National Aeronautics
and Space Administration

Update on Wide Bandgap (WBG) Device Radiation Hardness Assurance

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Abbreviations and Acronyms

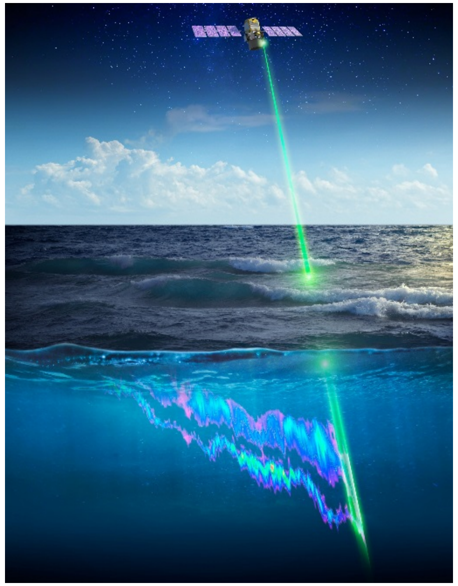
Acronym	Definition
BJT	Bipolar Junction Transistor
BV_{DSS}	Drain-Source Breakdown Voltage
DDD	Displacement Damage Dose
ETW	Electronics Technology Workshop
GaN	Gallium Nitride
GCR	Galactic Cosmic Ray
HEMT	High Electron Mobility Transistor
I_D	Drain Current
IEEE	Institute of Electrical and Electronics Engineers
JBS	Junction Barrier Schottky
JFET	Junction Field Effect Transistor
LBNL	Lawrence Berkeley National Laboratory
LET	Linear Energy Transfer
MOSFET	Metal Oxide Semiconductor Field Effect Transistor

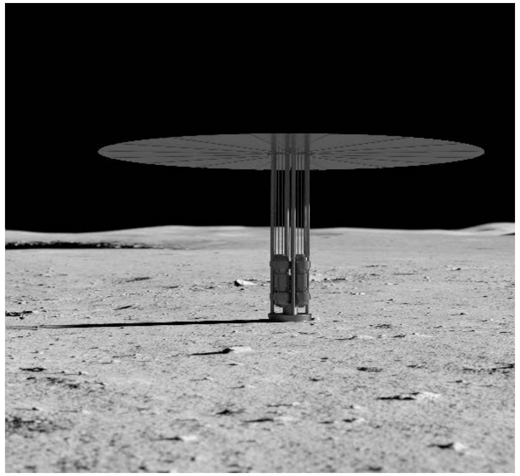
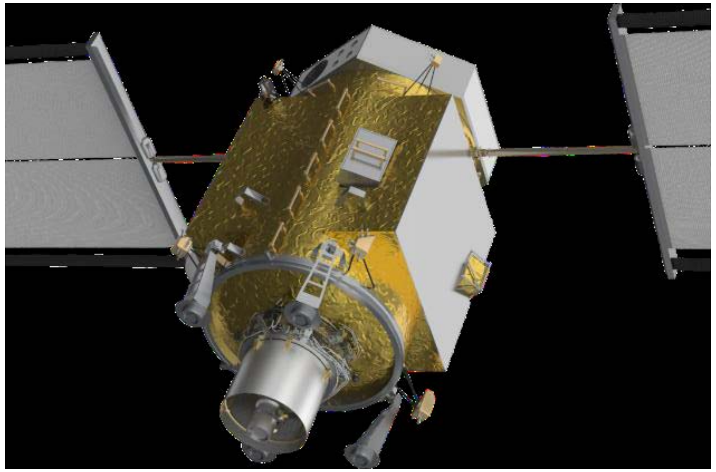
Acronym	Definition
NSREC	Nuclear and Space Radiation Effects Conference
REAG	Radiation Effects & Analysis Group
RF	Radio Frequency
RHA	Radiation Hardness Assurance
SEB	Single-Event Burnout
SEE	Single-Event Effect
Si	Silicon
SiC	Silicon Carbide
SMD	Science Mission Directorate
SOA	State Of the Art; Safe Operating Area
STMD	Space Technology Mission Directorate
SWAP	Size, Weight, And Power
TAMU	Texas A&M University cyclotron facility
TCAD	Technology Computer-Aided Design
VDMOS	Vertical Double-diffused MOSFET
V_{DS}	Drain-Source Voltage

Outline

- Enhancement-mode power GaN activities
  - Heavy-ion radiation test updates
  - Upcoming test plans
- RF GaN activities
  - Radiation test method evaluation plans
  - GSFC test capability development
- SiC power device research activity
  - SiC single-event effect failure mechanisms

NASA "Pulls" for WBG power technology include
science instrument and avionic & space power applications

