JBS and PiN Diodes at Cree

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Outline

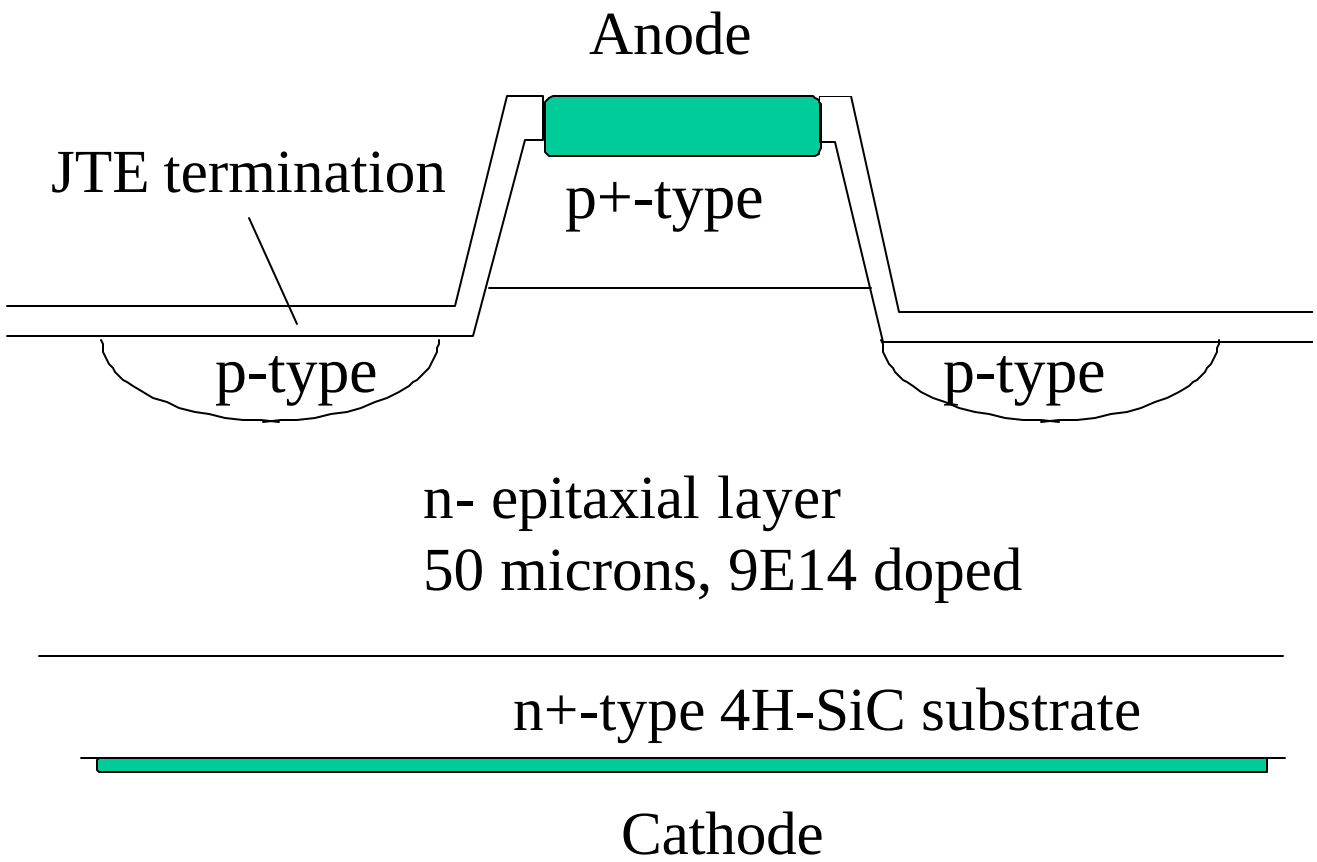
- *Goals for this program*
- *4H-SiC PiN diodes with >4.5 kV blocking*
  - *Static characteristics*
  - *Switching characteristics*
- *High voltage 4H-SiC JBS Diodes*
  - *Diode design and conclusions from previous lots*
  - *Static characteristics from new batch*
- *Conclusions*

High Voltage Diodes

Goals

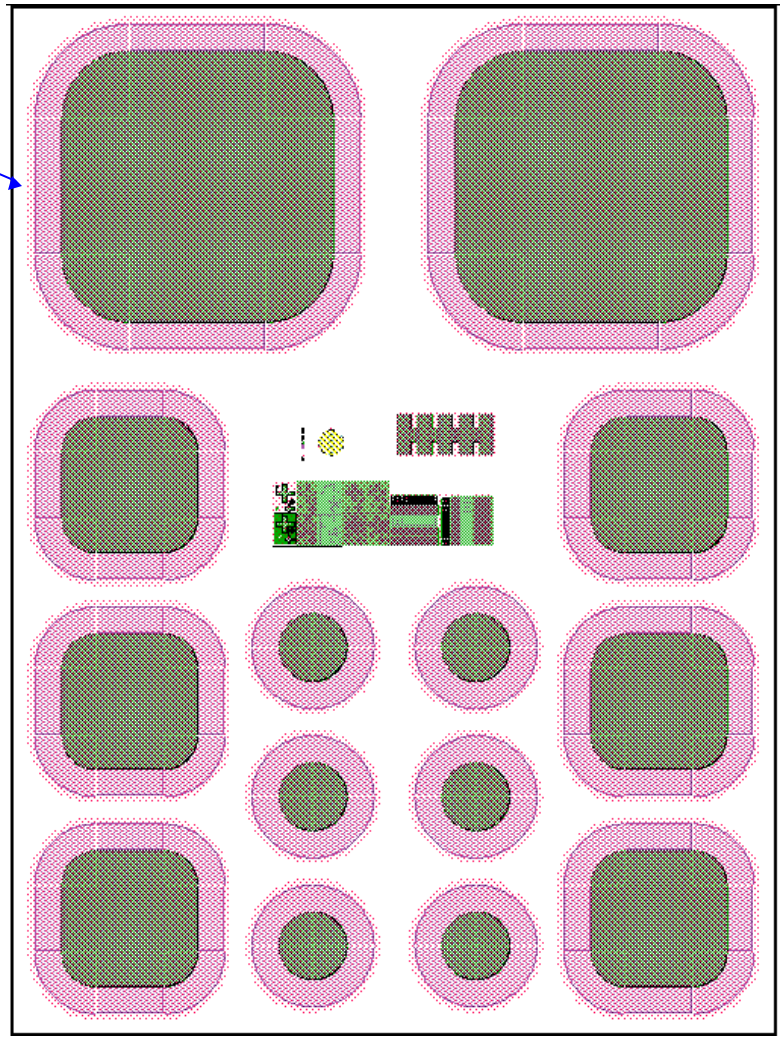
- 2000 V, 100 A packaged Junction Barrier Schottky (JBS) Diode
  - Single chip current = 20 A
  - Paralleling to 100 A based on follow-on funding
- 4.5 kV, 50 A packaged P-i-N rectifier
  - Single chip current = 10 A
  - Paralleling to 50 A based on follow-on funding
- Package development to test 4.5 kV, 50 A devices
- Get feedback from CHPS team members on their needs

