NASA SBIR 2021 Phase I Solicitation

Z1.06 Radiation-Tolerant High-Voltage, High-Power Electronics

Lead Center: GSFC

Participating Center(s): GRC, JPL, LaRC

Scope Title:

Radiation-Tolerant High-Voltage, High-Power Electronics

Scope Description:

NASAâ€™s directives for space exploration and habitation require high-performance, high-voltage transistors and diodes capable of operating without damage in the natural galactic cosmic ray space radiation environment. Recently, significant progress has been made in the research community in understanding the mechanisms of heavy-ion-radiation-induced single-event-effect (SEE) degradation and catastrophic failure of wide bandgap (WBG) 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: Taxonomy Area (TX) 03.3.4, Power Management and Distribution (PMAD) - Advanced Electronic Parts, calls out the need for development of radiation-hardened high-voltage components for power 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. Forward voltage drop should not exceed 150% of that in state-of-the-art unhardened diodes.
    - Transistors: minimum 650 V, 40 A, with <24-mohm on-state drain-source resistance.
- High-voltage, low-power solutions: In support of TX 8.1.2 (Sensors and Instruments - Electronics), 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.Â Forward voltage drop should not exceed 150% of that in state-of-the-art unhardened diodes.
- 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 galactic cosmic ray heavy-ion space radiation environment (SEEs resulting in permanent degradation or catastrophic failure). These diodes and/or transistors will form the basis of innovative high-efficiency, low-mass and low-volume systems and therefore must significantly improve upon the electrical performance available from existing heavy-ion SEE radiation-tolerant devices.

Other innovative heavy-ion SEE 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 SEE radiation-tolerant power devices.

Expected TRL or TRL Range at completion of the Project:Â 4 to 5Â
Primary Technology Taxonomy:Â
Level 1: TX 03 Aerospace Power and Energy StorageÂ
Level 2: TX 03.3 Power Management and Distribution**Â**
Desired Deliverables of Phase I and Phase II:

- Hardware
- Prototype
- Analysis

Desired Deliverables Description:

Phase I deliverables 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 40Â MeV-cm^2/mgÂ and sufficient energy to 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 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).

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

State of the Art and Critical Gaps:

High-voltage silicon power devices are limited in current ratings and have limited power efficiency and higher losses than do commercial WBG power devices. Efforts to space-qualify WBG power devices to take advantage of their tremendous performance advantages revealed that they are very susceptible to damage from the high-energy, 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 transistors now available, but these are limited to 300 V. Recent radiation testing of 600-V and higher GaN transistors has 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.Â

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Specific needs in STMD (Space Technology Mission Directorate) and SMD (Science Mission Directorate) areas have been identified for spacecraft power management and distribution (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 units) 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), and its lunar/planetary habitation objectives requiring tens to 100 kW power production, the technology sought by this subtopicÂ is truly enabling.

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State-of-the-art, currently available heavy-ion SEE-tolerant silicon power devices include a Schottky diode capable of 600 V, 30 A, and 27-ns recovery time, and a power

MOSFET capable of 650 V, 8 A, with on-state resistance of 450 mohm. Commercial (non-SEE tolerant) SiC and GaN offerings are available that meet the electrical performance needs indicated in this subtopic, but that cannot meet the heavy-ion SEE requirements indicated. At this time, there are no publicly available data on the heavy-ion SEE performance of Ga_2O_3Â or diamond power devices.

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 SEE (heavy-ion) radiation-hardened state-of-the-art device technologies that achieve higher voltages with lower power consumption and greater efficiency than presently available.

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Taxonomy Area (TX) 03.3.4, Power Management and Distribution (PMAD) - Advanced Electronic Parts, calls out the need for development of radiation-hardened high-voltage components for power systems.Â This subtopic serves as a feeder to the subtopic Lunar and Planetary Surface Power Distribution, in which WBG circuits for PMAD applications are solicited. The solicited developments in this subtopic will also feed systems development for the NASA Kilopower project due to the savings in size/mass combined with radiation hardness.

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TX 08.1.2, Sensors and Instruments - Electronics: 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.

References:

Partial listing of relevant references:

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2. M. Zerarka*,Â* etÂ al.,Â "TCAD Simulation of the Single Event Effects in Normally-OFF GaN Transistors After Heavy Ion Radiation,"Â *IEEE Transactions on Nuclear Science,Â* vol. 64, pp. 2242-2249, 2017.
3. C. Abbate, et al., "Experimental Study of Single Event Effects Induced by Heavy Ion Irradiation in Enhancement Mode GaN Power HEMT,"Â *Microelectronics Reliability,Â* vol.Â 55, pp. 1496-1500, 2015.
4. J. Kim*,Â* etÂ al.,Â "Radiation damage effects in Ga2O3 materials and devices,"Â *Journal of Materials Chemistry C,Â* vol. 7, pp. 10-24, 2019.
5. S. J. Pearton*,Â* etÂ al.,Â "Perspective: Ga2O3 for ultra-high power rectifiers and MOSFETS,"Â *Journal of Applied Physics,Â* vol. 124, p. 220901, 2018.
6. D. R. Ball, et al.,â€œIon-Induced Energy Pulse Mechanism for Single-Event Burnout in High-Voltage SiC Power MOSFETs and Junction Barrier Schottky Diodes,â€Â *IEEE Transactions on Nuclear Science,Â* vol.

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7. J. McPherson, et al., "Mechanisms of Heavy Ion Induced Single Event Burnout in 4H-SiC Power MOSFETs," Materials Science Forum, 1004, 889â€“896, 2020.
8. S. Kuboyama, etÂ al.,Â "Thermal Runaway in SiC Schottky Barrier Diodes Caused by Heavy Ions,"Â *IEEE Transactions on Nuclear Science,Â* vol. 66, pp. 1688-1693, 2019.
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10. J.-M. Lauenstein, â€œGetting SiC Power Devices Off the Ground: Design, Testing, and Overcoming Radiation Threats,â€ Microelectronics Reliability and Qualification Working (MRQW) Meeting, El Segundo, CA, February 2018.Â https://ntrs.nasa.gov/search.jsp?R=20180006113