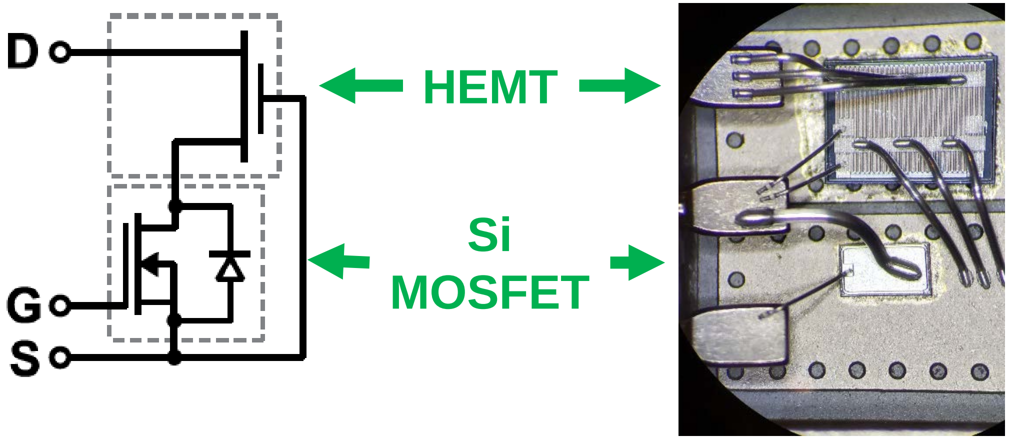



images: NASA

Single-Event Effect (SEE) Test Results: Normally-Off GaN HEMT

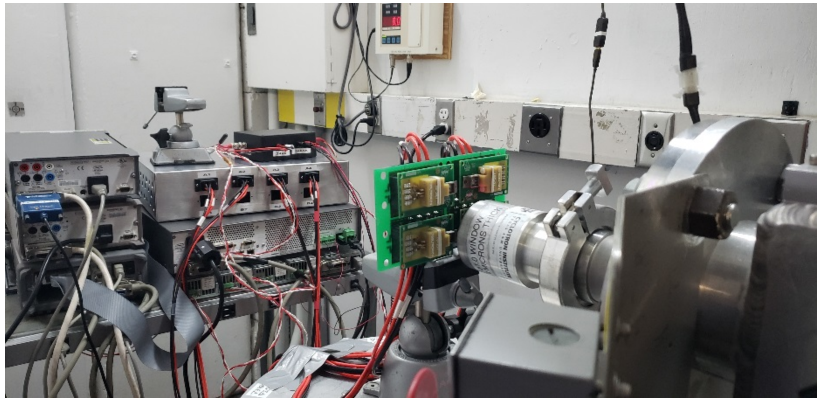
- **SSDI SGF15E100 1000-V, 15 A:**

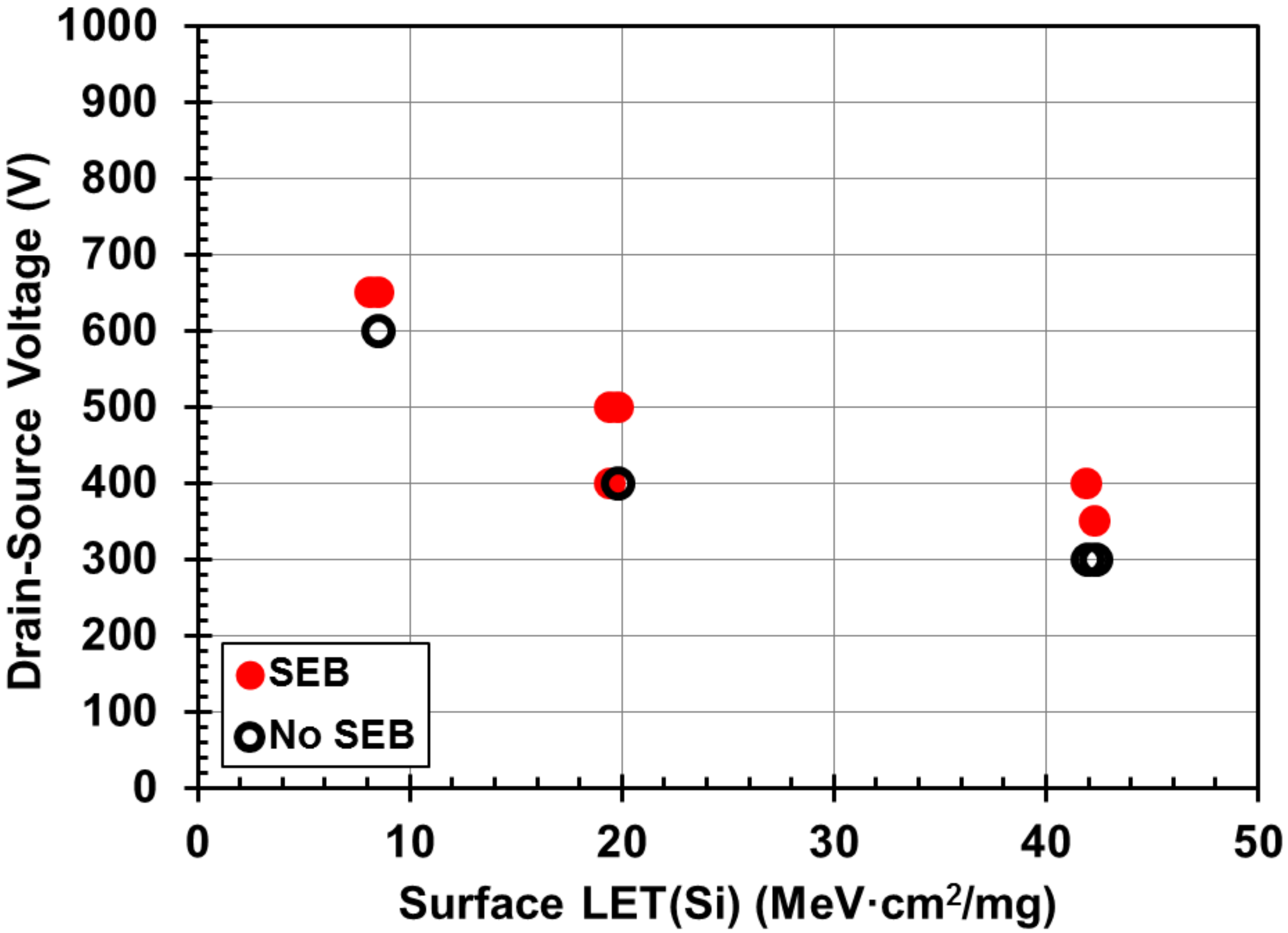


