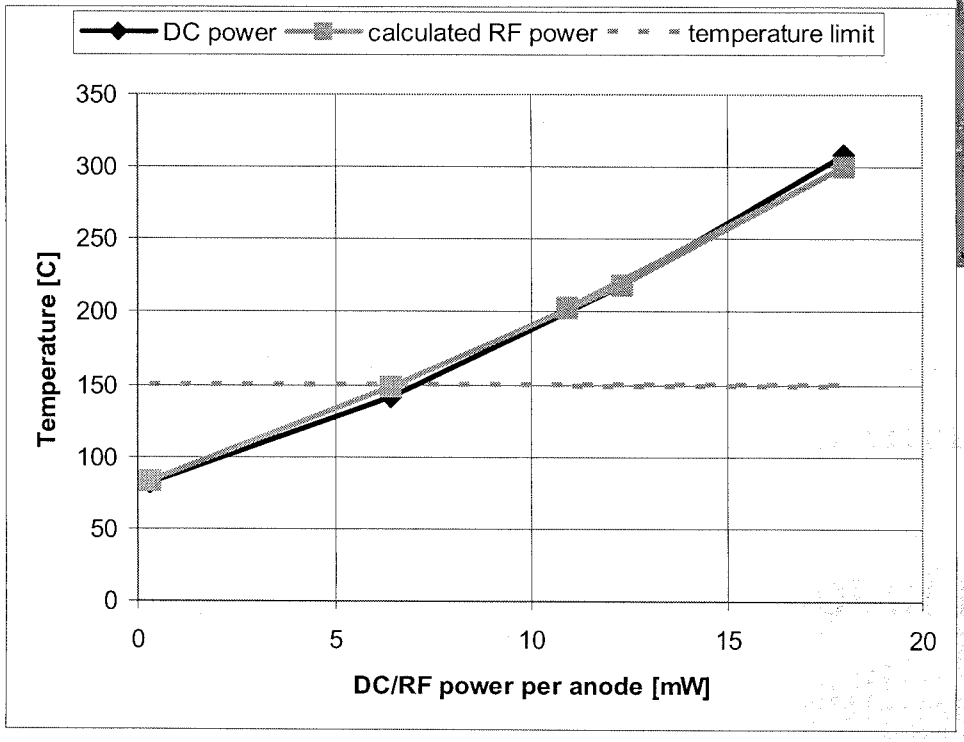

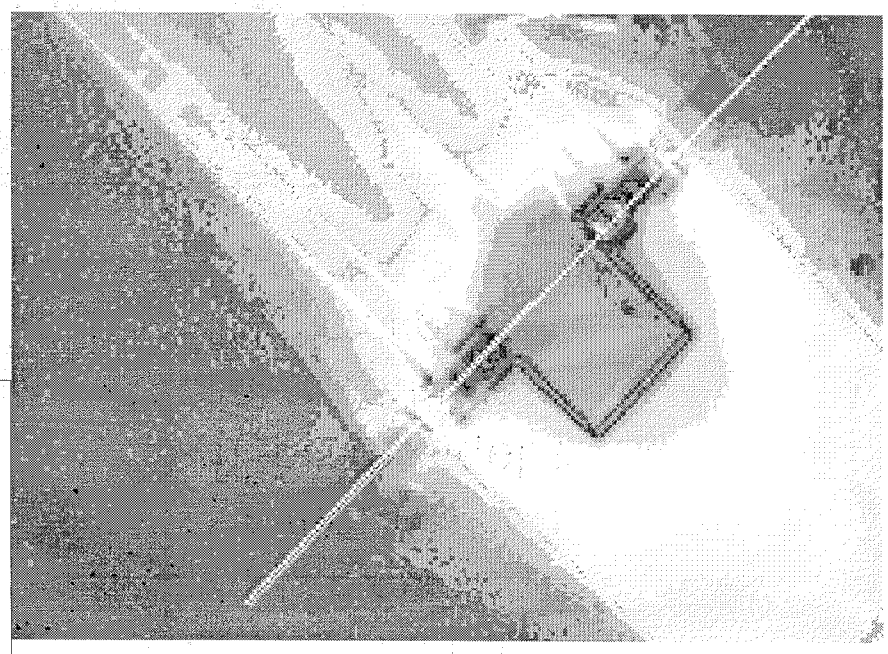