High voltage P-I-N Diode structure

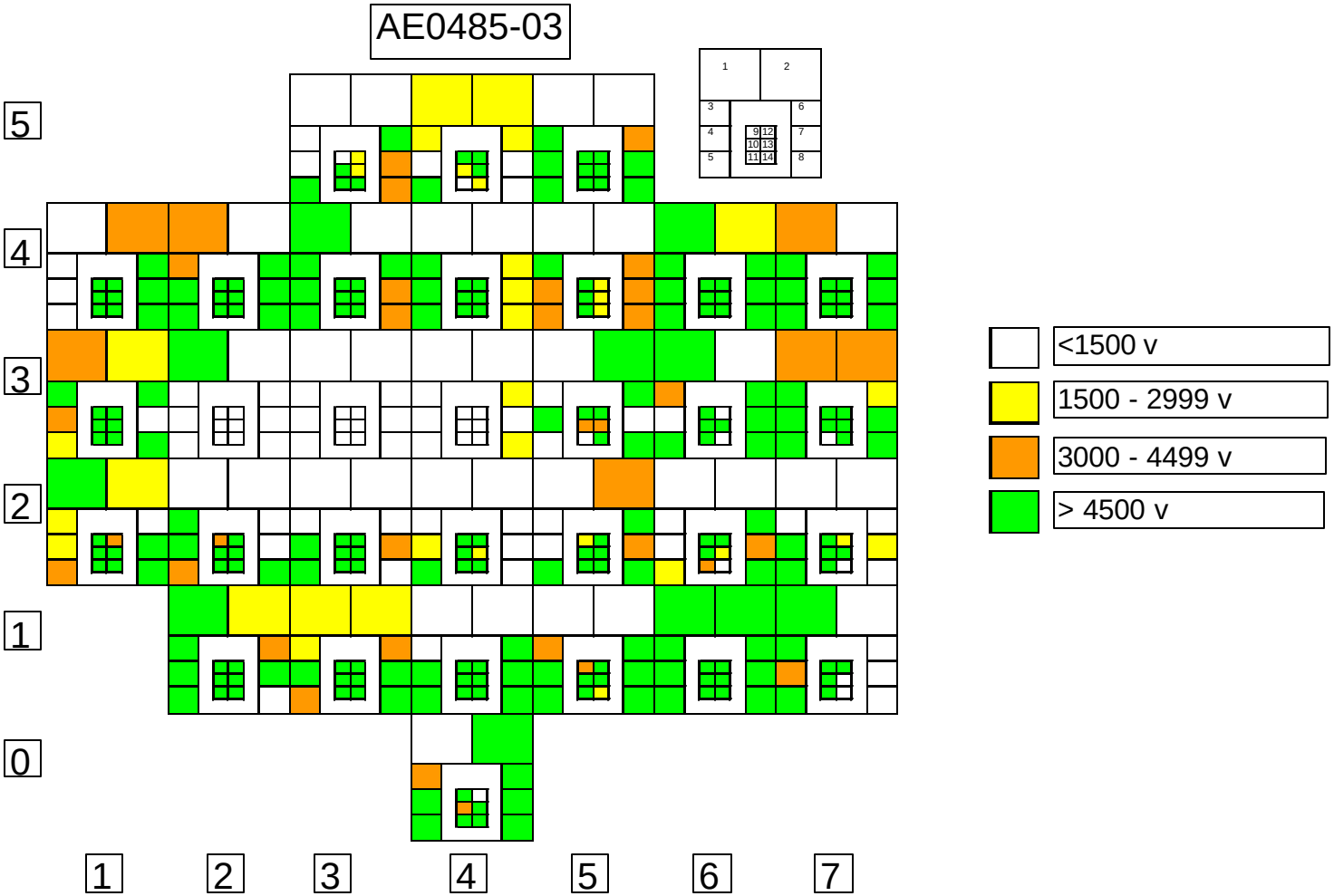


New mask for 4.5 kV, 10 Amp devices

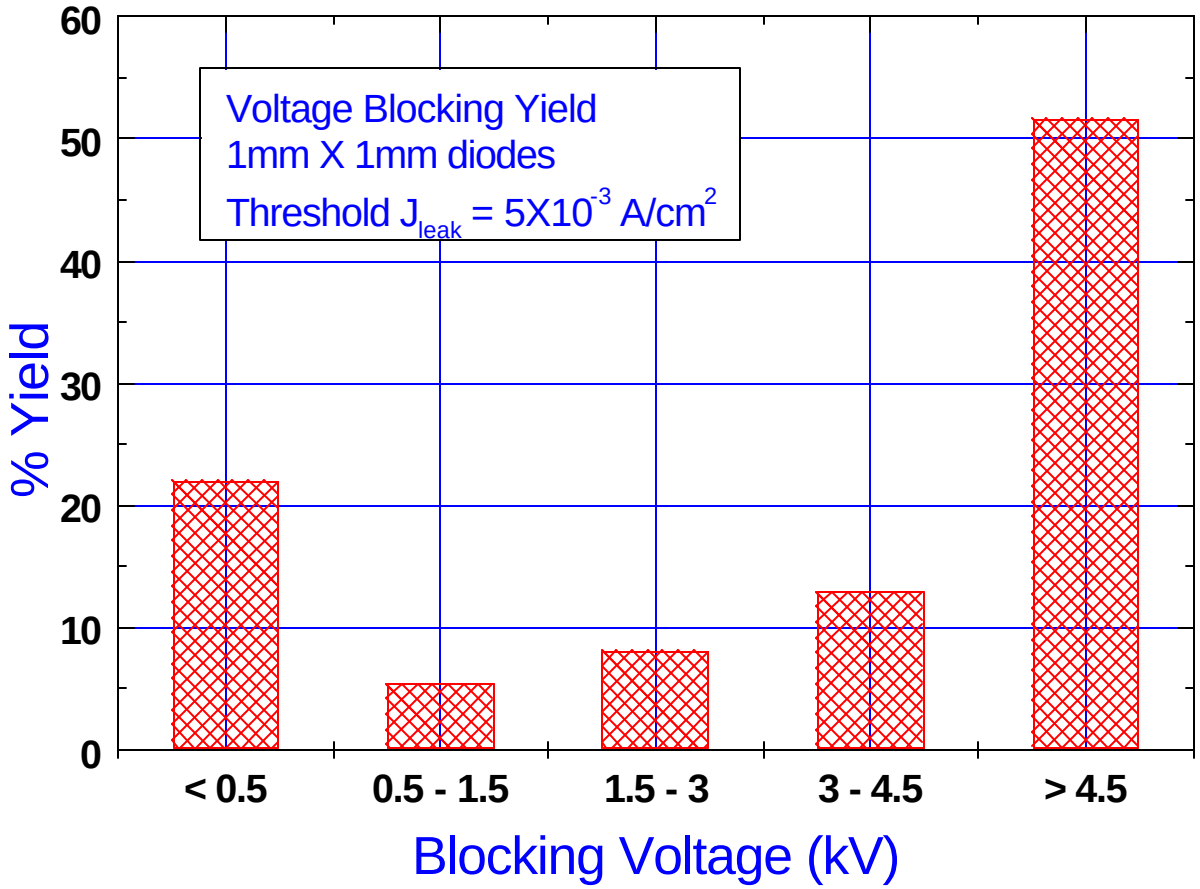
2mmX2mm



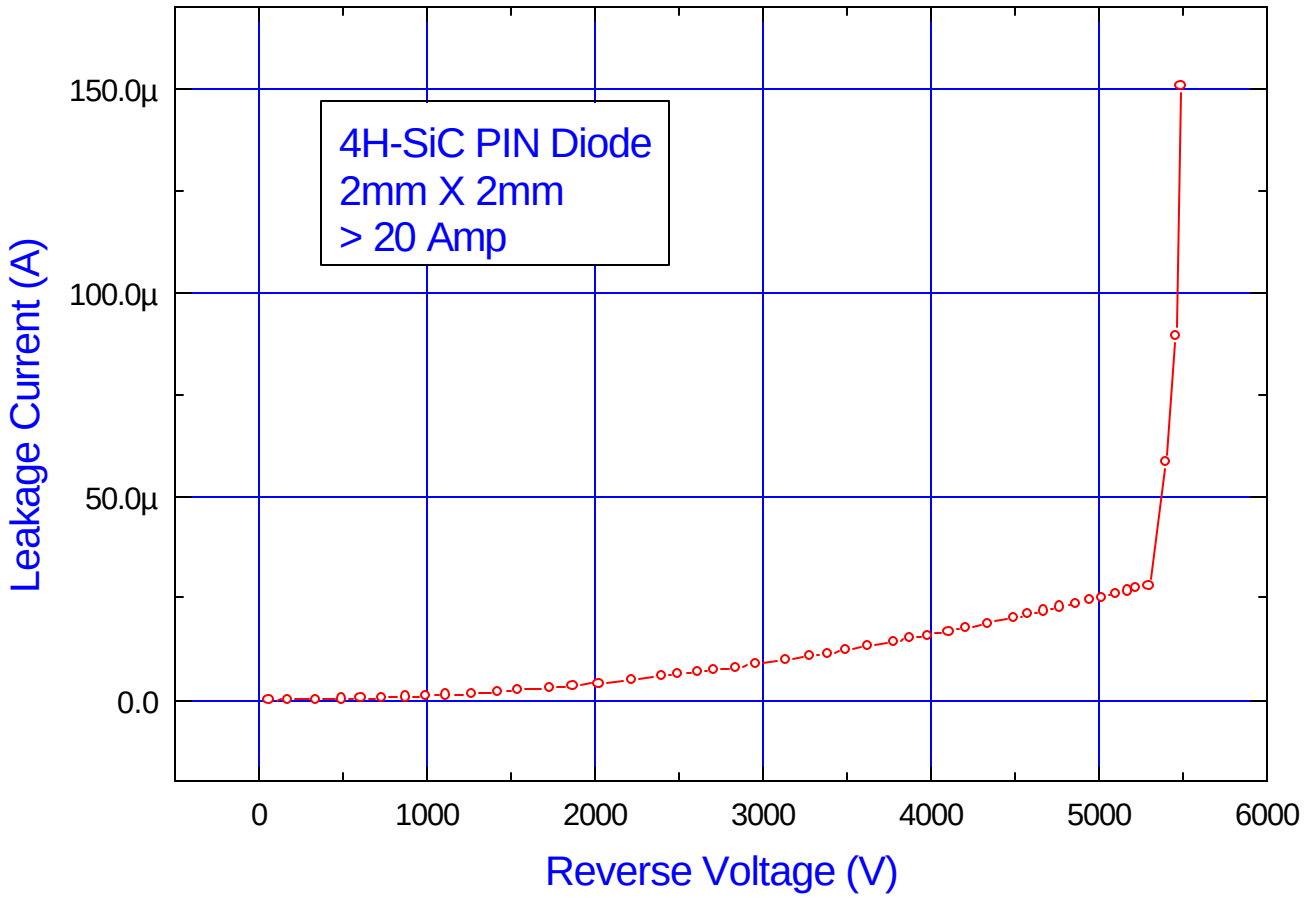
Blocking yield map



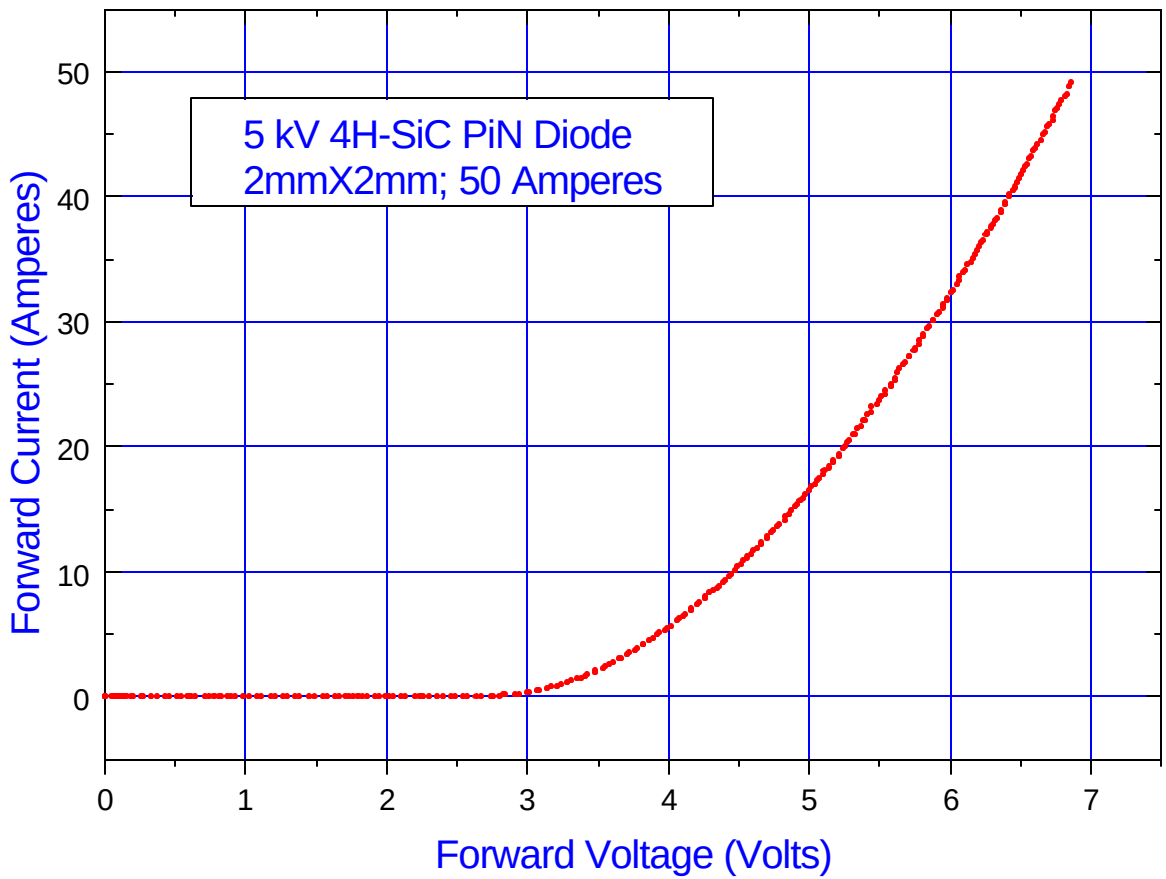