- **Cascoded design to achieve normally-off operation**
- **MIL-PRF-19500 S-Level screening available**

SEE Test Results: Normally-Off GaN HEMT

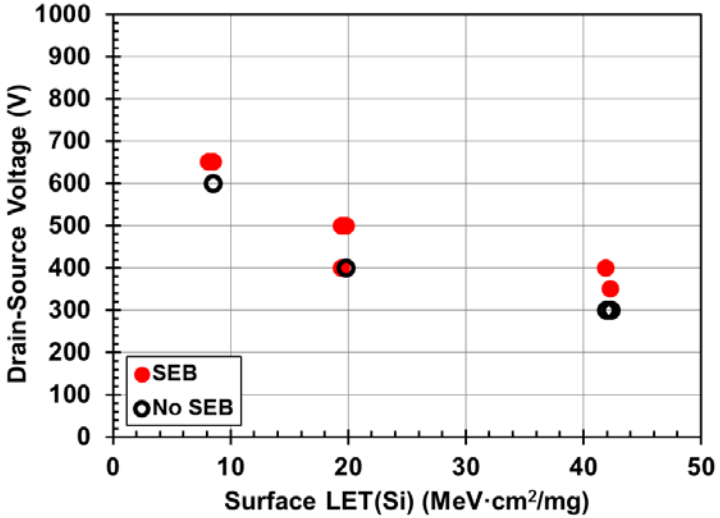
- **SSDI SGF15E100 1000-V, 15 A:**
- **SEB at 350 V_{DS} for LET(Si) = 42 MeV-cm^2/mg**

