Silicon Carbide Devices for Demanding Power Conversion Applications

CoolCAD Electronics

Designs and Fabricates Semiconductor Devices, Chips and Subsystems for Extreme Applications

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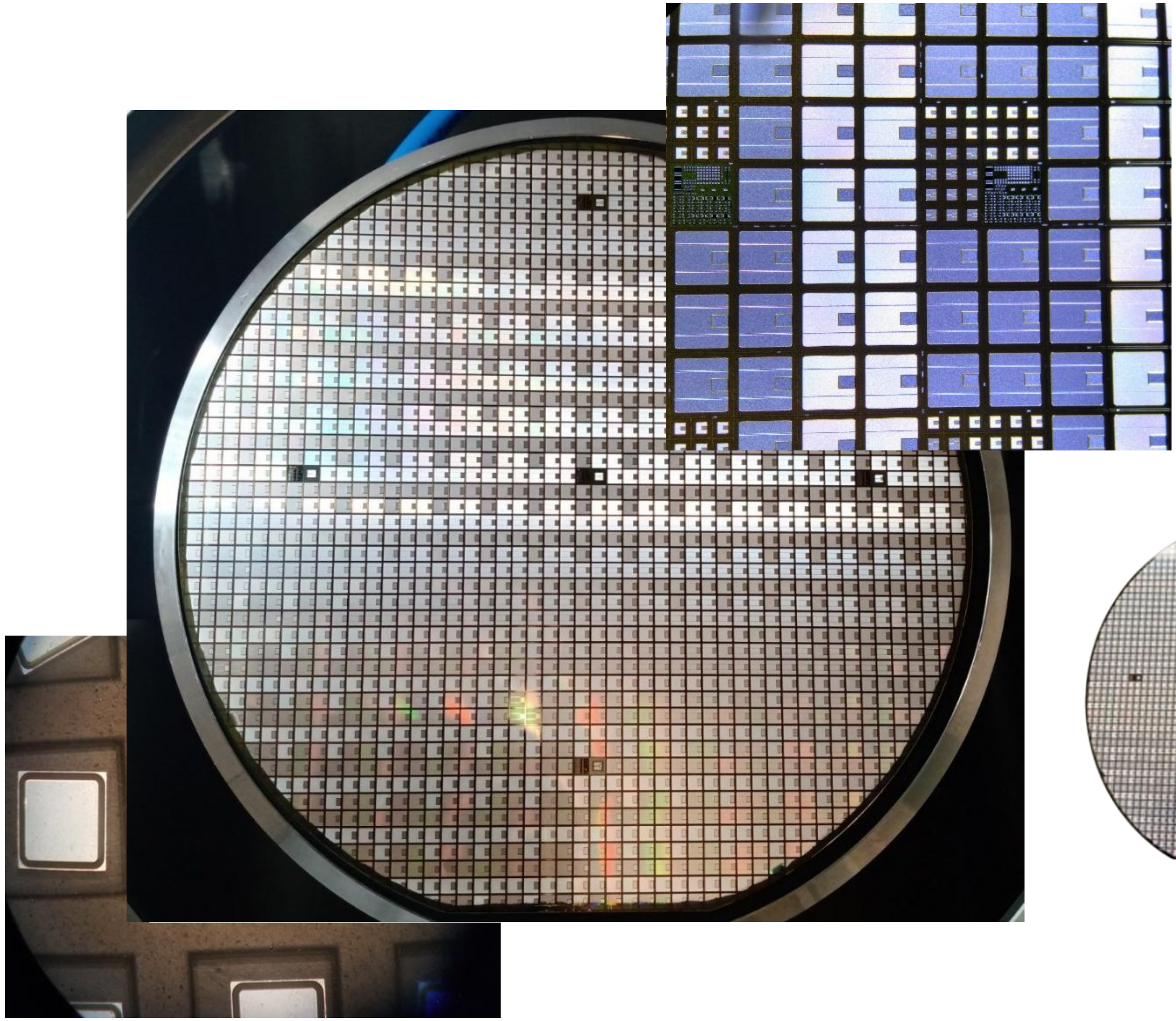
Silicon Carbide Device Fabrication Capabilities



Technology - SiC:

- MOSFET (N)
- IGBT (N and P)
- Diode (JBS, MPS, TVS)
- JFET (N and P)
- Normally-On and Normally-Off

Package:

- TO 247 3L / 4L
- TO 252 / 263
- D2PAK
- SOT 23 / 89 & TSOT 223
- SOT 227 & VPM (Modules)

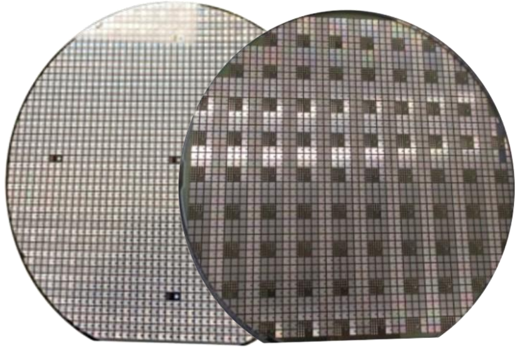
Voltage Rating:

- 650 – 3300V Standard and Custom
- >3300V Custom

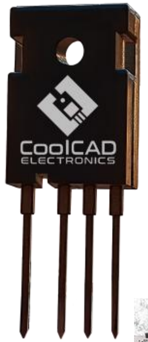
Current:

- <1A to >100A in package
- <1A to >300A on die / module

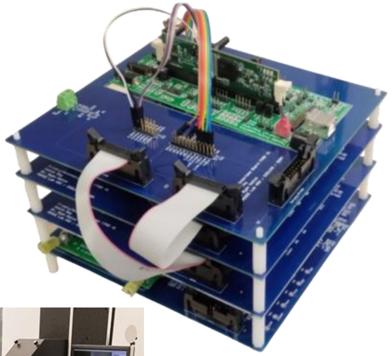
1-Wafers



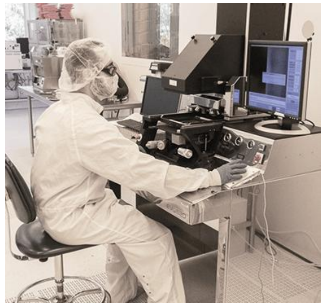
2-Components



3-Subsystems



4-Testing & Modeling



Silicon Carbide Power and Circuit Protection Devices

2000s
CoolCAD personnel helping with silicon carbide technology development: TCAD focused

2006
CoolCAD founded

2009
CoolCAD became LLC

2010s
Software development for SiC designs: TCAD and SPICE

2012
1st SiC MOSFET test chip fabrication

SiC optical sensor chips

2013-
SiC high temperature electronics

1st SiC Lateral power MOSFET Fabrication

2017

2019
1st SiC power diode fabrication

2020
1.2kV SiC power diode fabrication

2020
1.2kV SiC power MOSFET
80-120mΩ / 1.2kV

2021
100mΩ / 0.65kV
650V and 1.7kV SiC power MOSFETs

2022
3.3kV SiC power MOSFET
>200mΩ / 3.3kV

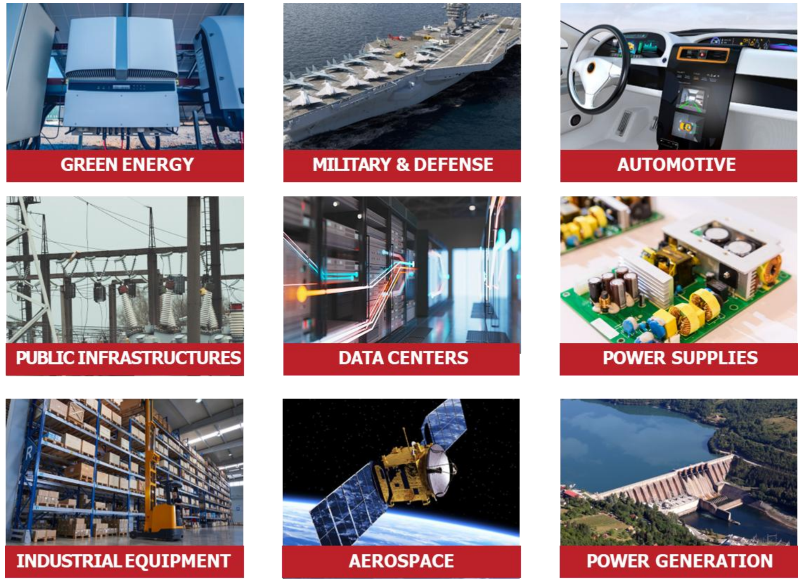
>500mΩ / 1.7kV
1.2kV SiC JFET fabrication

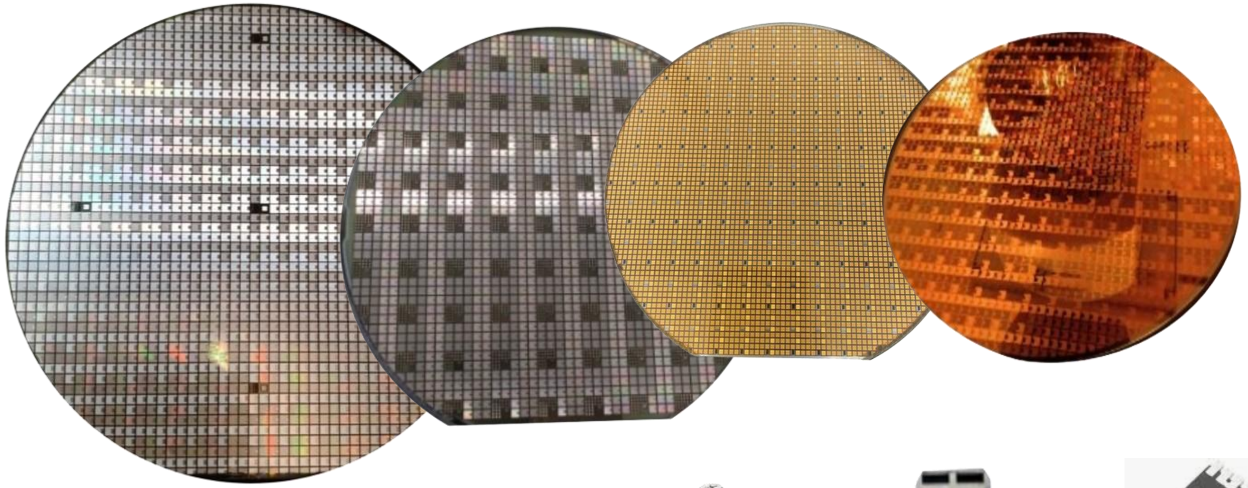
2023
Production 1.2kV MOSFET
75mΩ / 1.2kV