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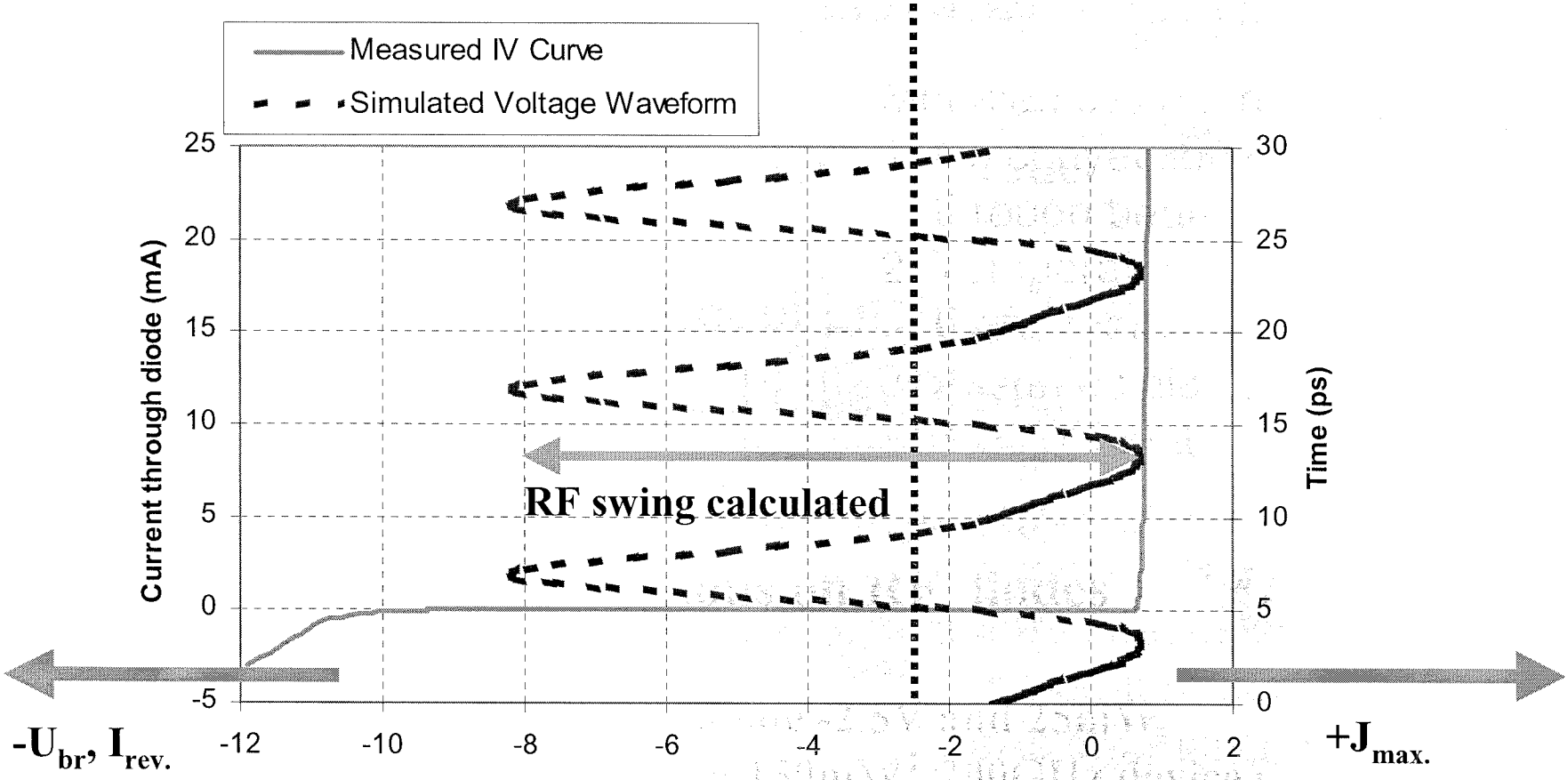
RF/DC limitations on RF diodes