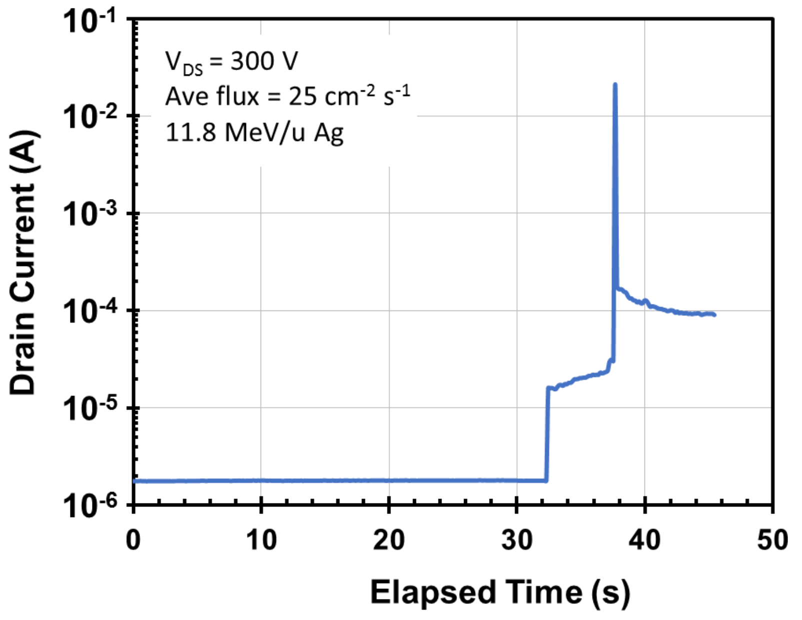


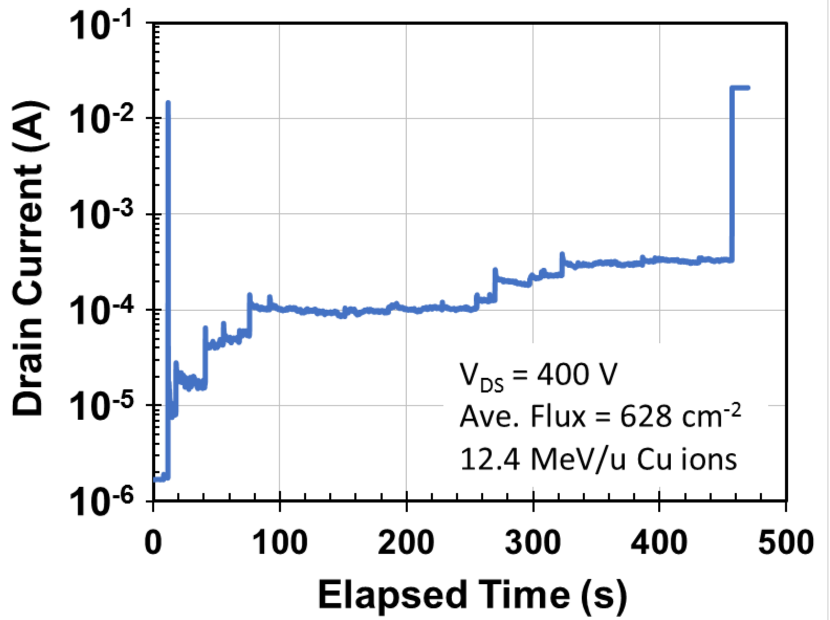


SEE Test Results: Normally-Off GaN HEMT

- **SSDI SGF15E100 1000-V, 15 A:**
- **SEB at 350 V_{DS} for LET(Si) = 42 MeV-cm²/mg**
- **Non-catastrophic degradation of I_D**
  - At higher LET (Ag), becomes substantial (mA levels) near threshold V_{DS} for SEB
  - With lighter Cu ions, can reach standard test fluences to identify low cross-section SEB event

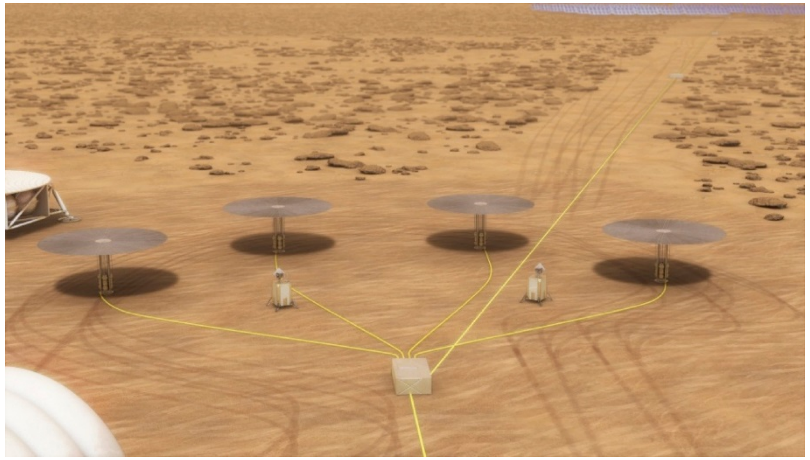






Planned eGaN Activities

- **Joint heavy-ion SEE test with a GaN manufacturer:**
  - **Evaluate our new power device test board featuring low parasitics**
    - Lower risk of systematic influences on test data
  - **Validate manufacturer test data**
- **Combined-effects testing for displacement damage dose (DDD) influence on SEE**
  - **STMD Kilopower Project in partnership with GaN supplier**



Fission nuclear power system for planetary surface habitation.