2024 - 2025
CoolCAD became C-Corp
60mΩ / 1.2kV

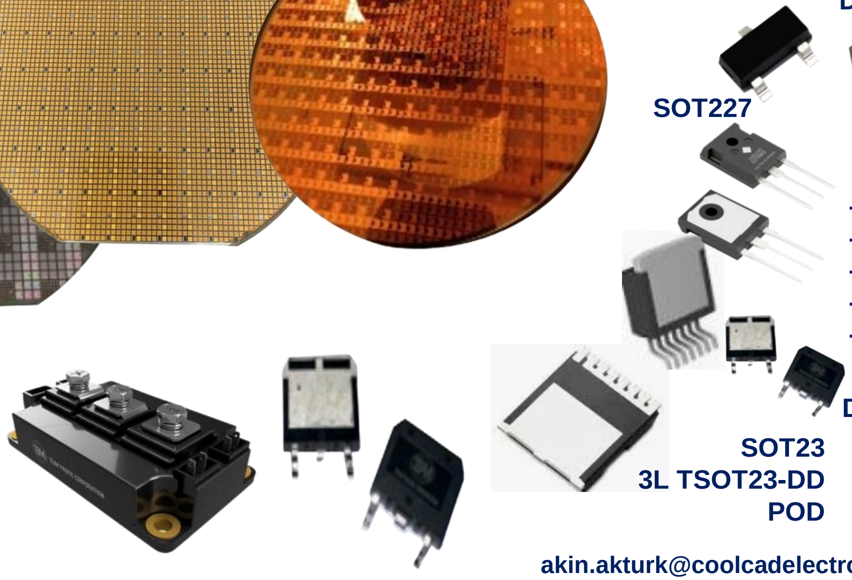
18mΩ / 1.7kV
40mΩ / 1.7kV
80mΩ / 3.3kV
20mΩ / 1.2kV

20Ω / 1.7kV
30Ω / 1.7kV





Packages



DPAK
D3PAK
SOT227
TO247
TO220
TO254
TO257
TO263
TOLL
D2PAK
SOT23
3L TSOT23-DD
POD

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Silicon Carbide Power Device Differentiators

For grid and demanding applications, we work on the following:

>3300V

- ***High voltage and low rdson devices***
  - ***1.7kV and higher***
- **Temperature hardened devices and packages**
  - **High temp rated dies, and encapsulants / molding with high Tg**
- **Reliable die attach**
  - **Solder vs Sintering; Ag vs Cu**
- ***Low failure rate devices***
  - ***At high voltages / fields, terrestrial radiation induced failures give rise to high failure rates***
  - **Oxide and material; MTTF needs to be very high**
- **Low leakage devices**

FET Type	N-Channel
Technology	SiC MOSFET
Drain to Source Voltage (Vdss)	3300V
Current - Continuous Drain (Id) at 25°C	5 – **40A** (Ta)
Drive Voltage (Max Rds On, Min Rds On)	15 – 20V
Rds On at Id, Vgs	120 – 7500mOhm
Vgs(th) at Id/10K	2 – 3V
Gate Charge (Qg) at Vgs	10 – 50nC
Vgs	15 – 20V, -5 – -8V
Input Capacitance (Ciss) at Vds	800 – 2500pF at 200V
FET Feature	Standard
Technology	100 – 300W (Tc)
Operating Temperature	175°C (Tj)
Mounting Type	Through Hole
Supplier Device Package	TO-247
Package / Case	TO-247-4L

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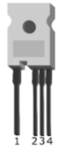
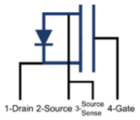
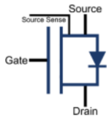
Devices for Solar Inverter Applications

CC_17_40_744L		  		MOSFET	Off (Standard - Enhancement mode)	1.7kV	40mΩ	Typical BV 2300V	TO-247-4L	230	16	15200

In wafer form: And packaged in TO47-4L

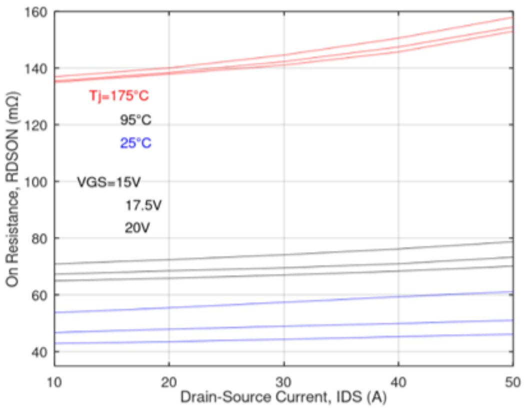


Figure 5: On-resistance vs. drain current.

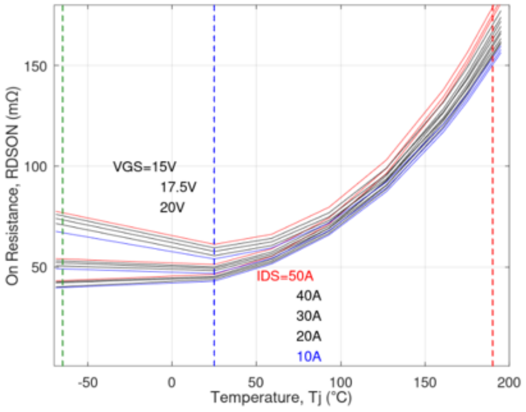


Figure 6: On-resistance vs. temperature. Dashed vertical lines indicate to room (25◦C), high (190◦C) and low (-65◦C) temperatures.

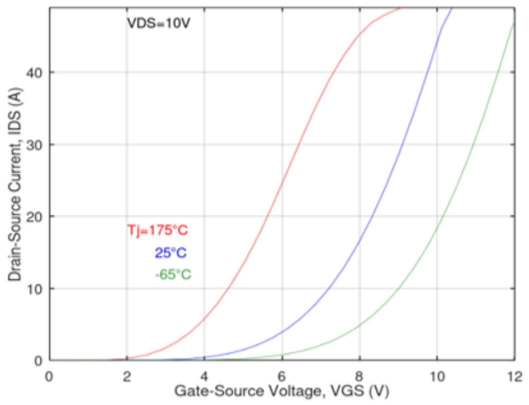


Figure 7: Transfer characteristics†.