Calculated waveform for a single diode -2.5V and 25mW

-7.5V and 150mW 200GHz device (2x3 anodes)



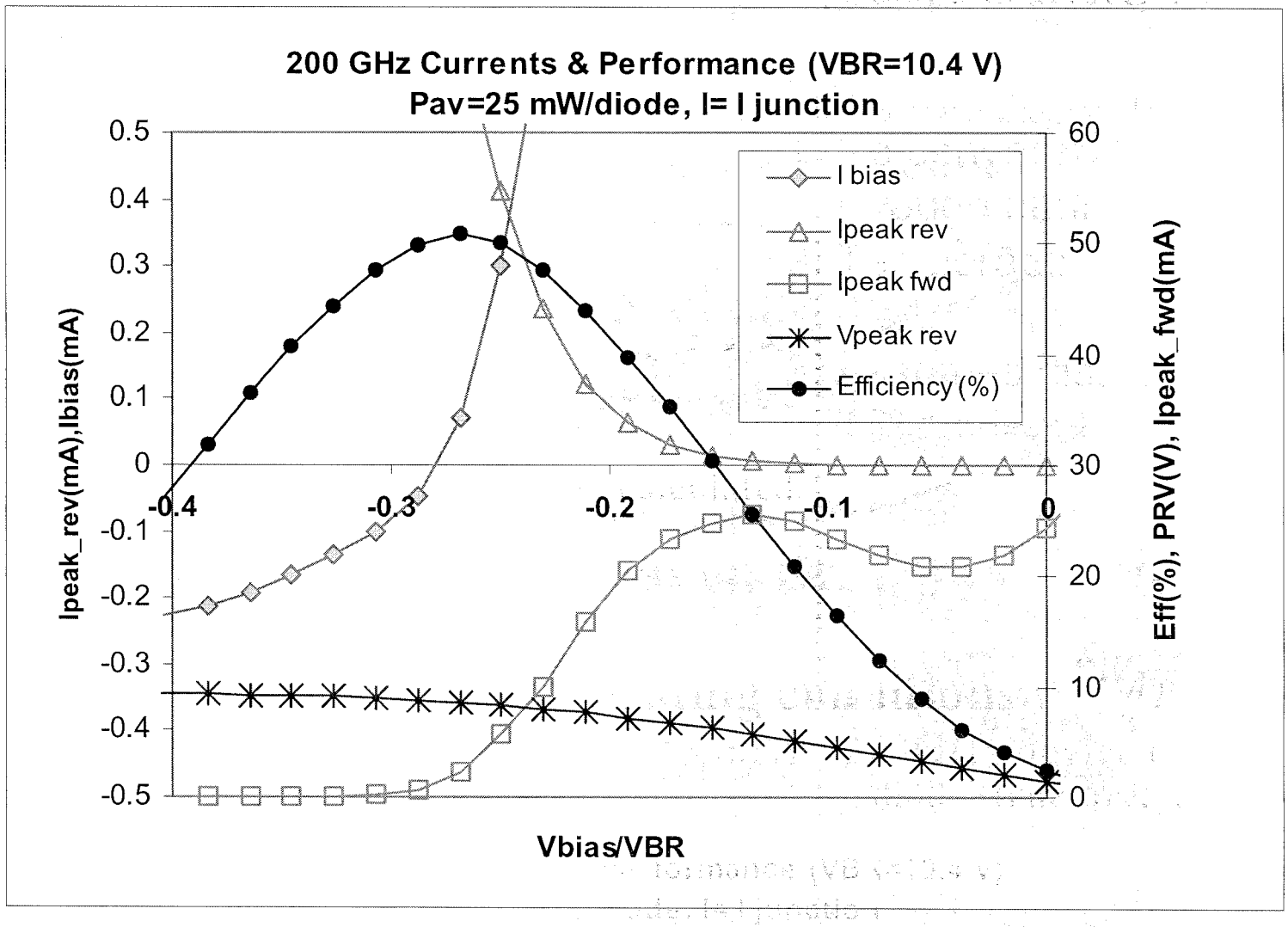
$-U_{br}$, $I_{rev.}$

~doping, Avalanche Effect