Image: NASA

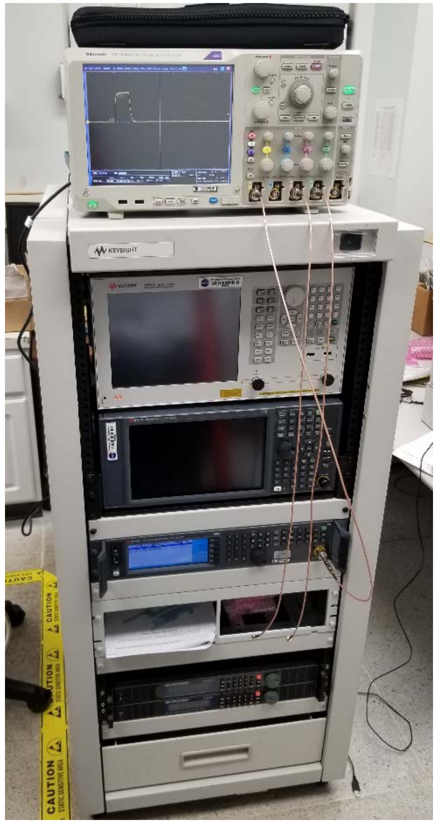
RF GaN Test Plans and Capability

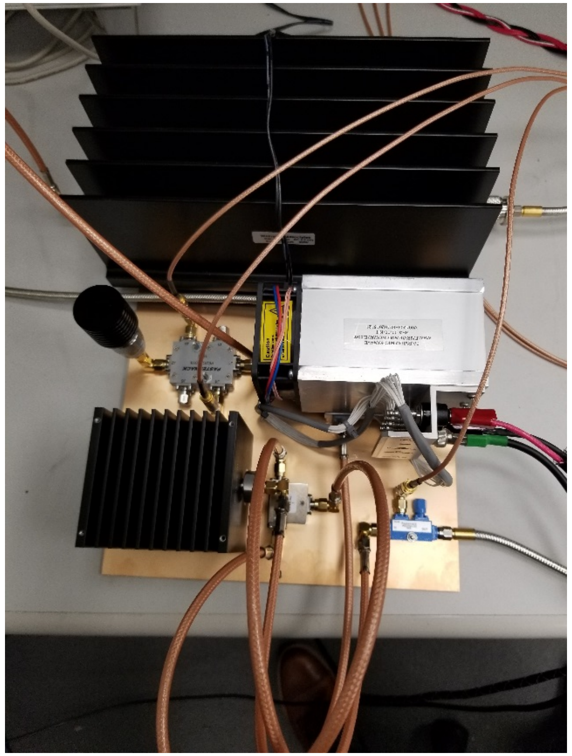
Plan:

- **RF mode vs. static mode for catastrophic SEE assessment**
  - Increase the body of data and devices evaluated to support test method standards

GSFC REAG Infrastructure Development:

- **RF test setup:**
  - Currently for high-wattage S & C bands;
  - Ability to expand up to Ka band
  - Power amplifier uses GaN HEMT technology!