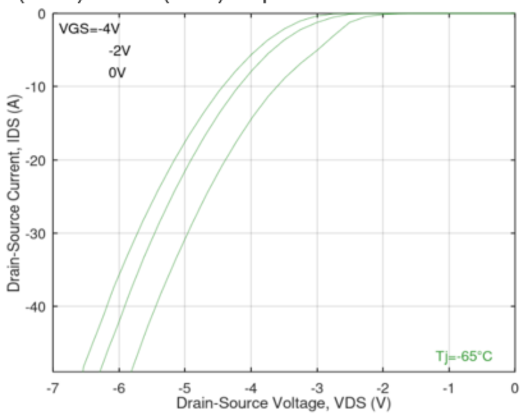
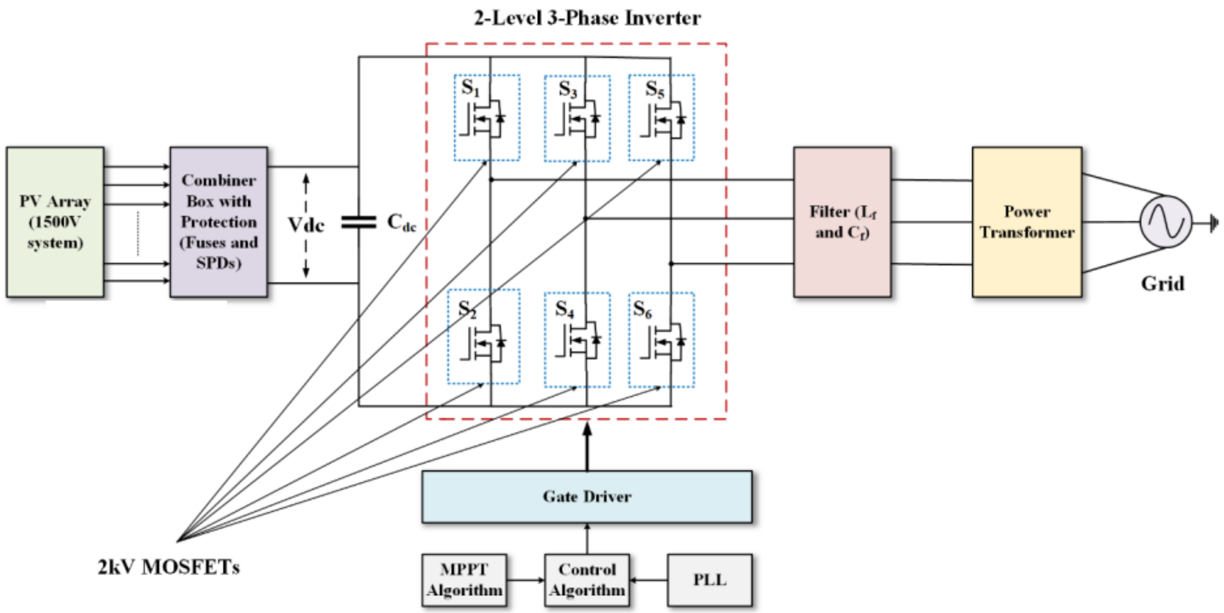


Figure 8: Low temperature body diode characteristics†.

Solar central inverter schematic



- *No. of panels in a string* – 32
- *Max. voltage per string* – 32xVoc = 32x45.8 = 1465.6V (this is under 1500V, which is the maximum input voltage rating of the central inverter)
- *Max. MPPT voltage* – 32xVmpp = 21x37.1 = 1187.2V (this is in MPPT range of the inverter 935-1500V)