Blocking yield for 1 mm^2 diodes



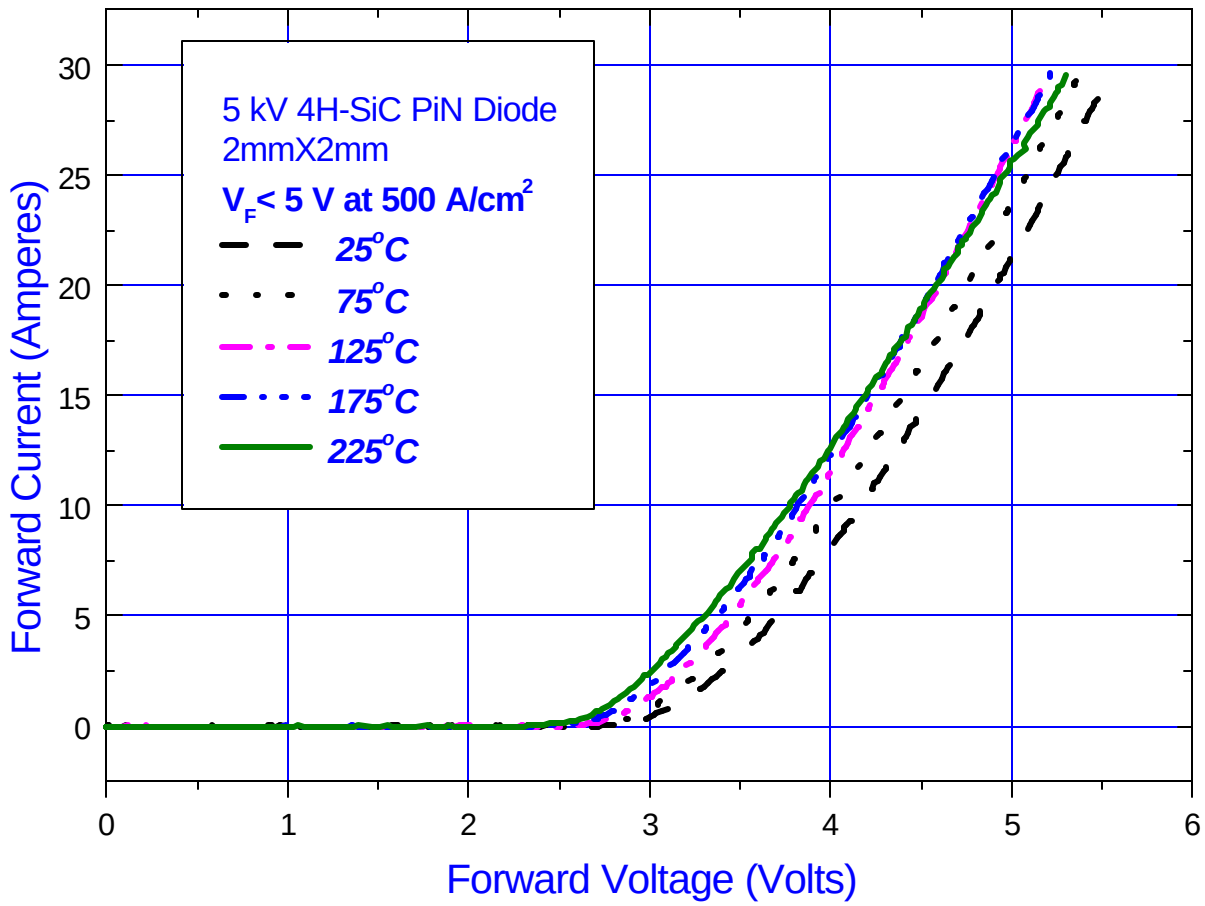
5.5 kV; >20 Amp diode



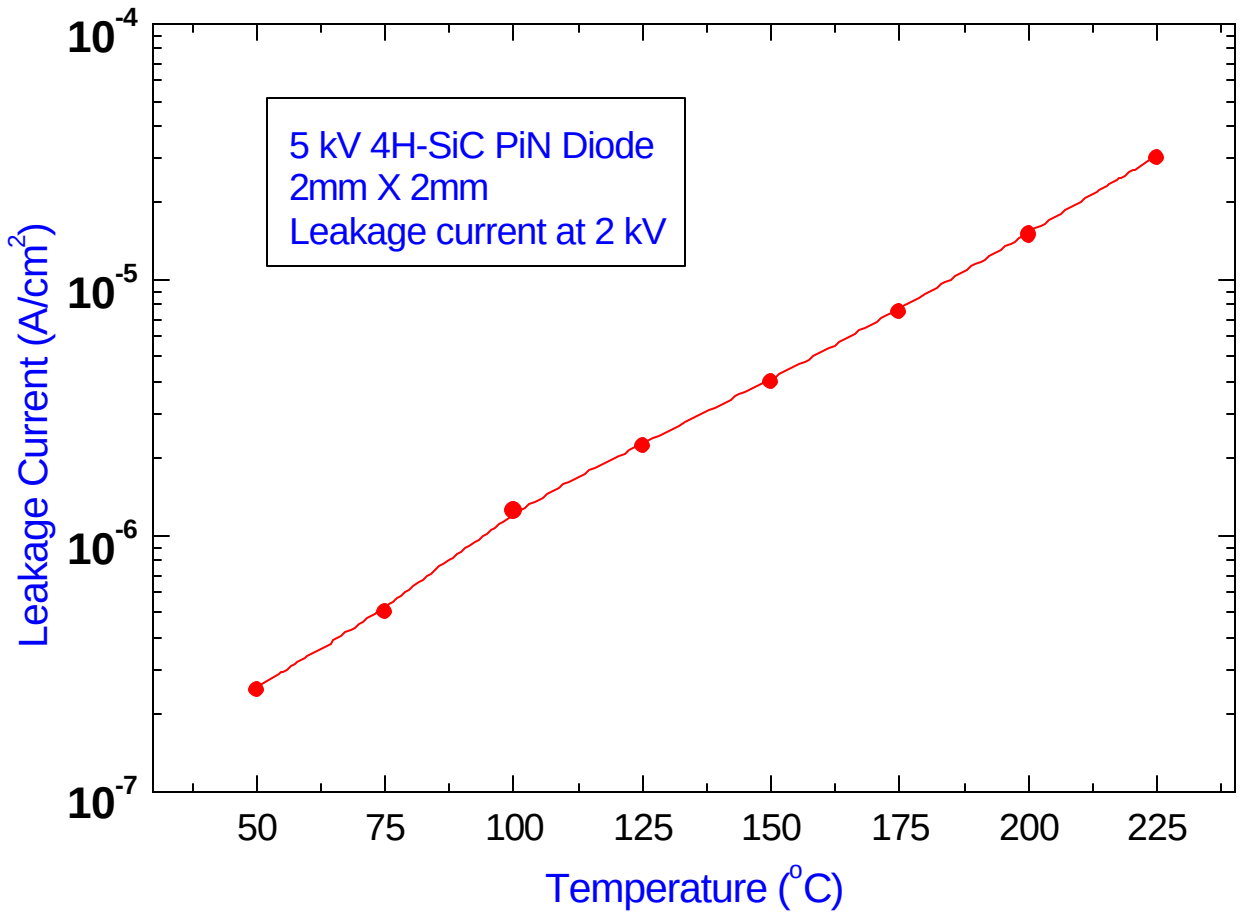
50 Amperes, 5 kV diodes



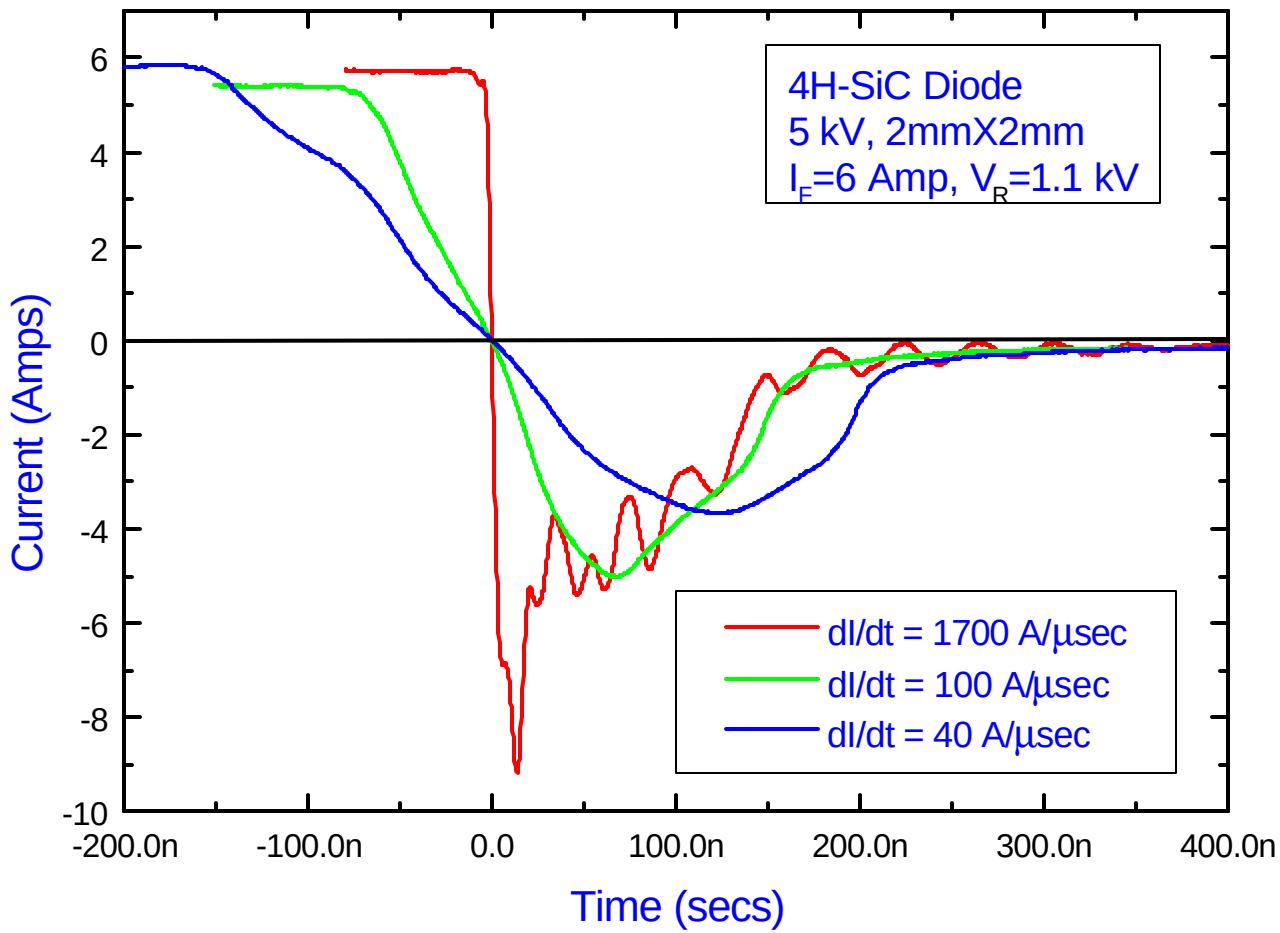
High Temperature forward I-V characteristics