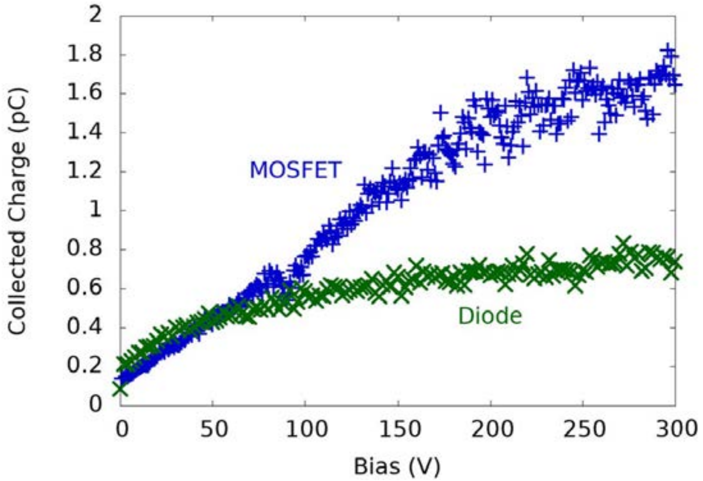


SiC Power Device Research Activity

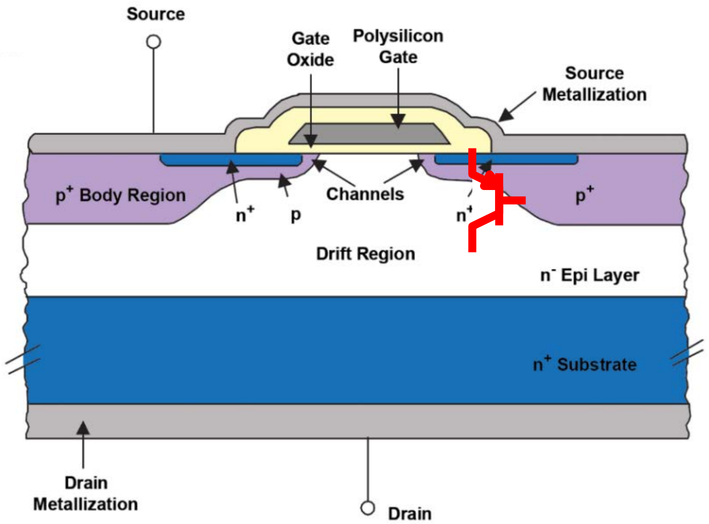
- **NASA STMD Early-Stage Innovation (ESI) grants funded efforts to increase our understanding of the heavy-ion radiation effects in SiC power devices**
  - **Publications:**
    - [1] R. A. Johnson, *et al.*, "Unifying Concepts for Ion-Induced Leakage Current Degradation in Silicon Carbide Schottky Power Diodes," *IEEE Trans Nucl Sci,* vol. 67, pp. 135-139, 2020.
    - [2] D. R. Ball, *et al.*, "Ion-Induced Energy Pulse Mechanism for Single-Event Burnout in High-Voltage SiC Power MOSFETs and Junction Barrier Schottky Diodes," *IEEE Trans Nucl Sci,* vol. 67, pp. 22-28, 2020.
    - [3] R. A. Austin, *et al.*, "Inclusion of Radiation Environment Variability for Reliability Estimates for SiC Power MOSFETs," *IEEE Trans Nucl Sci,* vol. 67, pp. 353-357, 2020.
    - [4] J. A. McPherson, *et al.*, "Mechanisms of Heavy Ion Induced Single Event Burnout in 4H-SiC Power MOSFETs," presented at ICSCRM, Kyoto, Japan, 2019.
    - [5] J. A. McPherson, *et al.*, "Heavy Ion Transport Modeling for Single-Event Burnout in SiC-Based Power Devices," *IEEE Trans Nucl Sci,* vol. 66, pp. 474-481, 2019.
    - [6] R. A. Johnson, *et al.*, "Enhanced Charge Collection in SiC Power MOSFETs Demonstrated by Pulse-Laser Two-Photon Absorption SEE Experiments," *IEEE Trans Nucl Sci,* vol. 66, pp. 1694-1701, 2019.
    - [7] D. R. Ball, *et al.,* "Estimating Terrestrial Neutron-Induced SEB Cross Sections and FIT Rates for High-Voltage SiC Power MOSFETs," *IEEE Trans Nucl Sci,* vol. 66, pp. 337-343, 2019.
    - [8] A. F. Witulski, *et al.*, "Single-Event Burnout Mechanisms in SiC Power MOSFETs," *IEEE Trans Nucl Sci,* vol. 65, pp. 1951-1955, 2018.
    - [9] A. F. Witulski, *et al.*, "Single-Event Burnout of SiC Junction Barrier Schottky Diode High-Voltage Power Devices," *IEEE Trans Nucl Sci,* vol. 65, pp. 256-261, 2018.
    - [10] A. Javanainen, *et al.*, "Molecular Dynamics Simulations of Heavy Ion Induced Defects in SiC Schottky Diodes," *IEEE Trans Dev Mater Rel,* vol. 18, pp. 481-483, 2018.
    - [11] K. F. Galloway, *et al.*, "Failure Estimates for SiC Power MOSFETs in Space Electronics," *Aerospace,* vol. 5, p. 67, 2018.
  - **Look for more presentations at IEEE NSREC 2020!**