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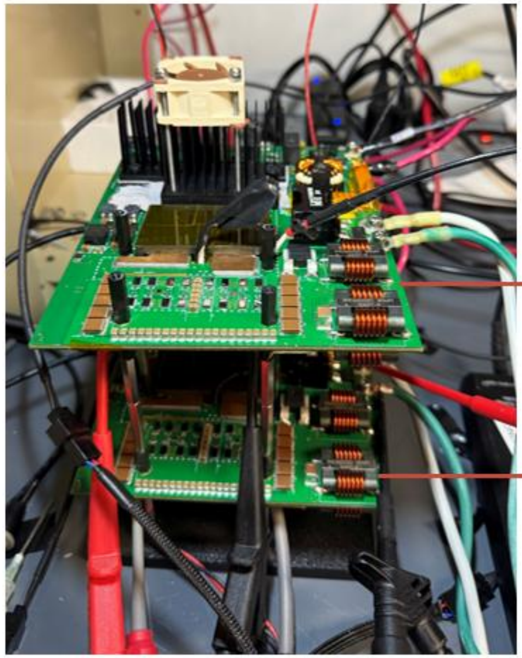
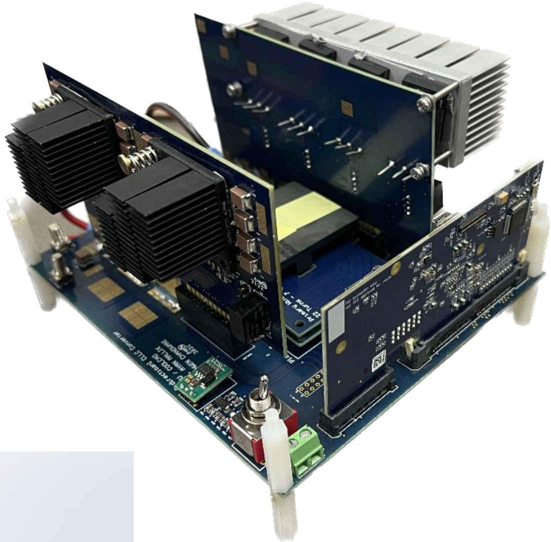
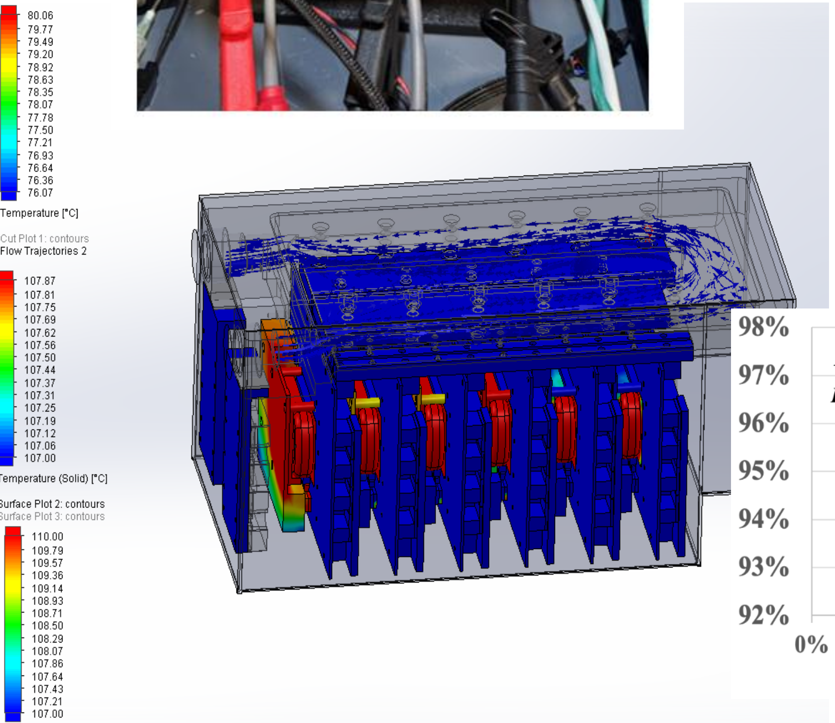
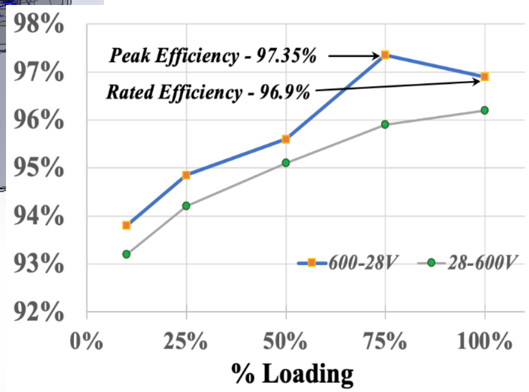
Power Circuits and Subsystems for Extreme Environments









•Leakage integrated High Frequency Planar Transformer (HFPT) is designed and implemented with optimized winding configuration to ensure reduced winding losses, enabling a power dense yet efficient magnetic solution.

•Zero Voltage Switching (ZVS) based turn on is obtained for the primary side switches during forward power flow, as well as ZVS based turn on is obtained for the primary and secondary side switches during reverse power flow, for a wide gain and load range for efficient power conversion.

•Synchronous Rectification (SR) based switching is achieved for the secondary side during forward power flow to ensure significantly reduced turn-off losses.

•Peak efficiency is measured at 97.35% for forward power flow and 95.93% for reverse power flow operation.

•Conducted EMI compliance is met according to MIL-STD-461G for both forward and reverse power flow.

•Terminal voltage ripple and overshoot/undershoot are designed and measured to comply with MIL – PRF – GCS600A (for 600V) and MIL – STD – 1275D (for 28V).

S. Dey, A. Mallik, **A. Akturk**, "Investigation of ZVS criteria and Optimization of Switching Loss in a Triple Active Bridge Converter using Penta-Phase-Shift Modulation," IEEE Journal of Emerging and Selected Topics in Power Electronics, 10(6) 7014-7028, 2022.

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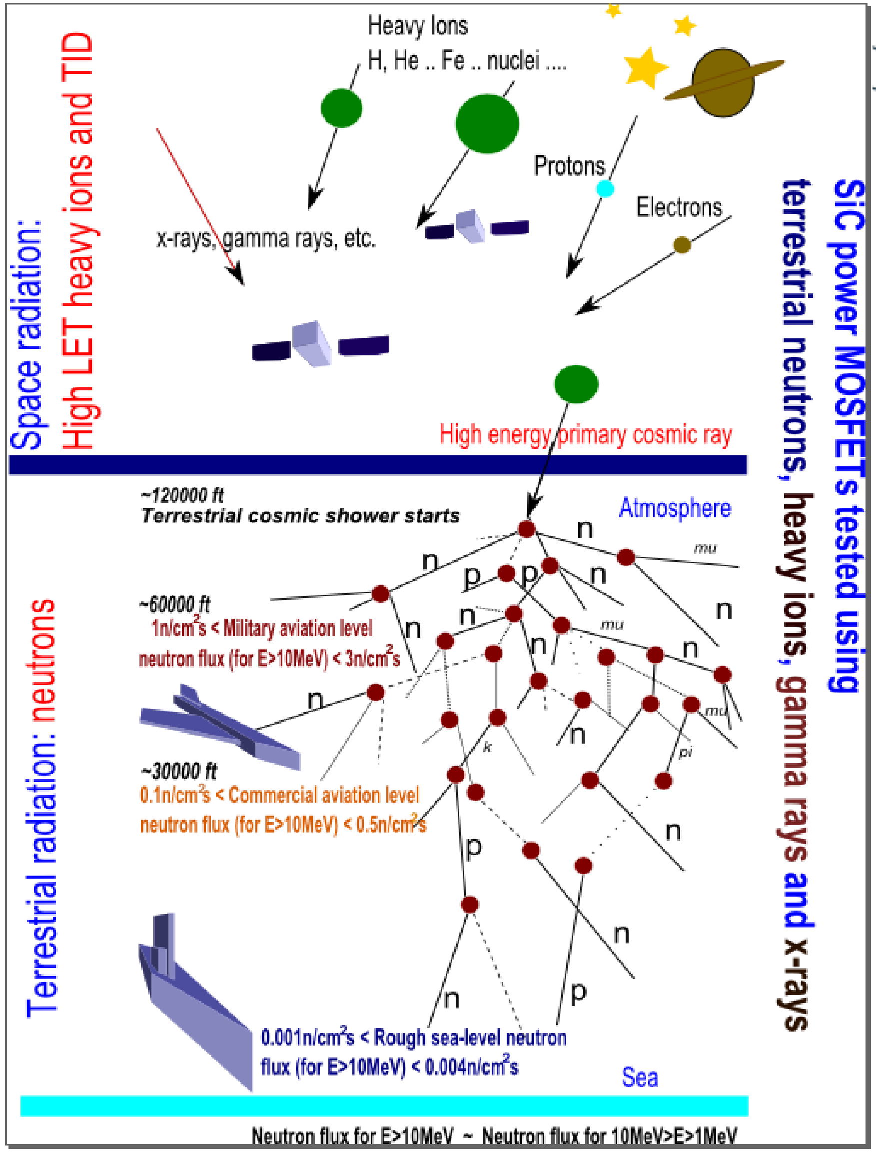
Devices with Low Failure Rates

