## NASA SBIR 2020 Phase I Solicitation

### Z1.06 Radiation tolerant high-voltage, high-power electronics

**Lead Center: GSFC**

**Participating Center(s): GRC, JPL, LaRC**

**Technology Area: TA3 Space Power and Energy Storage**

## Scope Description

NASA's directives for space exploration and habitation require high-performance, high-voltage transistors and diodes capable of operating without damage in the natural space radiation environment. Recently, significant progress has been made in the research community in understanding the mechanisms of heavy-ion radiation induced damage and catastrophic failure of wide bandgap power transistors and diodes. This subtopic seeks to facilitate movement of this understanding into the successful development of radiation-hardened high voltage transistors and rectifiers to meet NASA mission power needs reliably in the space environment. These needs include:

- High-voltage, high-power solutions: Technology Area (TA) 3.3.3, Power Management and Distribution (PMAD) Distribution and Transmission calls out the need for development of radiation-hardened, high-voltage, extreme- temperature components for power distribution systems. NASA has a core need for diodes and transistors that meet the following specifications:
  - Diodes: minimum 1200 V, 40 A, with fast recovery < 50 ns;
  - Transistors: minimum 600 V, 40 A, with < 24 mohm on-state drain-source resistance.
- High-voltage, low-power solutions: In support of TA 8.1 (Remote Sensing Instruments and Sensors), radiation-hardened, high-voltage transistors are needed for low-mass, low-leakage, high-efficiency applications such as LIDAR Q-switch drivers, mass spectrometers, and electrostatic analyzers. High-voltage, fast-recovery diodes are needed to enhance performance of a variety of heliophysics and planetary science instruments.
  - Transistors: minimum 1000 V, < 40 ns rise and fall times;

    - Diodes: 2 kV to 5 kV, < 50 ns recovery time.
- High-voltage, low- to medium-power solutions: In support of peak-power solar tracking systems for planetary spacecraft and small satellites, transistors and diodes are needed to increase buck converter efficiencies through faster switching speeds.
    - Transistors: minimum 600 V, < 50 ns rise and fall times, current ranging from low to > 20 A.

Successful proposal concepts should result in the fabrication of transistors and/or diodes that meet or exceed the above performance specifications without susceptibility to damage due to the heavy-ion space radiation environment (single-event effects resulting in permanent degradation or catastrophic failure). These diodes and/or transistors will form the basis of innovative, high-efficiency, low mass and volume systems and therefore must significantly improve upon the electrical performance available from existing heavy-ion radiation-tolerant devices. Proposals must state the initial state of the art for the proposed technology and justify the expected final performance metrics. Well-developed plans for validating the tolerance to heavy-ion radiation must be included, and the expected total ionizing dose tolerance should be indicated and justified. Target radiation performance levels will depend upon the device structure due to the interaction of the high electric field with the ionizing particle:

- For vertical-field power devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface incident Linear Energy Transfer (LET) of 40 MeV-cm$^2$/mg and sufficient energy maintain a rising LET level throughout the epitaxial layer(s).
- For all other devices: No heavy-ion induced permanent destructive effects upon irradiation while in blocking configuration (in powered reverse-bias/off state) with ions having a silicon-equivalent surface-incident Linear Energy Transfer (LET) of 75 MeV-cm$^2$/mg and sufficient energy to fully penetrate the active volume prior to the ions reaching their maximum LET value (Bragg peak).

Other innovative heavy-ion radiation-tolerant high-power, high-voltage discrete device technologies will be considered that offer significant electrical performance improvement over state-of-the art heavy-ion radiation-tolerant power devices.

**References**

*The following is only a partial listing of relevant references:*


1. S. Kuboyama*, et al.*, "Thermal Runaway in SiC Schottky Barrier Diodes Caused by Heavy Ions," *IEEE Transactions on Nuclear Science,* vol. 66, pp. 1688-1693, 2019.
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 Nuclear and Space Radiation Effects Conference, San Antonio, TX, July 2019.
3. J. McPherson, *et al.*, "Mechanisms of Heavy Ion Induced Single Event Burnout in 4H-SiC Power MOSFETs," International Conference on Silicon Carbide and Related Materials (ICSCRM), Kyoto, Japan, to be presented, September, 2019.
4. C. Abbate, *et al.*, "Gate Damages Induced in SiC Power MOSFETs during Heavy-Ion Irradiation--Part I," *IEEE Transactions on Electron Devices,* to be published, 2019. [see also Part II ]
5. J.-M. Lauenstein, “Getting SiC Power Devices Off the Ground: Design, Testing, and Overcoming Radiation Threats,” Microelectronics Reliability and Qualification Working (MRQW) Meeting, El Segundo, CA, February 2018. https://ntrs.nasa.gov/search.jsp?R=20180006113
6. E. Mizuta, *et al.*, "Single-Event Damage Observed in GaN-on-Si HEMTs for Power Control Applications," *IEEE Transactions on Nuclear Science,* vol. 65, pp. 1956-1963, 2018.
7. M. Zerarka, *et al.*, "TCAD Simulation of the Single Event Effects in Normally-OFF GaN Transistors after Heavy Ion Radiation," *IEEE Transactions on Nuclear Science,* vol. 64, pp. 2242-2249, 2017.
8. J. Kim, *et al.*, "Radiation damage effects in $Ga_2O_3$ materials and devices," *Journal of Materials Chemistry C,* vol. 7, pp. 10-24, 2019.
9. S. J. Pearton, *et al.*, "Perspective: $Ga_2O_3$ for ultra-high power rectifiers and MOSFETS," *Journal of Applied Physics,* vol. 124, p. 220901, 2018.