Highlights of SiC SEB Mechanism Research

Despite the same epitaxial structure, MOSFET shows charge amplification

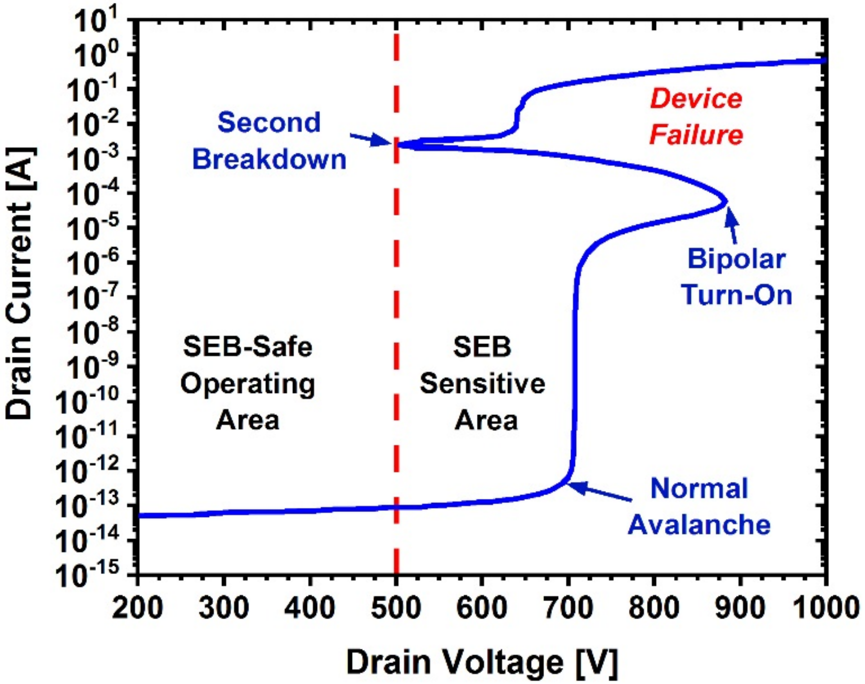


R. A. Johnson, *et al.*, *IEEE TNS* 2019



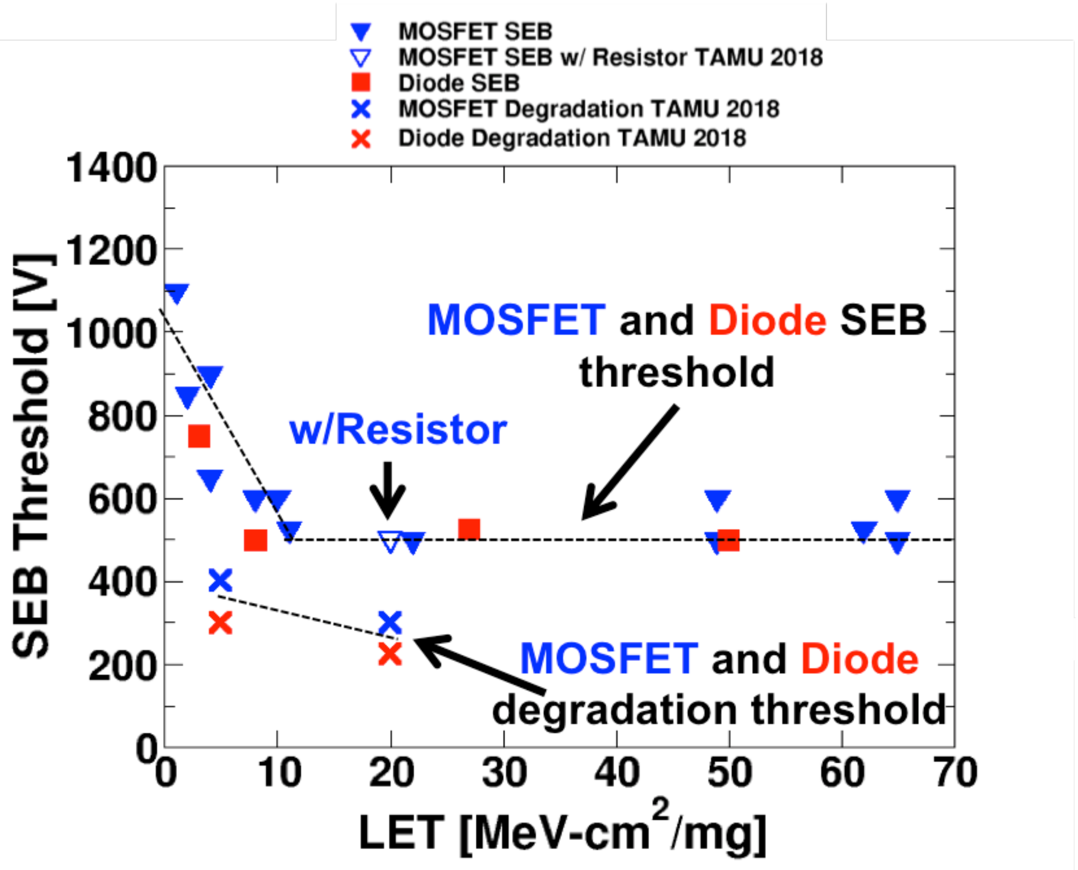
- **Laser tests suggest MOSFET bipolar structure can turn on despite poor gain**
  - Suggested SEB mechanism similar to Si