Terrestrial Radiation can damage the grid!

- *Space radiation includes particle and ionizing dose radiation effects.*
- ***Terrestrial radiation starts with energetic particles from outer space penetrating the magnetic field around Earth, and then interacting with gases in the atmosphere, giving rise to a cosmic / neutron shower.***
- ***Semiconductor power devices are susceptible to terrestrial and extraterrestrial radiation to different extent.***



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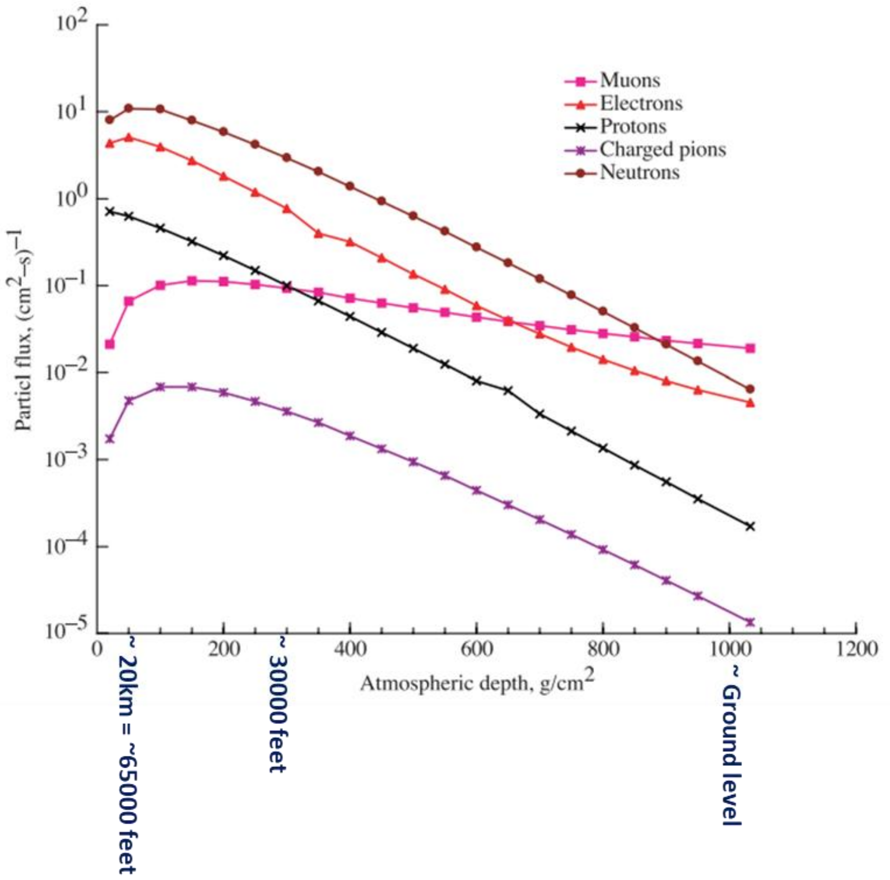
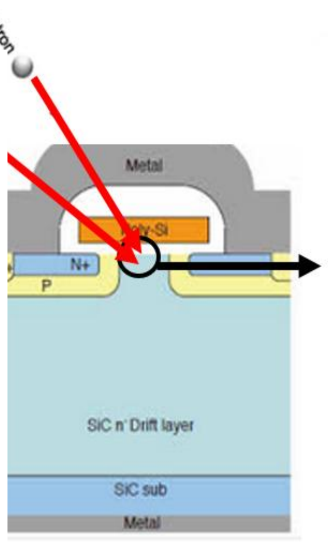
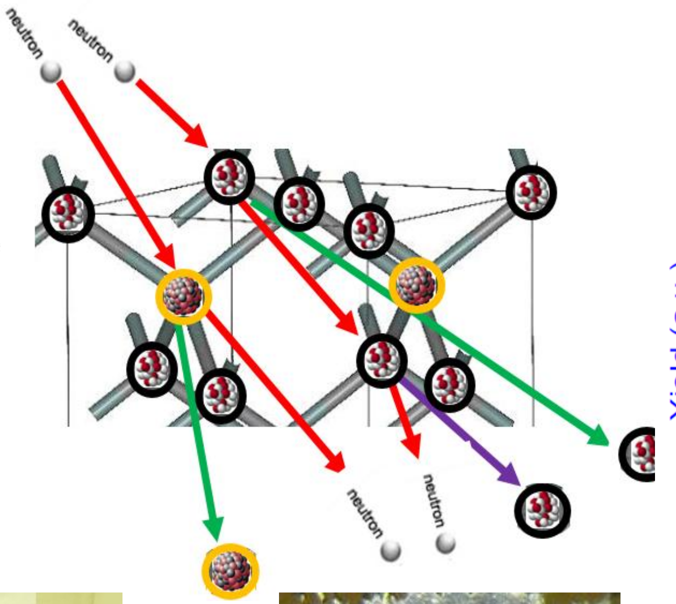
Devices with Low Failure Rates