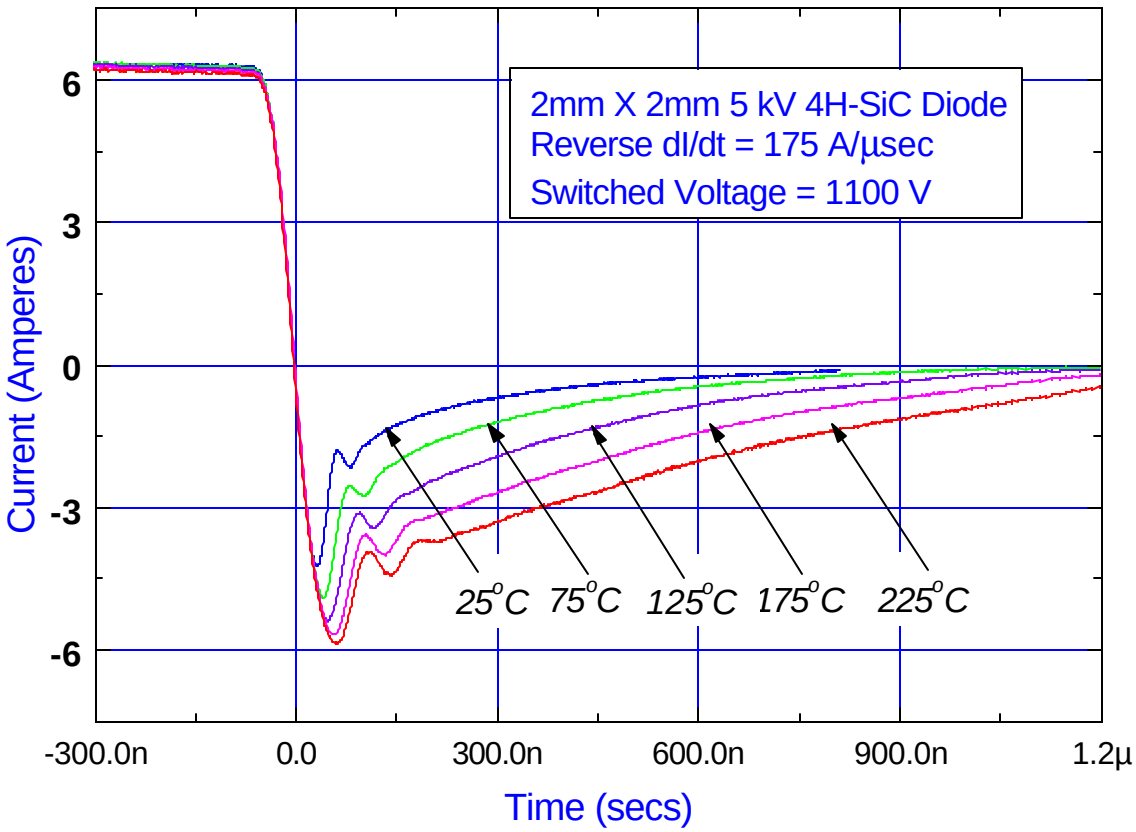
High temperature reverse leakage



Reverse recovery chars up to 1700 A/µsec

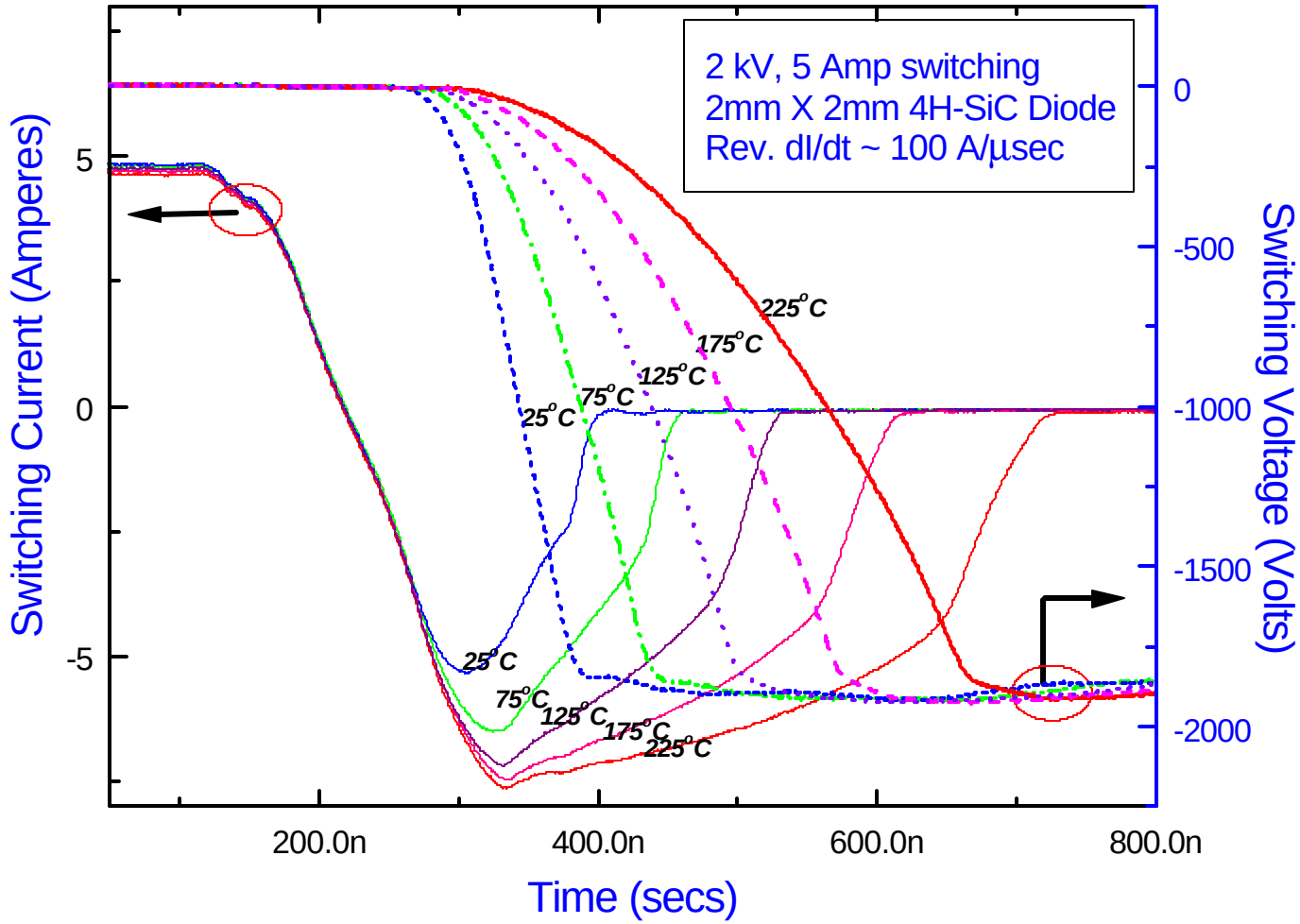


High temperature switching characteristics

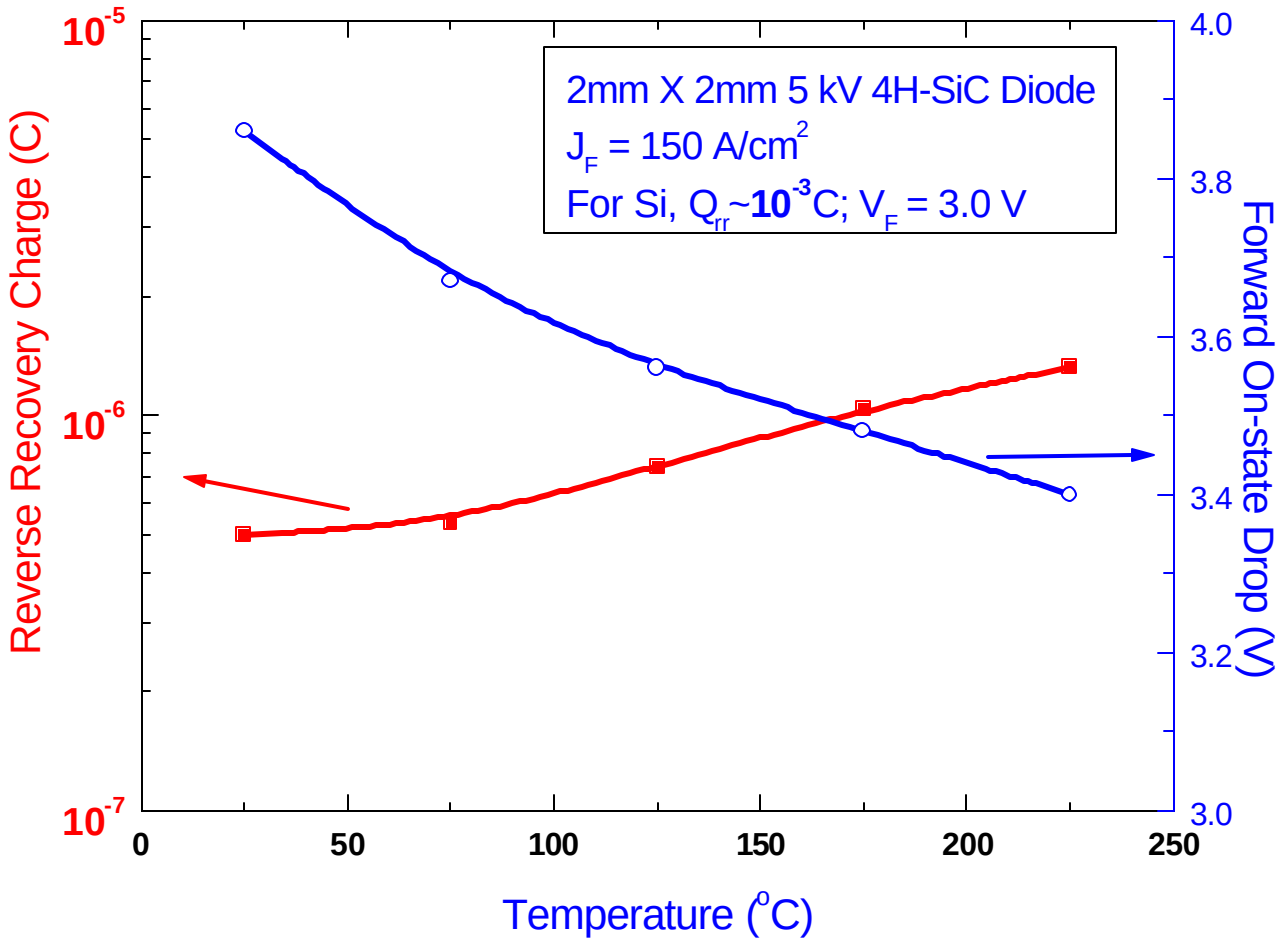


- *Peak Reverse Current increases by only 30% from 25-225°C*
- *Total Reverse Charge increases by only 100% from 25-225°C*

2 kV, 5 A (125 A/cm^2)
225°C switching



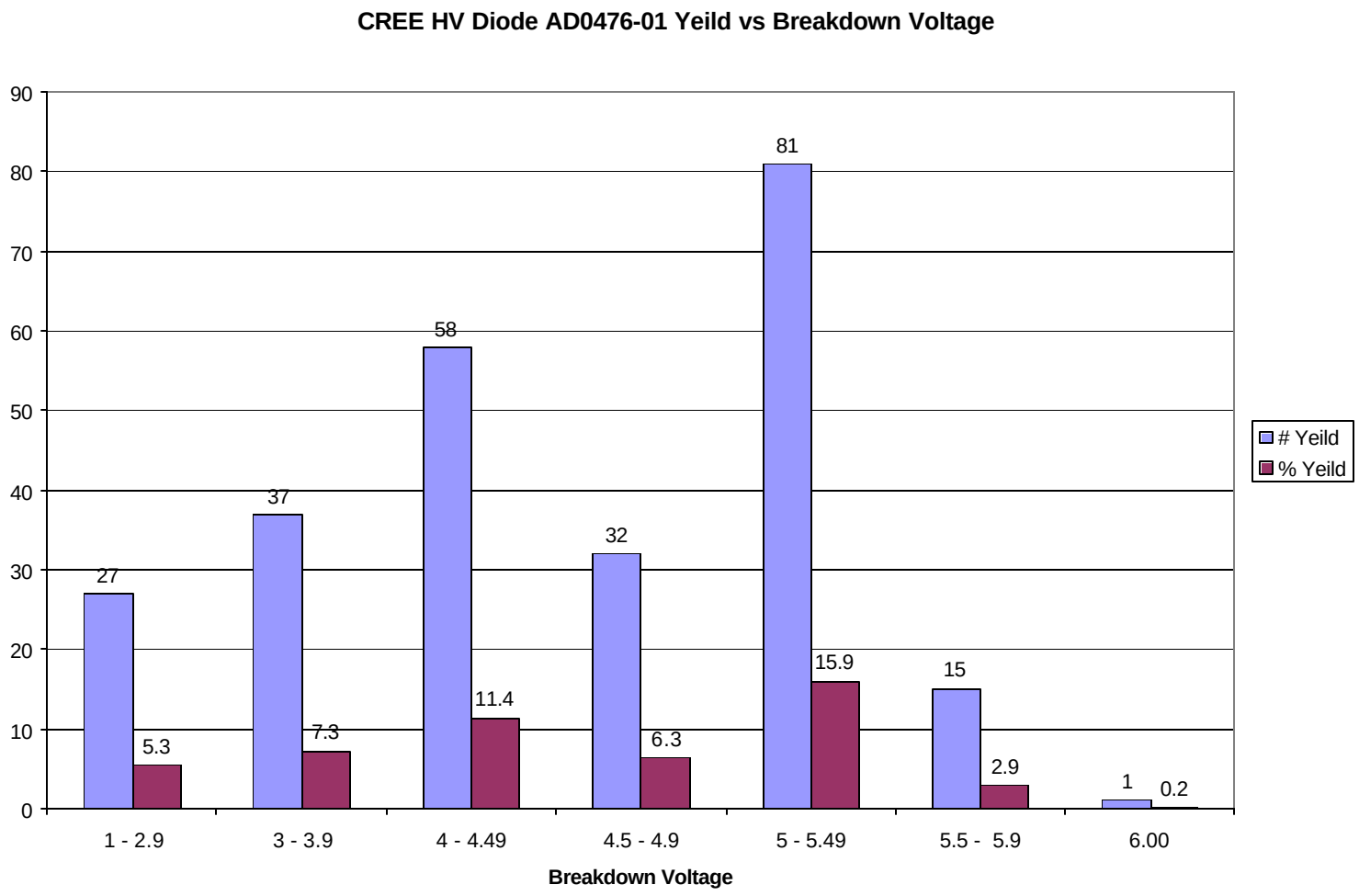
Reverse Recovery/ Forward Drop Trade-off



CHPS/Northrop Grumman P-i-N diodes

- *4 kV, 62 Amperes Inverter demonstration*
- *4 wafers with 70 mm epi layers with 5-7E14 cm^{-3}*
- *1 mm X 1mm PiN diodes fabricated with 5 kV terminations*
- *>100 diodes with > 5 kV delivered by Cree with good on-state drop (all specs met)*
- *These numbers are sufficient to supply the entire needs for this demonstration*
- *Lower blocking voltage (3 kV) devices used for paralleling package test*

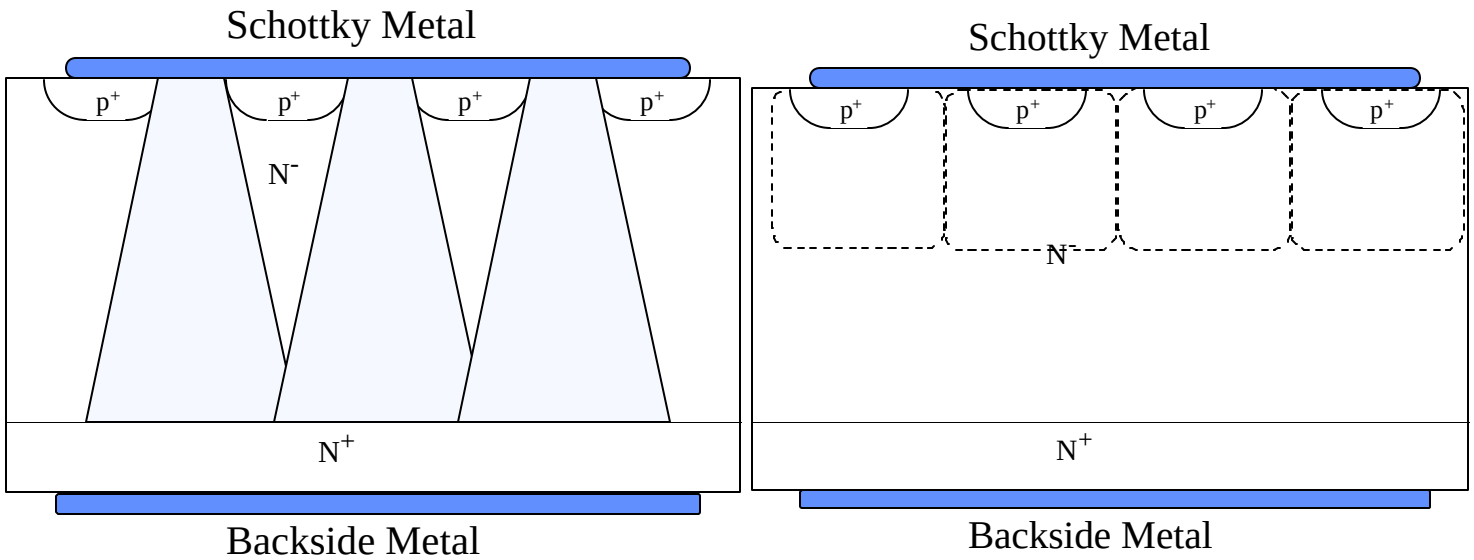
High Voltage yield for 1mmX1mm diodes



Package for multi-kV, >10 Amp high temp devices

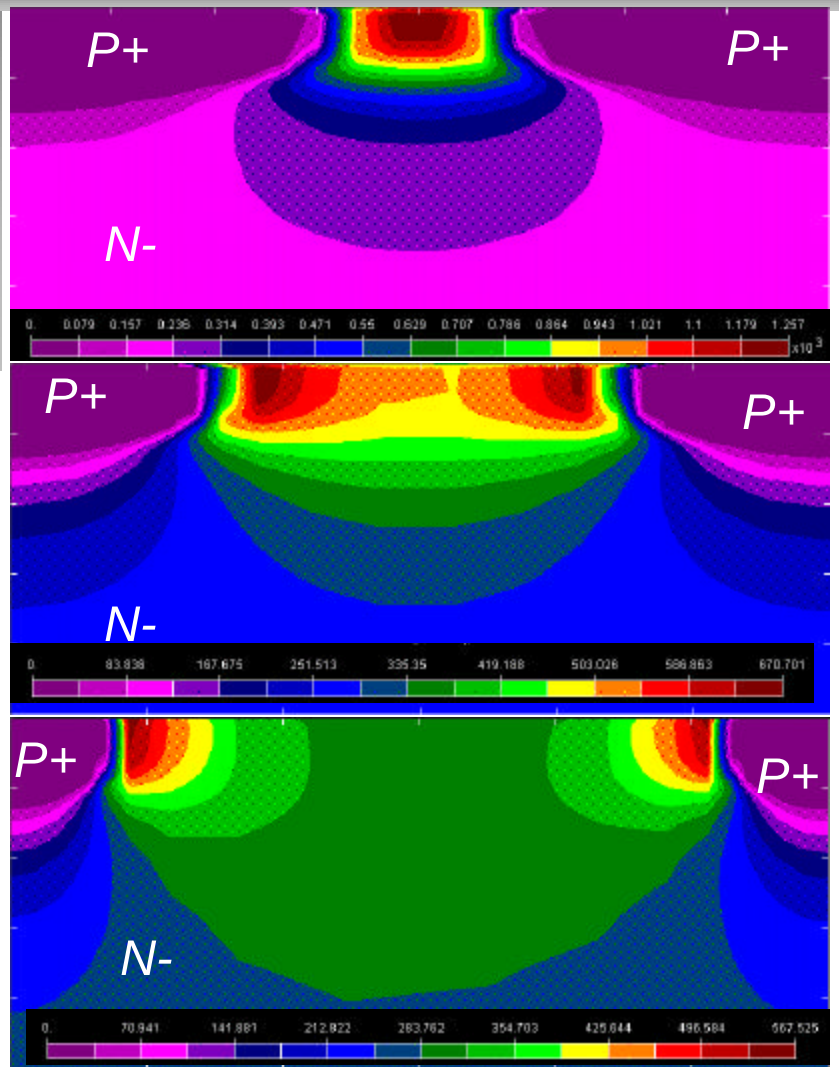
- *Packages for >2kV, >10 Amp*
  - *Not easily available off-the shelf*
  - *Packages available with >3kV also had more than 200 Amps and require specialized packaging equipment*
- *Our requirement guided by this program*
  - *>6 kV at 250-300°C*
  - *Compatible with standard wire bond, brazing equipment*
  - *50 Amperes or greater; relatively cheap*
- *Worked with custom packaging house and developed*
  - **10.5 kV blocking** *measured at room temperature*
  - *Completely compatible with standard brazing/wire bonding*
  - *Very good thermal contact and good heat dissipation*