Silicon MOSFET bipolar turn-on



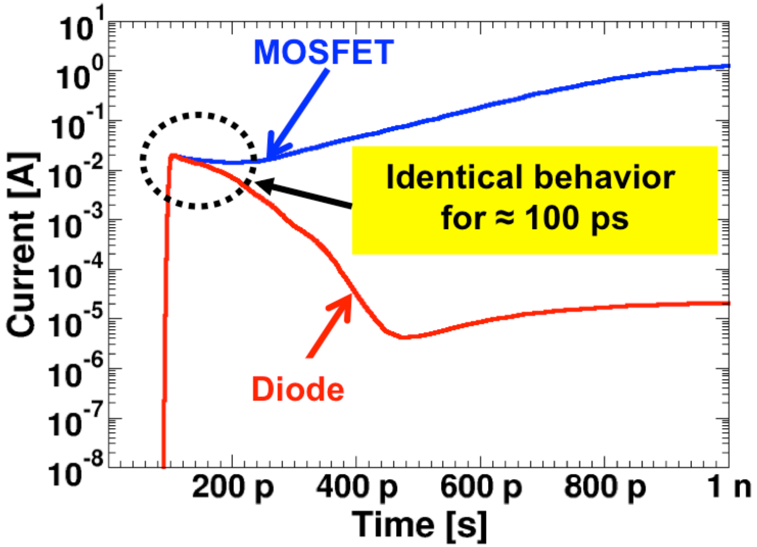
S. Liu, *et al.*, *IEEE TNS* 2006

Highlights of SiC SEB Mechanism Research

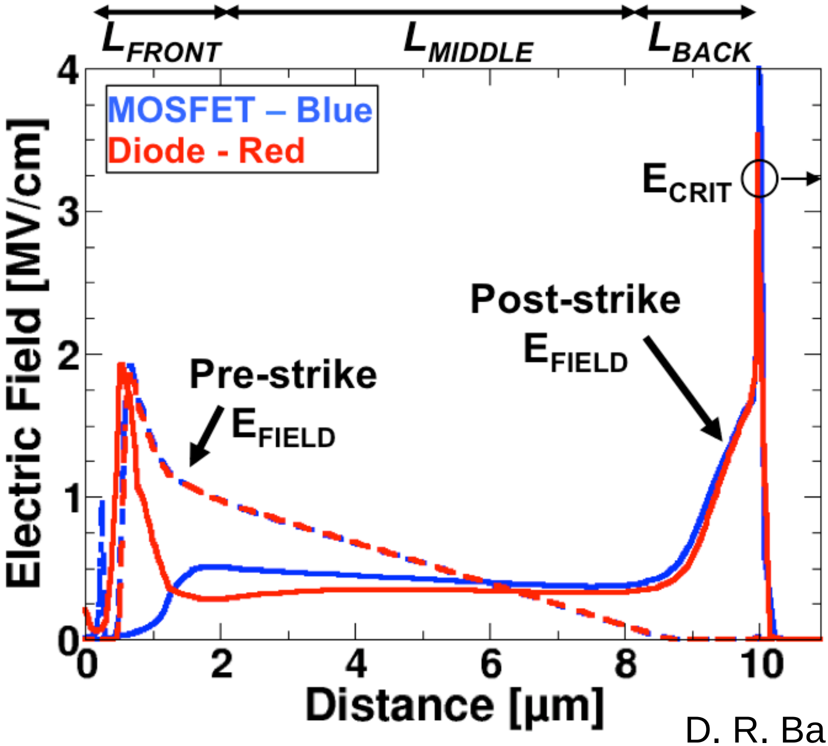


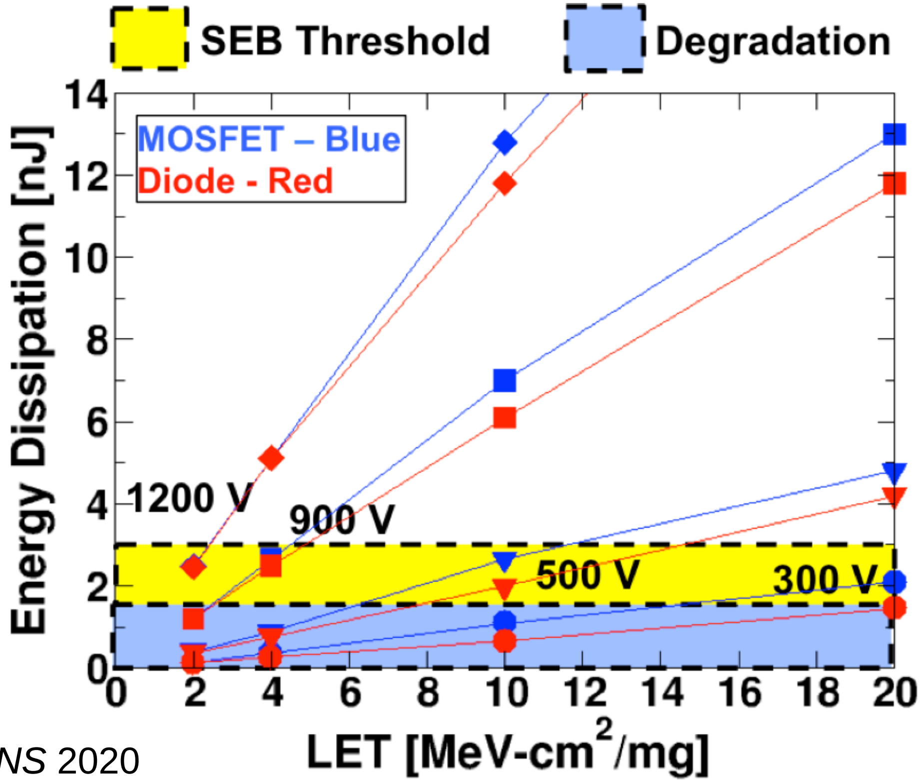
D. R. Ball, *et al.*, *IEEE TNS* 2020

- **BUT:**
  - **1200-V SiC MOSFET and JBS diode have similar SEE thresholds**
  - **SEB in MOSFET despite protective-mode (voltage quenching) test circuit**
- **Behavior is similar for short time (<100 ps) after ion strike**
  - TCAD: 500 V_{DS} with LET(SiC) = 10 MeV-cm^2/mg



Highlights of SiC SEB Mechanism Research





D. R. Ball, *et al.*, *IEEE TNS* 2020

- **Ion strike redistributes electric field in epitaxial region**
- **Field peaks at back epi-n$^+$ drain interface for both MOSFET and diode**
- **Power density extremely high over epi region, with extremely fast generation**
- **Per T. Shoji, et al., heat generation density 100x faster in SiC than in Si**

Conclusions

- WBG power devices enable game-changing power systems
  - Spacecraft transport
  - Lunar and planetary surface power
  - Electric aircraft
  - Science instruments
- Advancement of space radiation risk identification and mitigation will assure on-orbit reliability of systems built from these new technologies
- NASA will continue to mature radiation hardness assurance for WBG technology
  - In-house efforts
  - Leveraged partnerships and collaborations
  - Contract and grant initiatives