**Expected TRL or TRL range at completion of the project:** 5 to 6

**Desired Deliverables of Phase II**

Prototype, Analysis, Hardware

**Desired Deliverables Description**

Deliverables in Phase II shall include prototype and/or production-ready semiconductor devices (diodes and/or transistors), device electrical and radiation performance characterization (device electrical performance specifications and heavy-ion radiation test results and total dose radiation analyses).

**State of the Art and Critical Gaps**

A prior version of this subtopic, "High-Power, High-Voltage Electronics" was active in 2016-2017 and paused for two years to give time for funded proposals and a similar Early Stage Innovation topic designed to understand the radiation-induced failure mechanisms in wide bandgap semiconductors to mature. This pause has allowed these studies to mature and it is now time to re-open this subtopic to provide a means for applying the knowledge gained toward fabrication of radiation hardened power devices that are tailored to meet performance criteria of a number of NASA technology needs.

High voltage silicon power devices are limited in current ratings and have limited power efficiency and higher losses than do commercial Wide Bandgap (WBG) power devices. Efforts to space-qualify WBG power devices to take advantage of their tremendous performance advantages revealed they are very susceptible to damage from the heavy ion space radiation environment (galactic cosmic rays) that cannot be shielded against. Higher voltage devices are more susceptible to these effects; as a result, to date, there are space qualified GaN (Gallium Nitride) transistors now available but these are limited to 300 V. Recent radiation testing of 600 V and higher GaN transistors have shown failure susceptibility at about 50% of the rated voltage, or less. Silicon carbide power devices have undergone several generation advances commercially, improving their overall reliability, but catastrophically fail at less than 50% of their rated voltage. NASA has funded modeling and experimental efforts to understand the silicon carbide's susceptibility to heavy-ion radiation. Re-opening of this topic will provide a path for development and fabrication of hardened designs based upon this research, and encourage progress in other wide bandgap technologies such as higher voltage GaN, gallium oxide, and possibly diamond.

Specific needs in STMD (Space Technology Mission Directorate) and SMD (Science Mission Directorate) areas have been identified for spacecraft PMAD and science instrument power applications and device performance requirements to meet these needs are included in this subtopic nomination. In all cases, there is no alternative solution that can provide the mass and power savings sought to enable game-changing capability. Current PPUs (Power Processing Unit's) and instrument power systems rely on older silicon technology with many stacked devices and efficiency penalties. In NASA's move to do more with less (smaller satellites), the technology of this subtopic nomination is truly enabling.

A phase I funded SBIR under the S4.04 Extreme Environments Technology, was awarded ([https://sbir.nasa.gov/SBIR/abstracts/19/sbir/phase1/SBIR-19-1-S4.04-3611...](https://sbir.nasa.gov/SBIR/abstracts/19/sbir/phase1/SBIR-19-1-S4.04-3611...)) in 2019 to develop low-defect gallium oxide ($Ga_2O_3$) based high-voltage power diodes grown on commercially available bulk $Ga_2O_3$ substrates via a thin-film deposition technique. The S4.04 Subtopic Manager serves as a participating subtopic manager on this Z1 subtopic to foster good leveraging and to avoid duplication of efforts. The S4.04 subtopic solicits development of technology for extreme temperatures and high total ionizing dose radiation primarily.

Other non-NASA funded efforts include:

Vertical GaN diode development has been a focus of ARPA-E PNDIODE and (previous) SWITCHES programs. Diodes developed under the SWITCHES program were shown by Sandia National Lab to have good switching reliability, but another Italian team has found they may degrade under high current stress. Heavy-ion radiation susceptibility has not been assessed and is not expected to be robust without design alteration.

DoD (Department of Defense) has two funded $Ga_2O_3$ technology SBIRs that focus on development of manufacturing capabilities as opposed to device design itself.

**Relevance / Science Traceability**

Power transistors and diodes form the building blocks of numerous power circuits for spacecraft and science instrument applications. This subtopic therefore feeds a broad array of space technology hardware development activities by providing single-event effect (heavy ion) radiation-hardened state-of-the-art device technologies that achieve higher voltages with lower power consumption and greater efficiency than presently available.

TA 3.3.3, Power Management and Distribution (PMAD) Distribution and Transmission calls out the need for development of radiation-hardened, high-voltage, extreme-temperature components for power distribution systems. This subtopic will serve as a feeder to the subtopic Z1.05 - Lunar & Planetary Surface Power Management & Distribution" in which wide bandgap circuits for PMAD applications are solicited. The solicited developments in this subtopic will also feed systems development for Kilopower due to the savings in size/mass combined with radiation hardness. In addition, power distribution for lunar and Martian habitats will benefit from power circuits adopting this subtopic through significantly improved power efficiencies and radiation hardness.

TA 8.1, Remote Sensing Instruments and Sensors, radiation-hardened, high-voltage transistors are needed for low-mass, low-leakage, high-efficiency applications such as LIDAR Q-switch drivers, mass spectrometers, and electrostatic analyzers. These applications are aligned with science objectives including Earth Science LIDAR needs, Jovian moon exploration, and Saturn missions. Finally, mass spectrometers critical to planetary and asteroid research and in the search for life on other planets such as Mars require high voltage power systems and will thus benefit from mass and power savings from this subtopic's innovations.