JBS Diode concept



- *Low V_F Schottky-like characteristics in on-state*
- *Low leakage P-i-N-like characteristics in off-state*
- *Fast switching characteristics like Schottky diodes*
- *Good high temperature characteristics like P-i-N diodes*

J_F=200 A/cm^2 on-state simulations

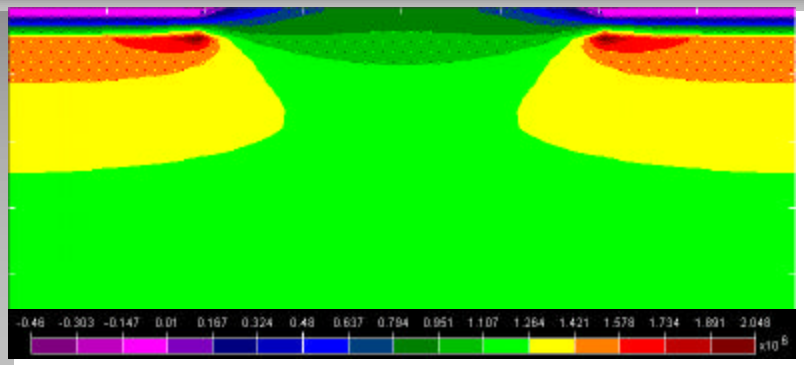


d_{sch} = 2 mm; m_{p+} = 1 mm
J_{peak} = 1200 A/cm^2

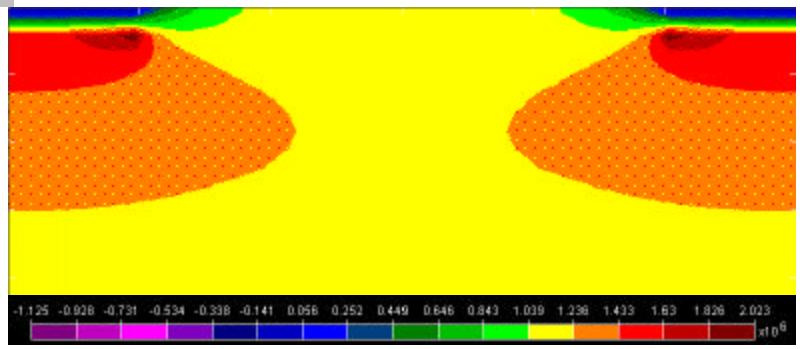
d_{sch} = 4 mm; m_{p+} = 1 mm
J_{peak} = 670 A/cm^2

d_{sch} = 10 mm; m_{p+} = 1 mm
J_{peak} = 570 A/cm^2

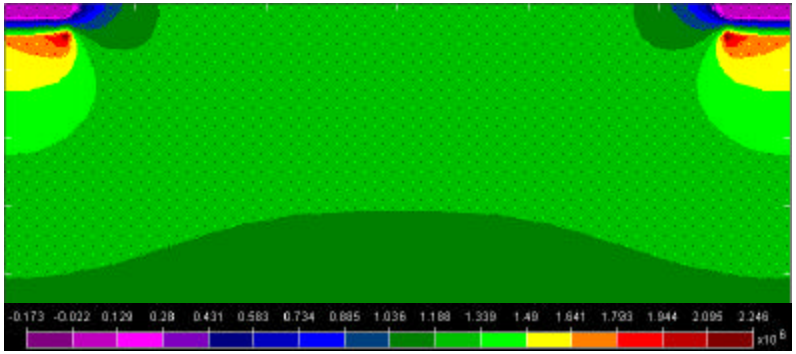
V_{rev}=2000 V blocking simulations



d_{sch} = 2 mm; m_{p+} = 1 mm
E_{sch}= 8x10^5 V/cm

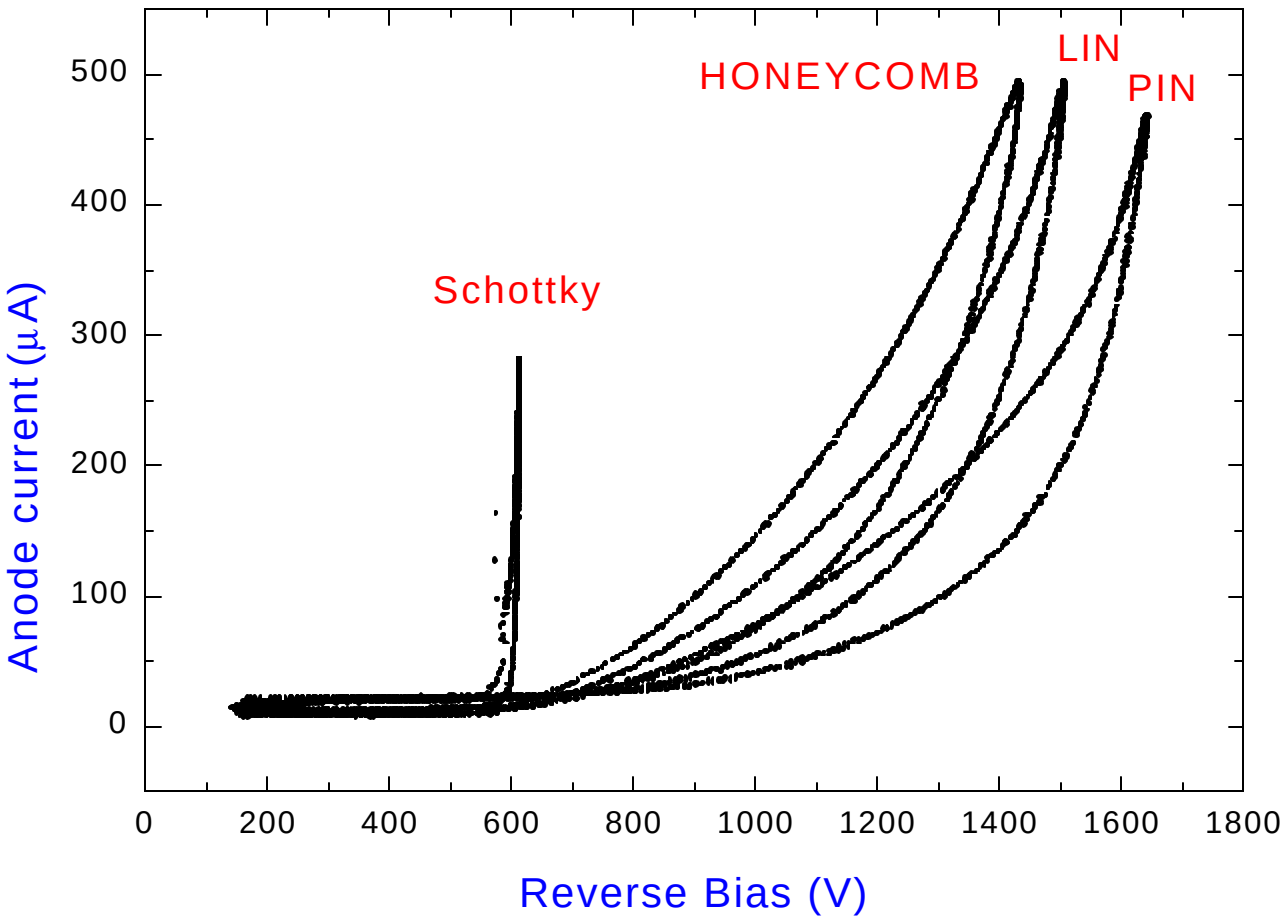


d_{sch} = 4 mm; m_{p+} = 1 mm
E_{sch} = 9.5x10^5 V/cm

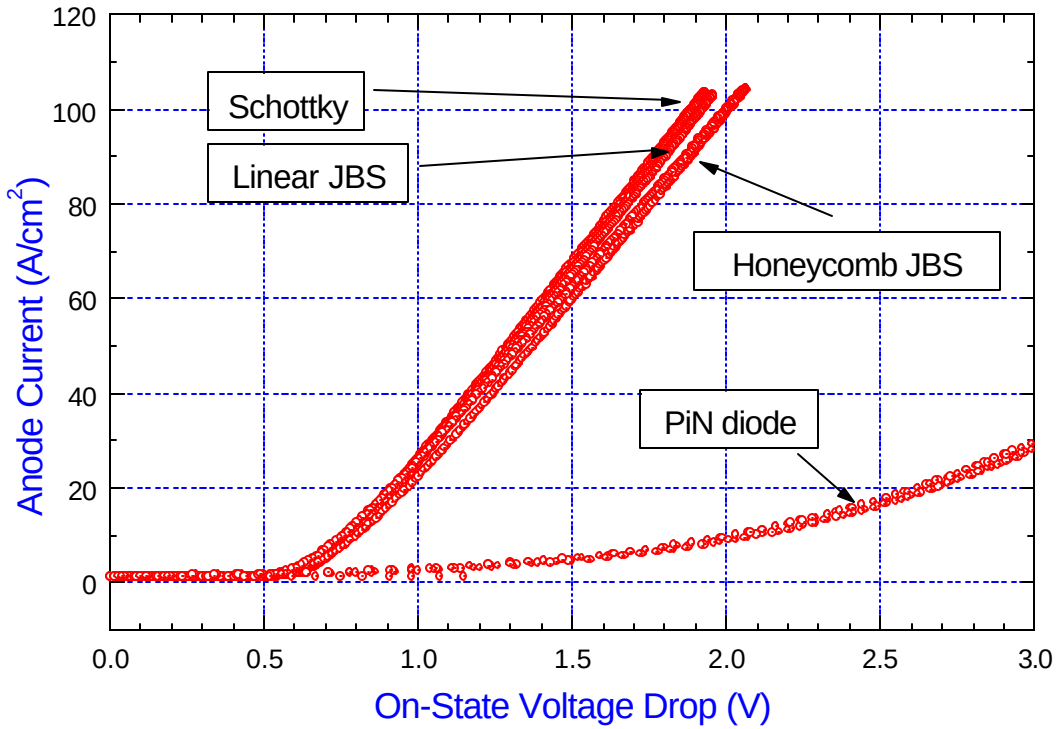


d_{sch} = 10 mm; m_{p+} = 1 mm
E_{sch} = 1.2x10^6 V/cm

Measured Reverse Bias Characteristics

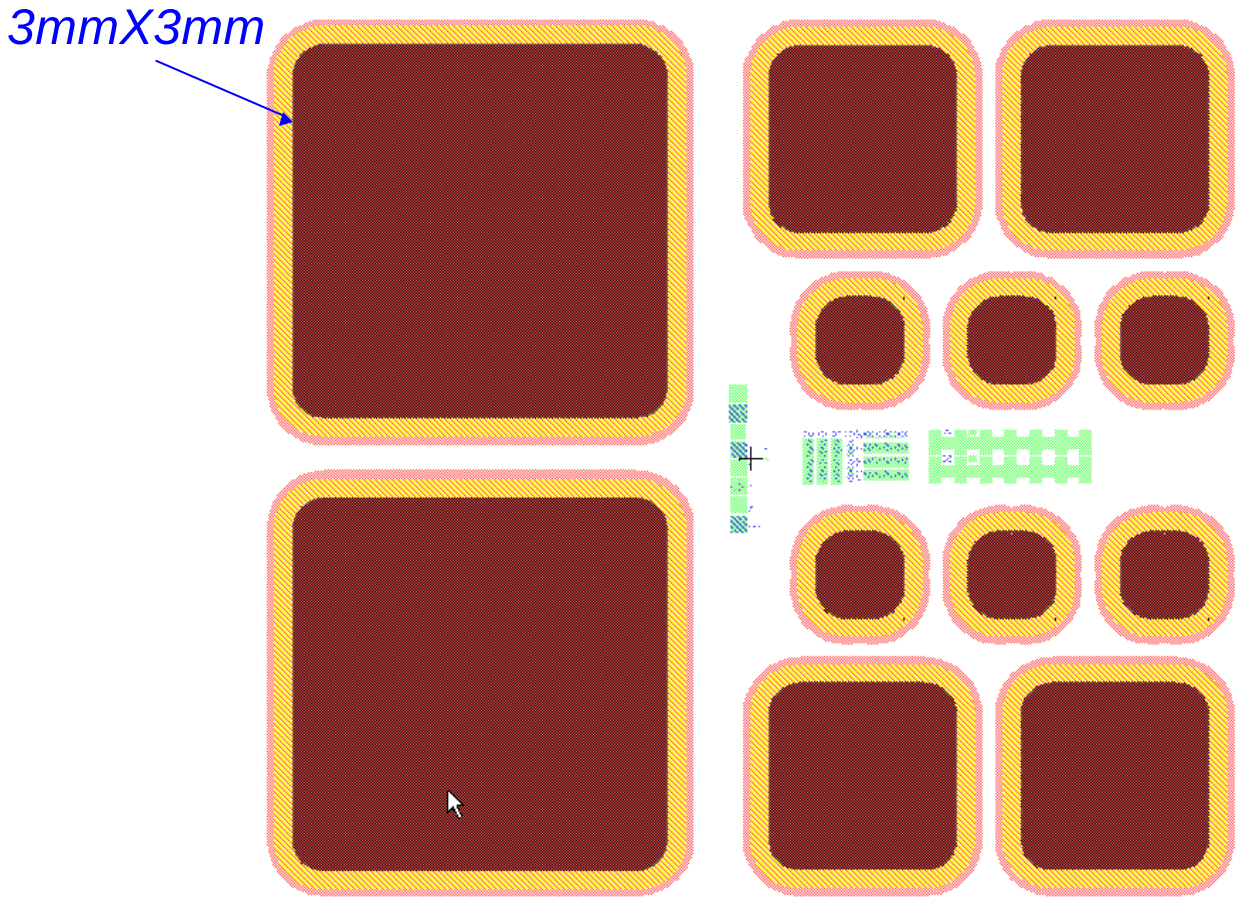


On-state I-V chars.