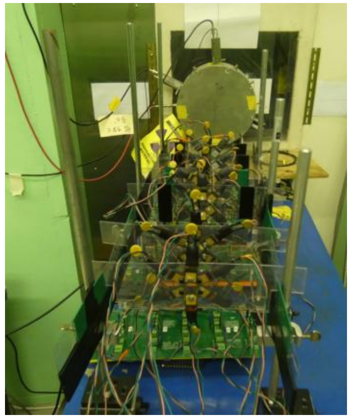
Concern:

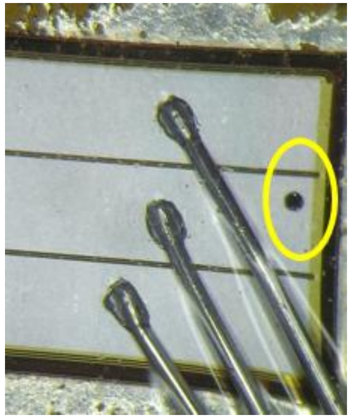
Terrestrial neutrons are relatively abundant, can have high energies and interact with lattice atoms.

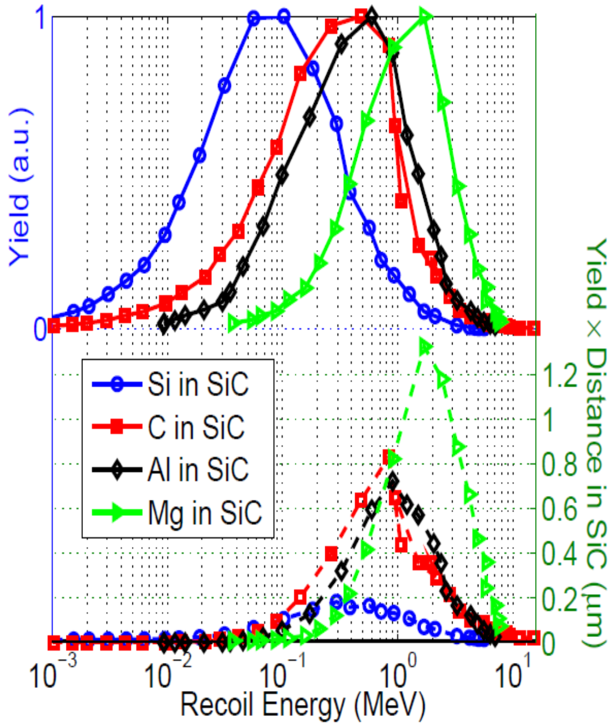












A. Akturk, J. McGarrity, N. Goldsman, D. Lichtenwalner, B. Hull, D. Grider, R. Wilkins, "Terrestrial neutron-induced failures in silicon carbide power MOSFETs and diodes," *IEEE Transactions on Nuclear Science* **65(6)**, 1248-1254 (2018).