$+J_{max.}$

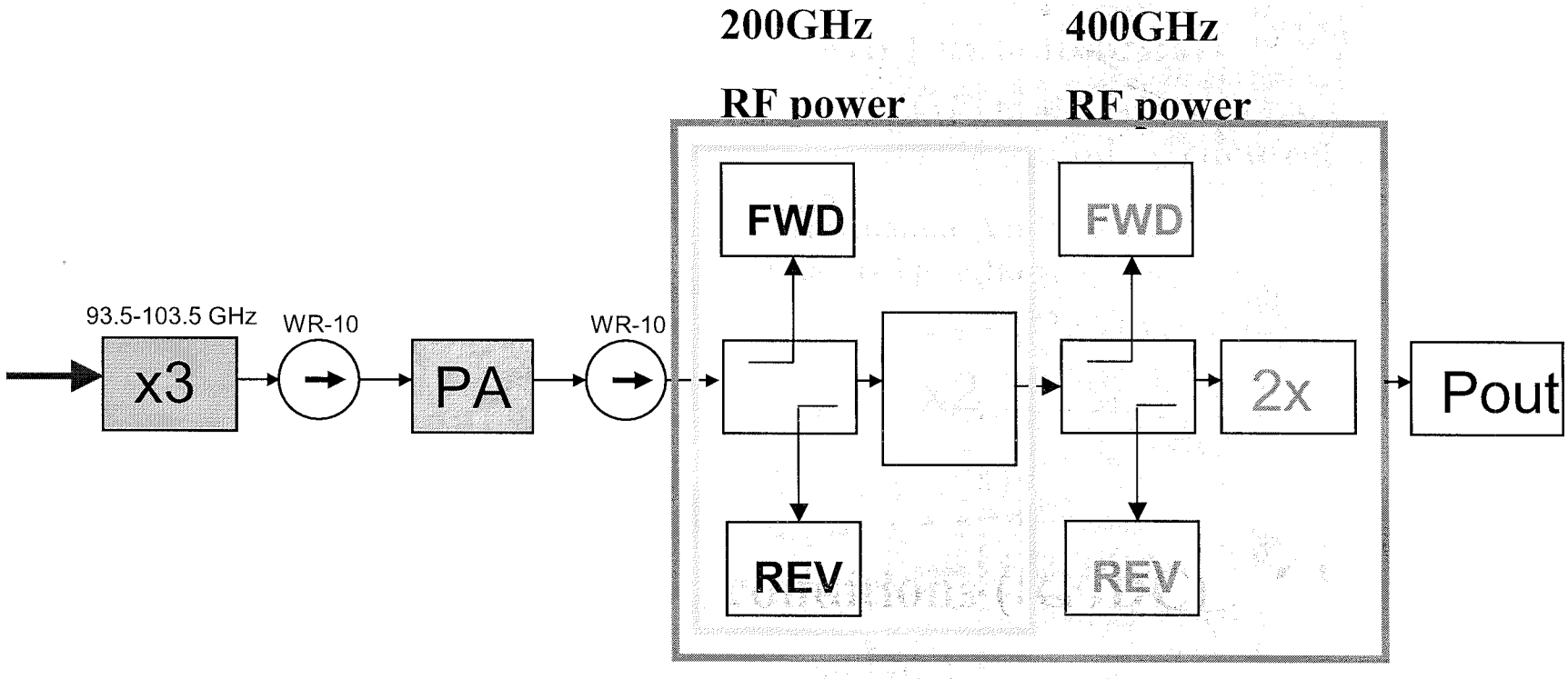
~diode structure, heat dissipation

Safe RF/DC operating conditions

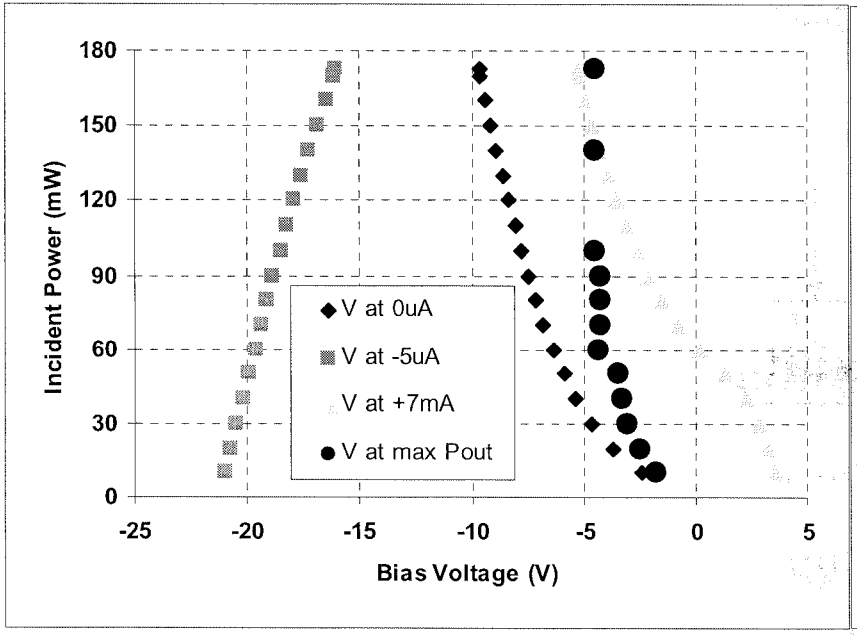