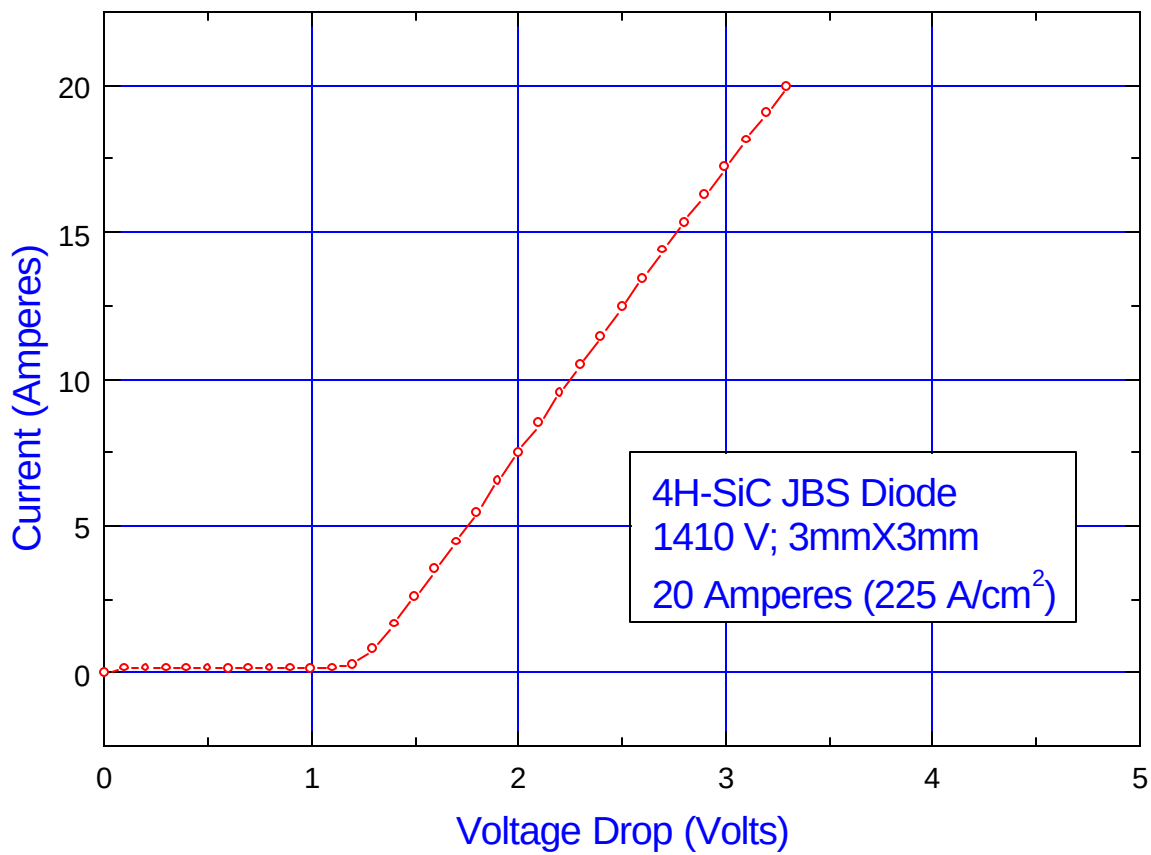


On-resistance of devices in the 9-11 mW-cm^2 range
Epi Resistance calculated to be 7.8 mW-cm^2 (25 mm, 2.5E15cm^{-3})
On-state of linear JBS very close to Schottky