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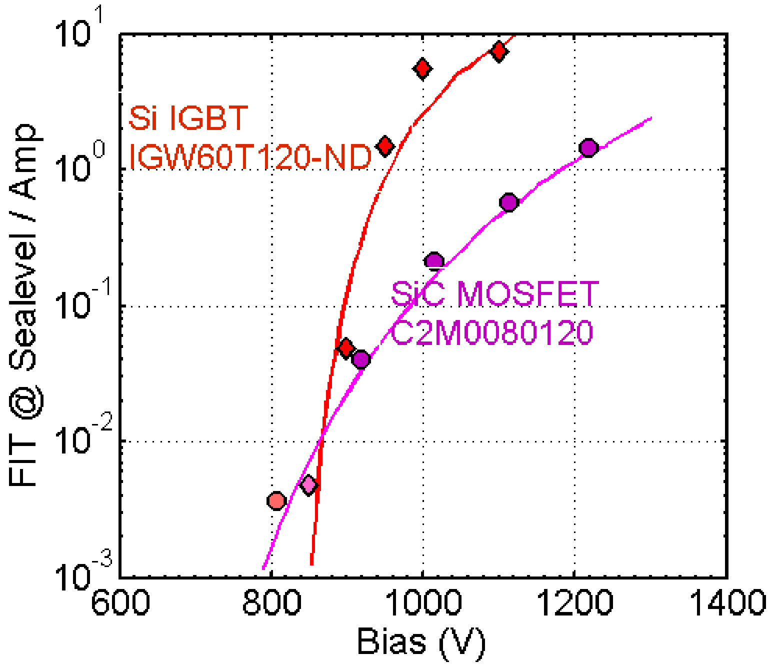
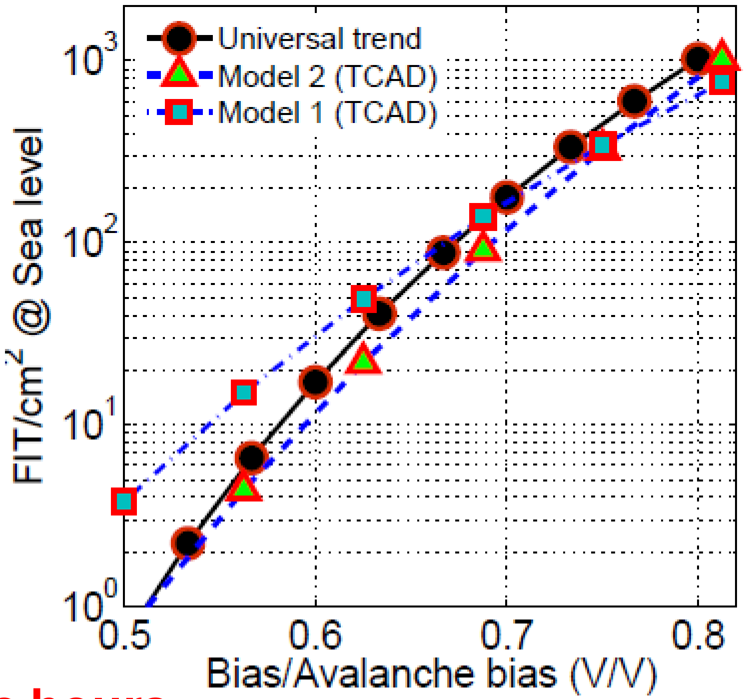
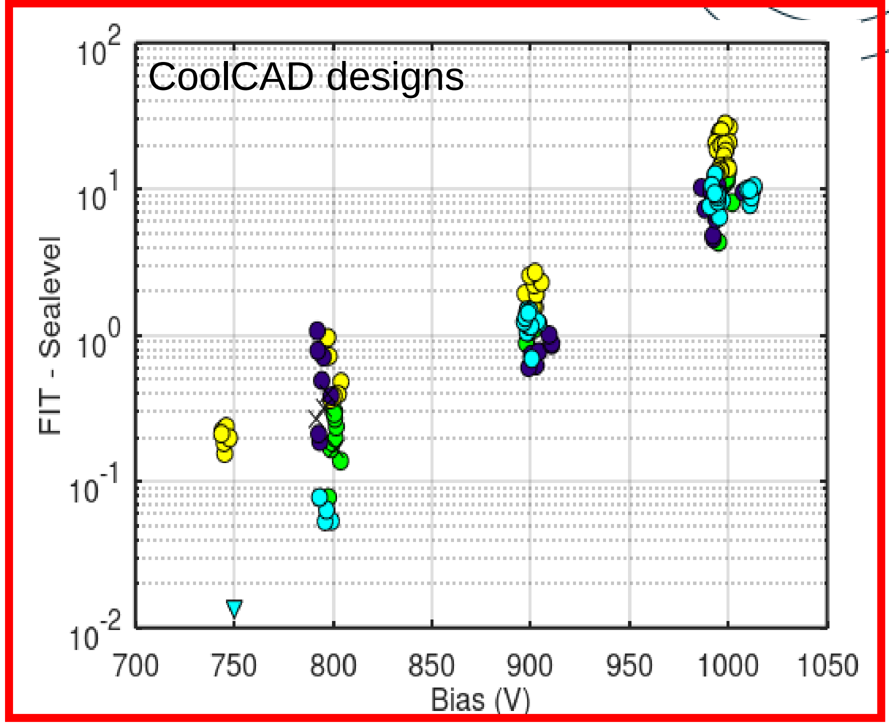
Devices with Low Failure Rates







FIT : Failure in one billion device hours

Design and process change can suppress failure rates at lower biases.

-A. Akturk, R. Wilkins, K. Gunthoti, S. A. Wender, N. Goldsman, "Energy dependence of atmospheric neutron-induced failures in silicon carbide power devices," IEEE Transactions on Nuclear Science 69(4), 900-907 (2022).

-A. Akturk, R. Wilkins, J. McGarrity, B. Gersey, "Single event effects in Si and SiC Power MOSFETs due to terrestrial neutrons," *IEEE Transactions on Nuclear Science* **64(1)**, 529-535 (2017).

-A. Akturk, J. McGarrity, N. Goldsman, D. Lichtenwalner, B. Hull, D. Grider, R. Wilkins, "Predicting cosmic ray-induced failures in silicon carbide power devices," IEEE Transactions on Nuclear Science 66(7), 1828-1832 (2019).

-A. Akturk, J. McGarrity, N. Goldsman, D. Lichtenwalner, B. Hull, D. Grider, R. Wilkins, "Terrestrial neutron-induced failures in silicon carbide power MOSFETs and diodes," IEEE Transactions on Nuclear Science 65(6), 1248-1254 (2018).

-D. J. Lichtenwalner, A. Akturk et al, "Reliability of SiC power devices against cosmic ray neutron single-event burnout," Proceedings of Int. Conference on Silicon Carbide and Related Materials (ICSCRM), (2017).

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Summary

CoolCAD Electronics designs and fabricates wide bandgap silicon carbide (SiC) semiconductor transistors and integrated circuits (ICs) for applications in ***Power Electronics***, ***Green Energy***, ***High-Temperature Electronics*** and ***Deep Ultraviolet (UV) Optical Electronics***

Grid needs high voltage devices that are reliable / have low failure rates.

Low failure rates require low intrinsic failures. It also requires hardening against the background radiation.

We engineer devices with low failure rates and high-power ratings.

Grid may also need devices tailored for certain applications: Solar power generation, fast charging, nano grids, micro grids……

We also work on power conversion circuits for nano grids and extreme environment DC-DC and DC-AC converters.

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