Terrestrial and Space Radiation Effects on SiC Power Devices

Akin Akturk, James McGarrity, Neil Goldsman, Zeynep Dilli, Mitch Gross, Adam Markowski

Partially supported by NASA, PowerAmerica, ARL
Thank you
Terrestrial and Space Radiation

Common knowledge:
I did not know there is any radiation at the sea-level!

Terrestrial Qualification requires:
Terrestrial neutron radiation tests
There are only two “true” terrestrial neutron simulators in the World: One of them is in the US, at Los Alamos.

Common knowledge:
Solar flares, aurora borealis, etc. Satellites are up there so it must not be bad!

Space Qualification requires:
Ionizing dose radiation tests
Heavy ion radiation tests
And sometimes proton and electron radiation tests since they are the most abundant.
Terrestrial Radiation

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

Possible knock-ons include Si and C with energies as high as 15 MeV.
Los Alamos Terrestrial Neutron Simulator

Best terrestrial neutron simulator. There is only one such simulator in the US.

http://wnr.lanl.gov/_assets/flight_paths/flight_paths.php
Terrestrial Neutron Tests

Pre Exp: Pre-electrical characterization
Pre Exp: Design and fabricate test boards

Exp: Track/record drain voltage on each device
Exp: Track/record neutron fluence
Exp: Continue until all devices fail or enough time/fluence reached
Exp: Track/record fast current transients for some devices

Post Exp: Calculate and plot FIT curves
Post Exp: Post-electrical characterization of survived parts
Post Exp: Post failure analysis
Failure In Time Curves of Si and SiC Parts

SiC has lower FITs at rated voltage compared to similarly rated Si

FIT : Failure in one billion device hours
**Neutron Induced Failures: How to Improve**

A - Correlate damage location with vulnerable device areas

B - Failure initiating transients provide clues regarding the nature of failure

C - Simulate devices

Harden against neutrons

![Graph showing critical charge for failure](image)
Space Radiation: 1- Heavy Ions

Example Galactic Cosmic Ray (GCR) and Solar Particle Event (SPE) spectra
[C. Poivey, “Radiation Hardness Assurance for Space Systems” report,
http://radhome.gsfc.nasa.gov/radhome/papers/nsrec02_sc_poivey.pdf]

https://www.gsi.de/work/forschung/biophysik/forschungsfelder/space_radiation_physics.htm
Heavy Ion Tests

Heavy ion testing at TAMU

Xenon with the 15 MeV/amu tune

Fluence in the $10^3$-$10^5$ ions/cm$^2$ range

Flux $\approx 10 - 10^3$ ions/cm$^2$s

Pre and Post Tests
Heavy Ion Induced Transients

A recovered heavy ion induced transient

Recovery does not mean absence of latent damage

Heavy Ion Test Summary:

- At high voltages, SiC power MOSFETs immediately fail with a single strike (x >500V)
- At medium voltages, SiC power MOSFETs fail post radiation due to latent gate damage (150V < x < 500V)
- At very low voltages, they do survive (x < 150V)
Example Heavy Ion Test Data

Dev # 70 300V VDS 0V VGS ~1e4 ions/cm² 22.7 ions/cm² 8.9rad

POST PRE

VTH = 2.1952
VTH = 2.6181

Blocking >1200V

VFWD = -3.5646
VFWD = -3.5689

FAIL
Example Heavy Ion Test Data

Dev # 91
500V VDS
0V VGS
~1e3 ions/cm²
21.5 ions/cm²s
0.89 rad

VTH = 2.8396
VTH = 2.8592
VFWD = -3.5725
VFWD = -3.5721

Blocking <200V
FAIL
Heavy Ion Fast Transients

We can determine failure mode to improve radiation response / hardness
Space Radiation: 2- Total Ionizing Dose

1- Positive charging of the oxide due to ionizing dose radiation (gamma, x-ray, e-beam etc.)

2- Increases in interface state densities over time

Most commonly used source for TID testing is Co60

We are experts in pursuing TID experiments to measure bulk trap densities.

ΔVTH = -3.8×10^{-8}D (rads )×Tox^2 (nm^2) \textit{if all holes trap at the interface and all electrons are swept out}

<5 % hole trapping

Excellent result for an unhardened thick oxide
Gen3 - Co60 and X-ray Results

- Co60 experiments were pursued at the Penn State Breazeale Nuclear Reactor facility using a gamma cell
- X-ray experiments were pursued at Prairie View A&M
• SiC power MOSFETs exhibit excellent terrestrial neutron and ionizing dose radiation response; however, their heavy ion response needs to be improved significantly for their potential use in space applications

• Similar trends have been observed for SiC power diodes as well

• Each and every SiC power device needs to be tested for terrestrial neutrons for commercial applications, and additional tests are required for space applications

• CoolCAD can perform terrestrial neutron, heavy ion, gamma, x-ray, e-beam, proton, and various other radiation tests for qualification and characterization

• Besides qualification, these tests can provide device design and process information, not otherwise measurable by electrical means

• CoolCAD low power SiC components fare well under heavy ion, gamma and x-ray exposure due to preliminary tests