New mask for 2 kV, 20 Amp devices

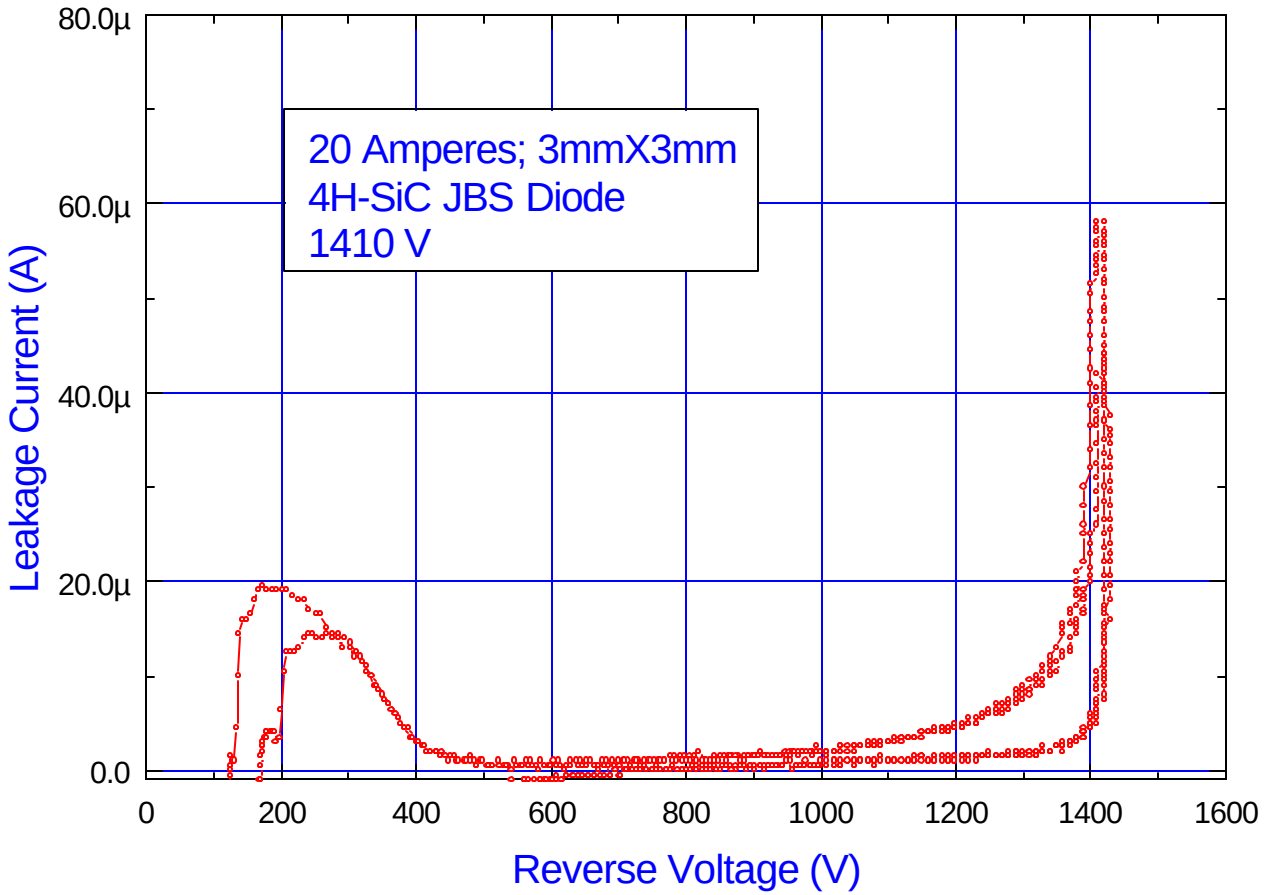


20 Amperes; 1410 V JBS diode I-V chars

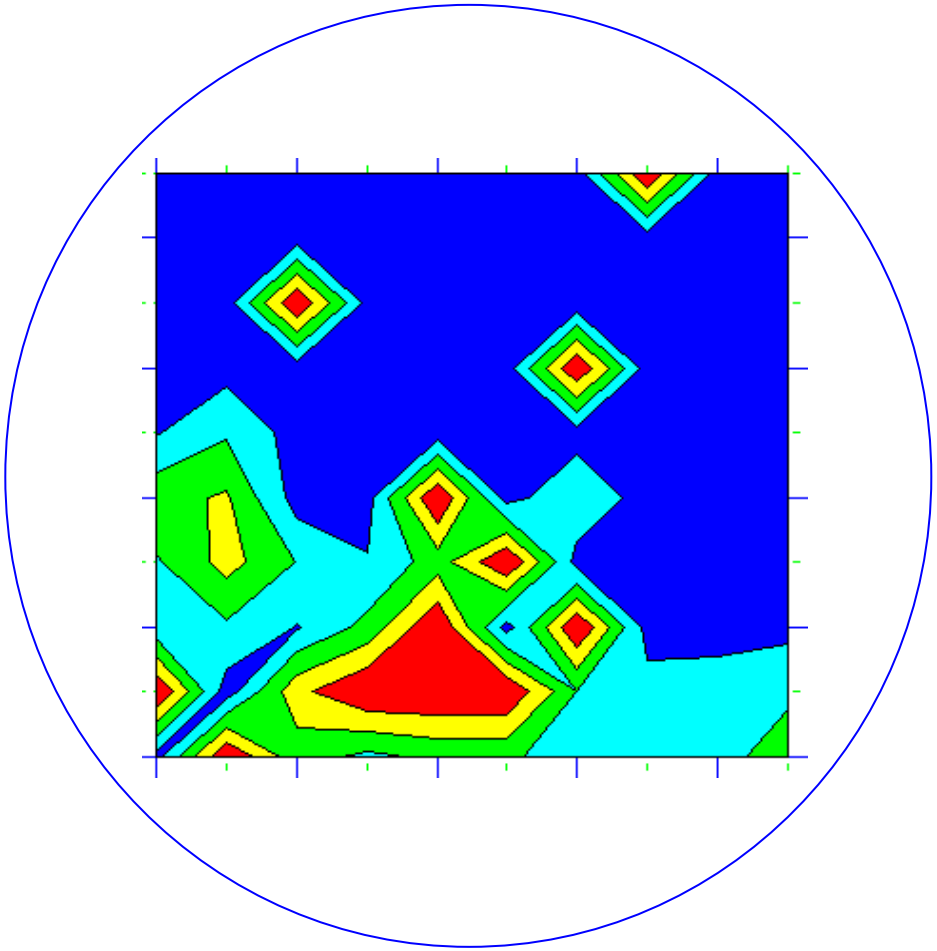


V_F = 3.25 V at 20 Amp.; 9 mW-cm^2 => limited by packaging

20 Amp; 1410 V Reverse leakage chars.



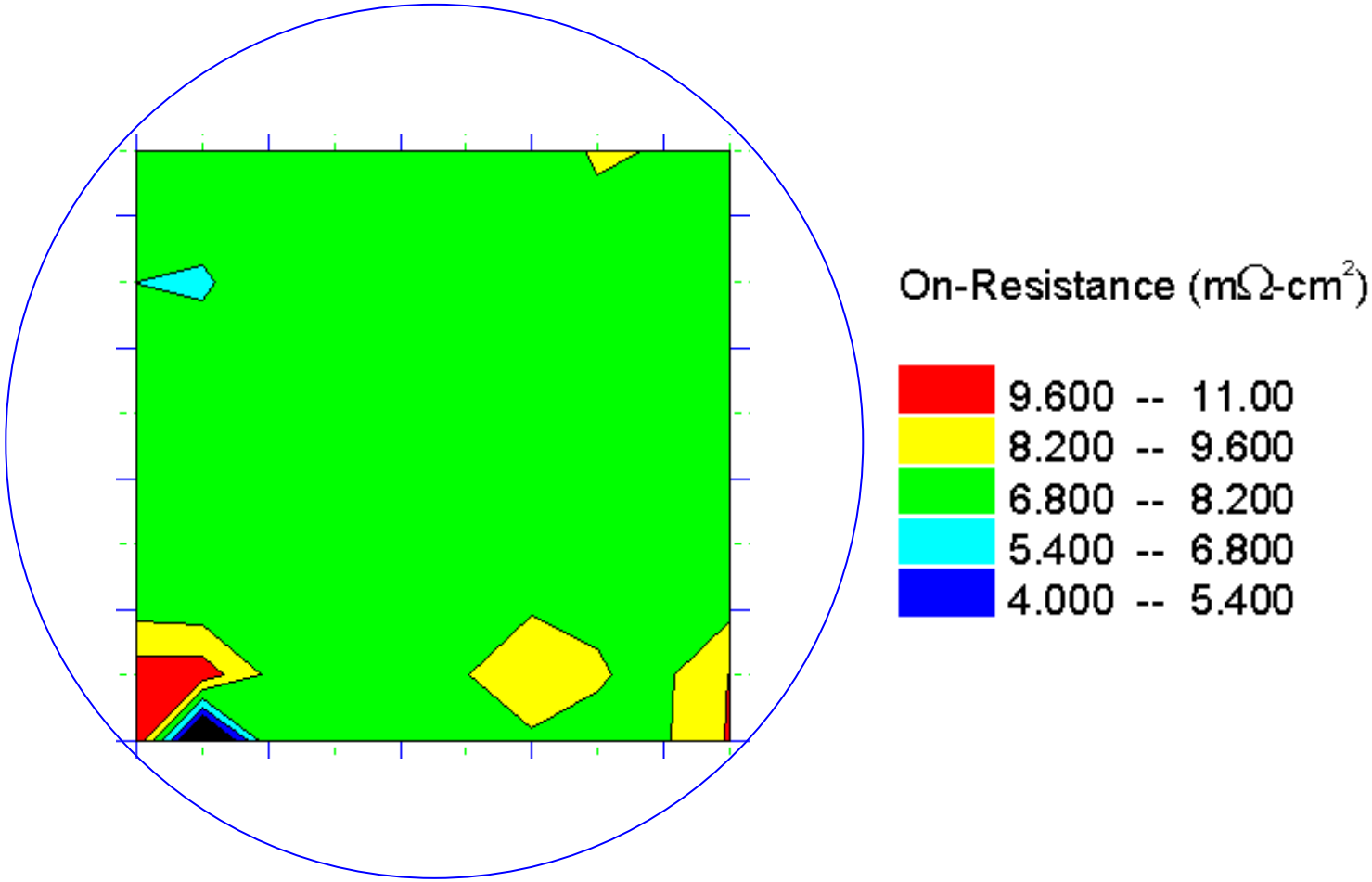
Blocking map of wafer at 200 V



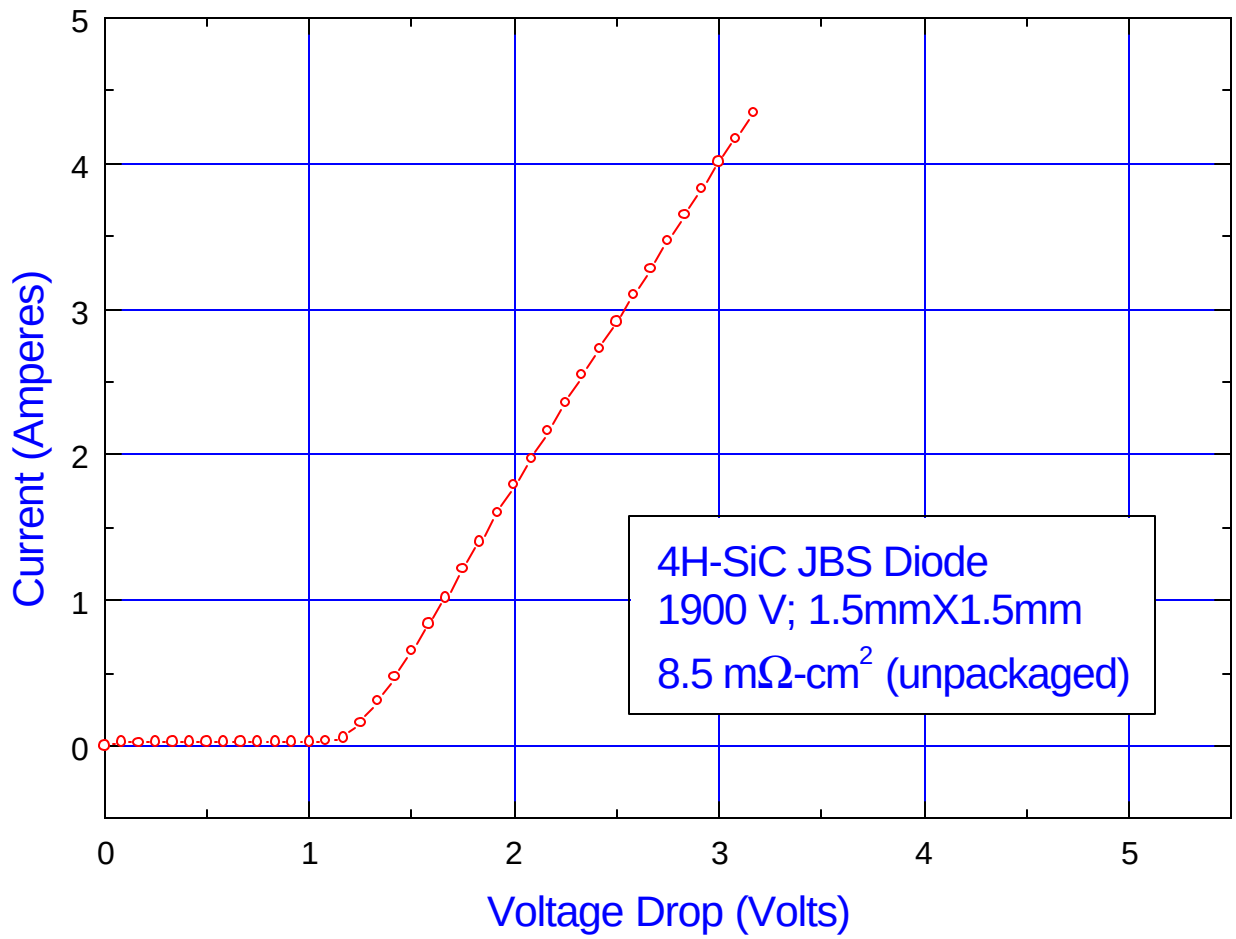
Leakage Current (A)

- 0.00382 -- 0.03000
- 4.856E-4 -- 0.00382
- 6.178E-5 -- 4.856E-4
- 7.86E-6 -- 6.178E-5
- 1E-6 -- 7.86E-6

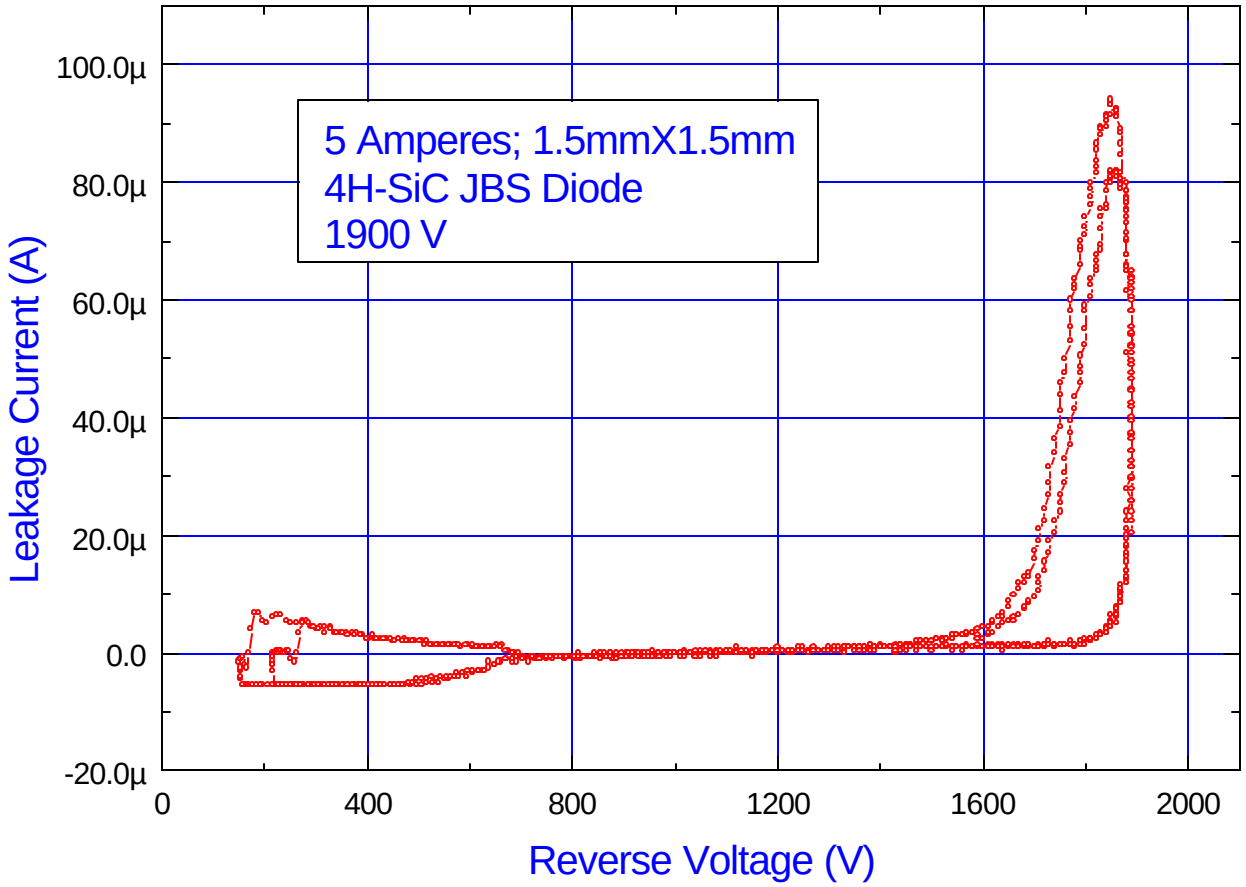
On-state uniformity across wafer



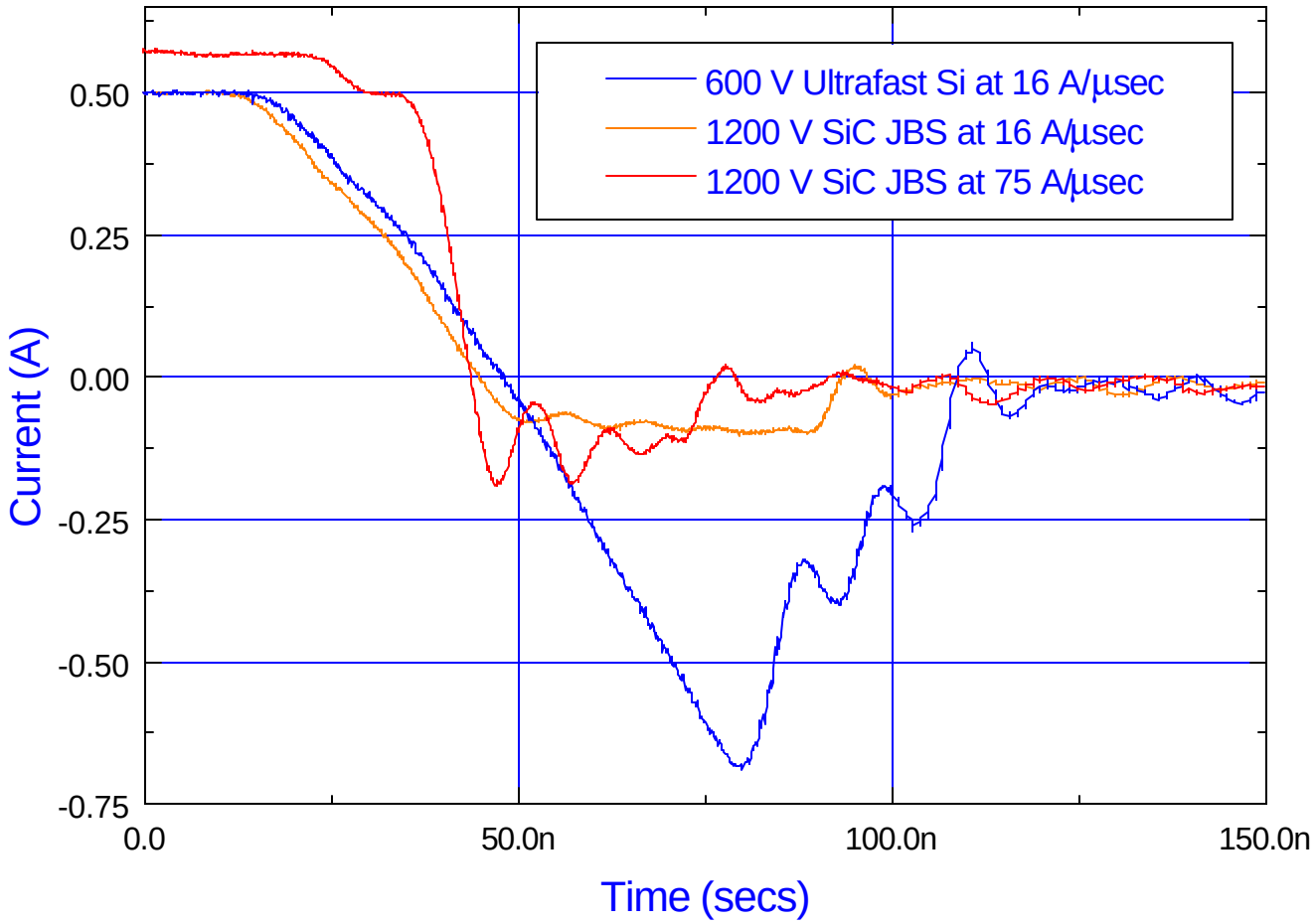
1900 V, 4 Amp JBS diode



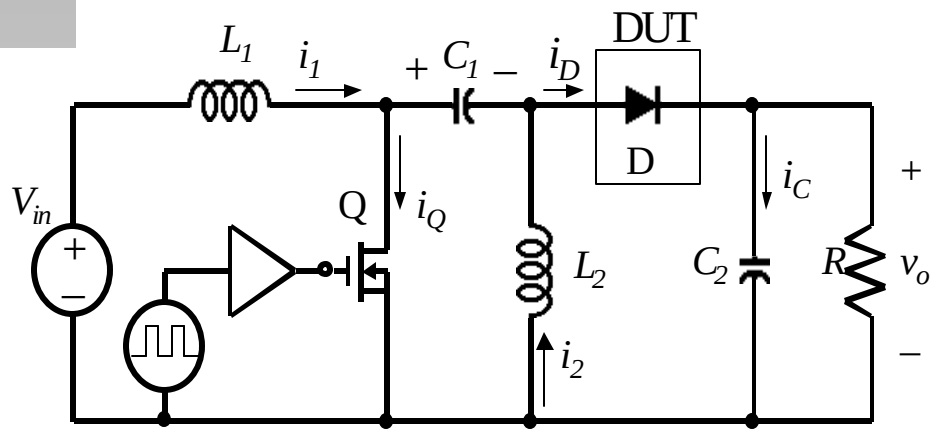
1900 V, 4 Amperes JBS diode



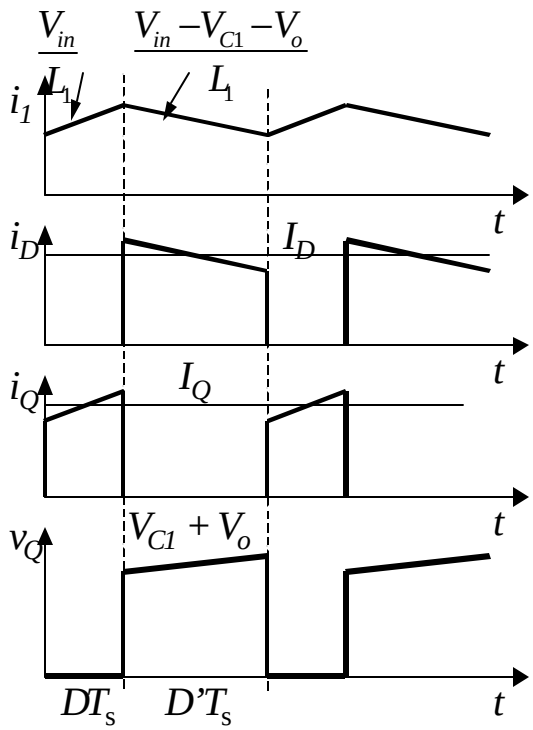
Switching of 1200 V SiC JBS and 600 V UF Si PiN