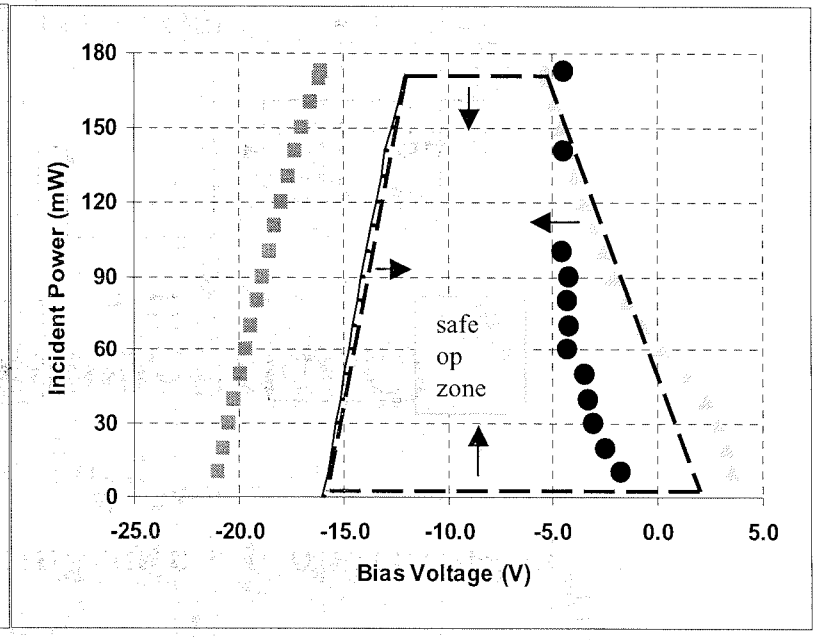
Safe operating conditions (RF/DC)

Experimental setup for determining safe RF operating conditions on 200GHz doublers and 400GHz doublers