DC-DC converter using CoolMOS

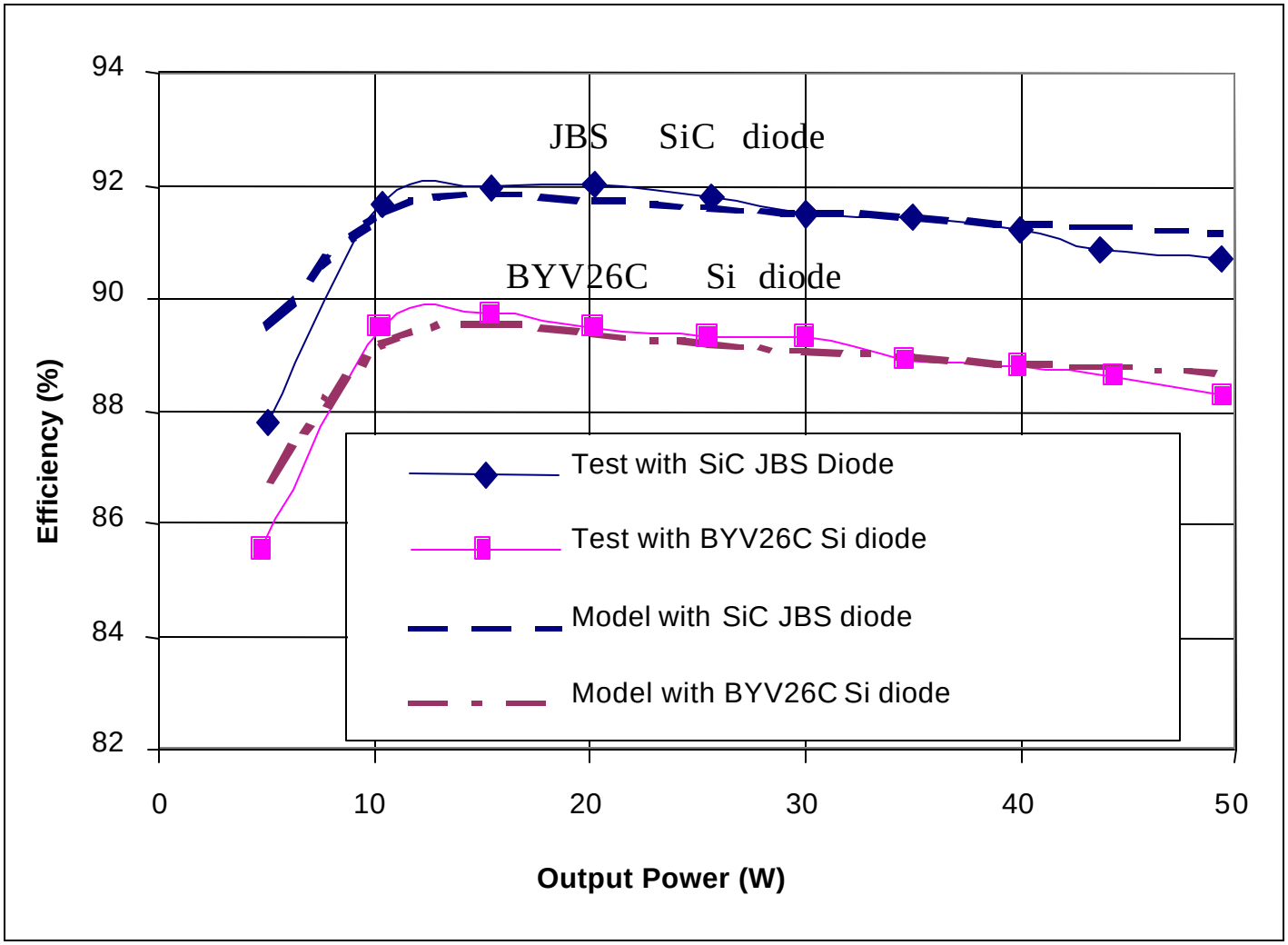


(a)

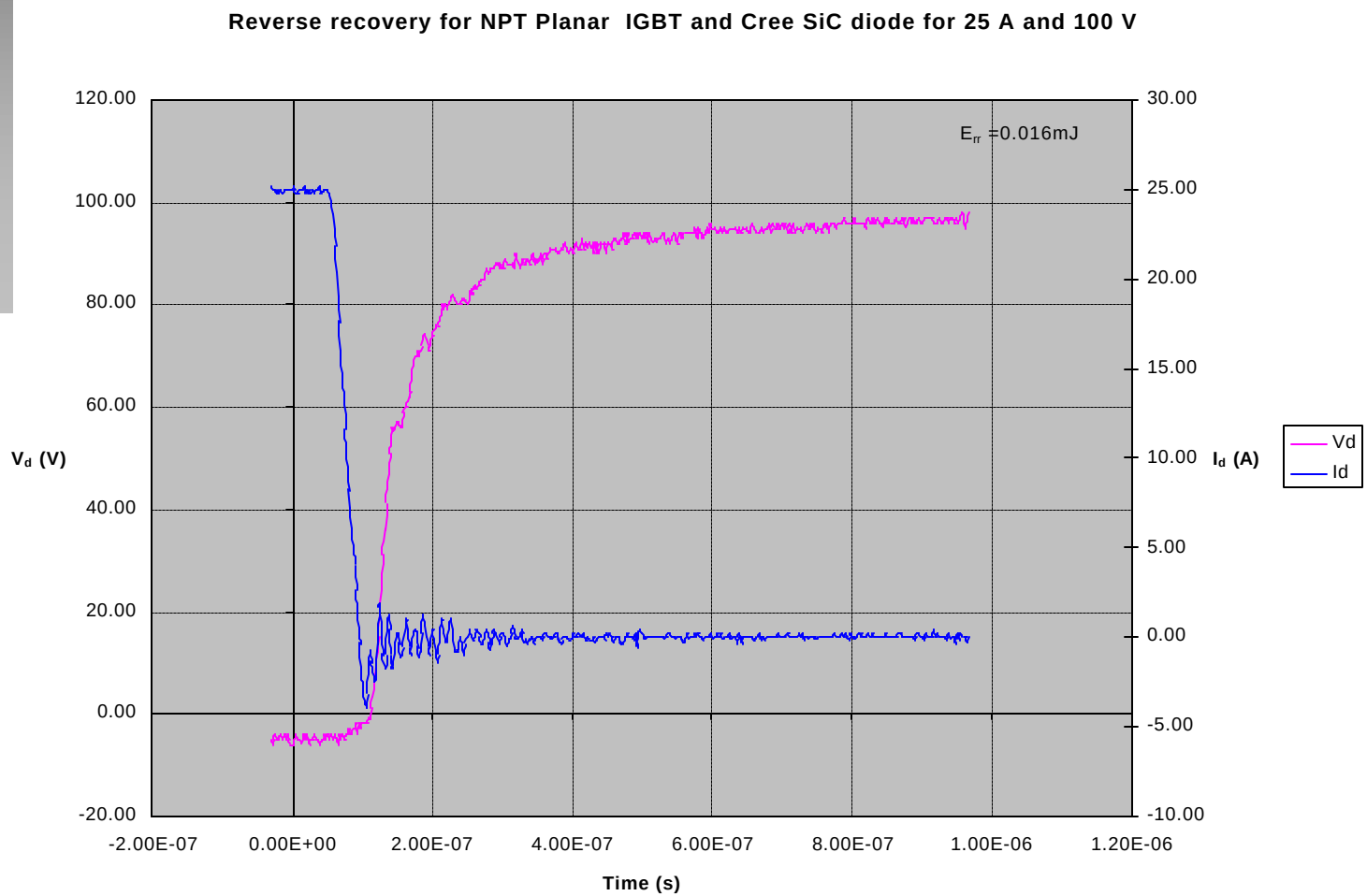


(b)

Circuit efficiency comparison

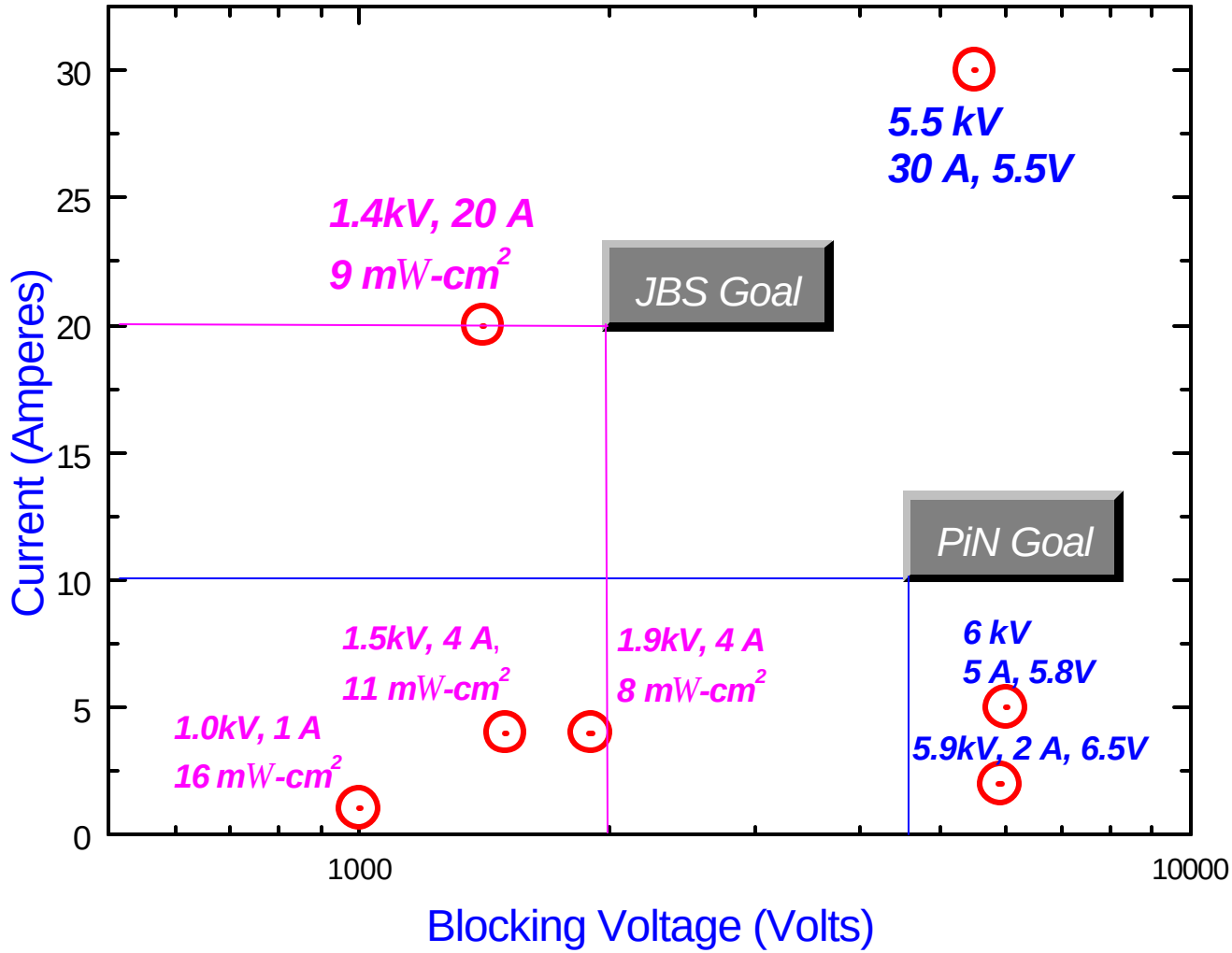


25 Amp. Cree SiC diode with Si NPT IGBT



Rockwell Data

Progress of program



Conclusions

- *5 kV, 50 A 4H-SiC PiN diodes demonstrated - exceeded program goals in terms of power levels*
- *2mmX2mm 5 kV PiN diodes tested up to 225°C*
- *Extremely fast switching (up to 1700 A/msec) demo*
- *Q_{rr}/V_F trade-off points that this is critical enabling technology for next-gen high voltage power ckts.*
- *JBS Diodes: Near theoretical - 7 to 8 mW-cm^2 R_{onsp} obtained over majority of wafers*
- *Scale-up to 20 Amps demo with no penality in Ron*
- *1410 V, 20 A and 1900 V, 4 A packaged JBS diode demo*