Safe RF/DC operating conditions

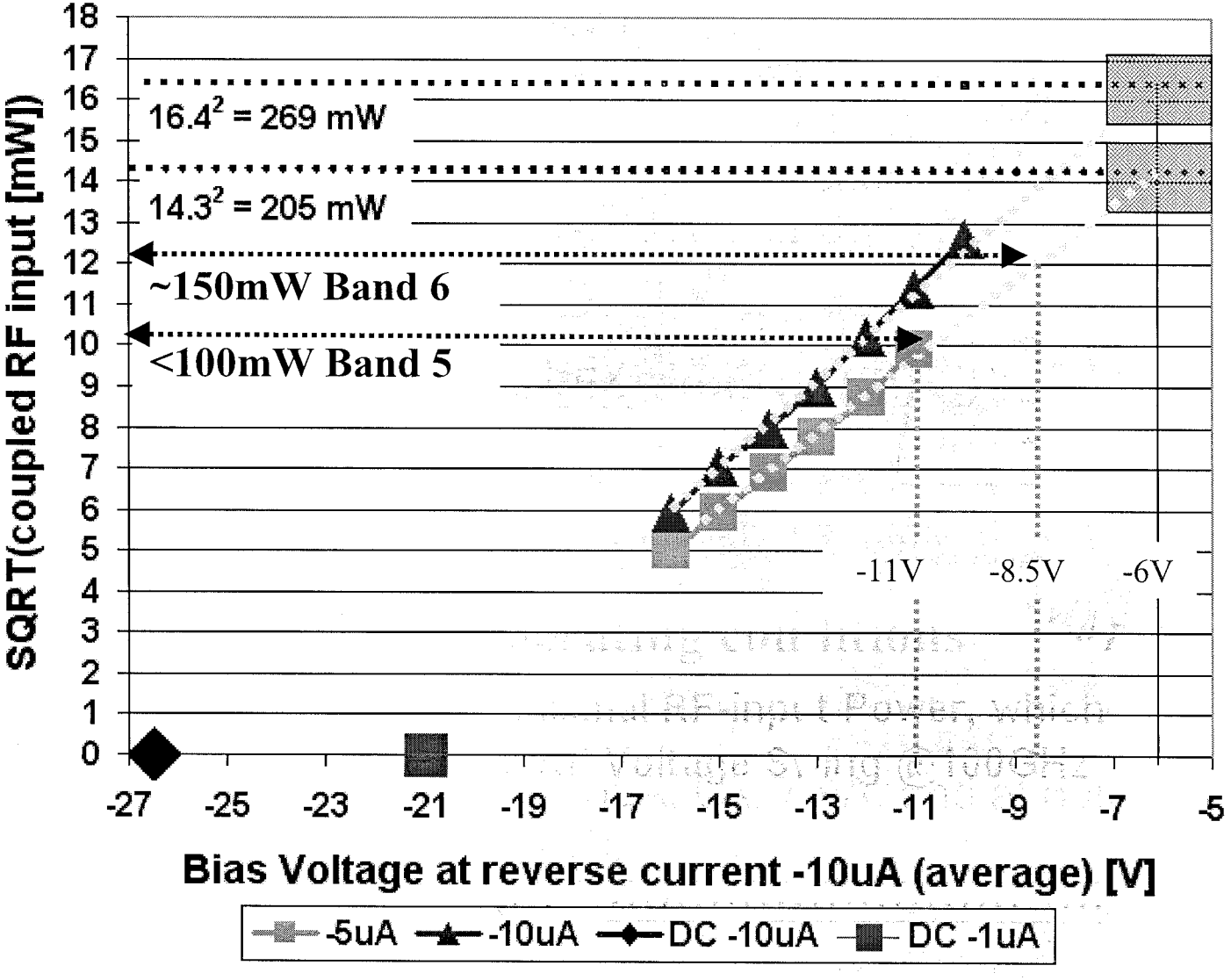




- variable input power @295K
- Measurement of Bias Voltage at –5uA, 0A, 7mA, and at optimized RF output power

Safe RF/DC operating conditions

Approximation of maximal RF-input Power, which is converted into a RF Voltage Swing @100GHz



Conclusion

- ESD risk can be substantially reduced by engineering.
- Temperature dependent lifetime plots are useful to determine infant mortality or long term failure modes.
- Testing with DC currents indicates that excessive amounts of forward and reverse current can damage diodes and even excessive probing of the reverse breakdown voltage can also degrade device performance.
- RF induced damage requires considerable effort in understanding the magnitude of the current and this is a strong function of the circuit.
- A preliminary approach is presented that can be used to determine the safe operating conditions for some of the higher power varactors in use at JPL.