Advanced Space Radiation Detector Technology Development

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Presenter
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• NASA Glenn Research Center since 2000
  – Physics background
  – Previously at AFRL (plasma physics research & technology) and
    FNAL (particle beam optical systems)

• Physical Sensors Instrumentation Research @ NASA GRC
  – Micro-fabricated thin-film sensor technology for temperature, strain,
    heat flux, and radiation measurement for aerospace systems
    applications

• NASA Support for GRC’s Advanced Radiation Detector Technology R&D:
  – ETDP/D Life Support & Habitation Systems/Radiation Protection
Outline

• Space Radiation Environment
  – Radiation Detector Issues
• GRC Technology Research & Development
• Application Concept System
  – Objectives
  – Design
• Detector Development
  – WBG LET Detectors
  – Fast Solid-State Cherenkov Detector
  – Solid-State UV Detector Investigation
• Technology Challenges
• Summary
Space Radiation Environment

- Types of Radiation from Space:
  - Solar Particle Events (SPE): Mostly protons, some helium ions, at moderate energies
  - Galactic Cosmic Radiation (GCR): Moderate to highly energetic ions, Z=1→26 (Hydrogen to Iron nuclei)
  - Trapped Radiation: Ions and electrons from SPEs, GCR trapped, scattered by the planetary magnetic field
Space Radiation Environment Impact on Air Travel

- Aircrews are considered Radiation Workers by the FAA due to Space Radiation exposure
  - Concern for altitudes over 8 km (26,000 ft)
  - Dose at 18km (60,000 ft) altitude is about 2x dose at 12km (40,000 ft)
  - Polar routes can receive about 3x exposure than equatorial routes
  - Solar Particle Events can increase doses 3x in flight

- Aircrew dose estimate models are dependent on the understanding of the space radiation environment
Space Radiation Environment Impact on Space Exploration

- Space Radiation exposure is more pronounced beyond the protection of Earth’s atmosphere and magnetic field
  - SPEs introduce a large variability to radiation dose for equipment and crew
  - Radiation Doses from Trapped Radiation need to be accounted for in traversing magnetic fields
  - Variations in HZE from GCR are not fully understood (do the most damage)

<table>
<thead>
<tr>
<th>Radiation Area</th>
<th>Average Exposure Rate</th>
</tr>
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<tbody>
<tr>
<td>Terrestrial (background)</td>
<td>0.25 µSv/hr</td>
</tr>
<tr>
<td>Aircraft (@ 12 km)</td>
<td>2.7-7.4 µSv/hr</td>
</tr>
<tr>
<td>LEO (@400 km)</td>
<td>2-16 µSv/hr</td>
</tr>
<tr>
<td>MEO (@20,000 km)</td>
<td>1 mSv/hr</td>
</tr>
<tr>
<td>Deep Space GCR</td>
<td>57 µSv/hr</td>
</tr>
<tr>
<td>Deep Space SPE</td>
<td>→125 mSv/hr</td>
</tr>
<tr>
<td>Europa (Jupiter orbit)</td>
<td>40 Sv/hr</td>
</tr>
</tbody>
</table>
Space Radiation Environment

Radiation Detector Issues

• Existing space radiation data sets have gaps in energy, ion type
• Understanding of variations in steady state and storm conditions are limited
• Current radiation detector technology is limited in lifetime, precision, discrimination, and directional sensitivity by the mass, power, and volume requirements for future missions
• Limitations of knowledge of the radiation environment impact:
  – Space Science/Exploration: Spacecraft design and operation
  – Earth Science: Heavy ion mechanisms in large-scale cloud cover
  – Aeronautics: Aircraft crew rotations on intercontinental flights
GRC Advanced Radiation Detector Technology Research and Development

- GRC Expertise and Facilities in:
  - Harsh Environment Thin Films
  - SiC Devices & Harsh Environment Packaging
  - Micro-Optics
  - Space-Based Instrumentation

- These strengths are combined into an in-house Radiation Instrumentation Research effort

MISSE 7 SiC JFET & Ceramic Packaging (arrow) on a Rad-Hard Electronics Board

SiC radiation detector for AEVA PCAI studies

Dosimeter based on SiC diode detector element for Constellation ETDP demonstration

In-House Microfabrication Facilities
Application Concept: Full-Field Radiation Detector System

• GRC is advancing the technology to develop a low-power radiation detector system capable of monitoring a wide range of high energy heavy ions (HZE ions) over a spherical (4π) aspect area

• The technology applied to this 4π HZE Detector System enables:
  – Improved temperature insensitivity to changes induced by transitions from sunlight into shadow (and vise-versa)
  – Improved precision with lower mass, power and volume requirements
  – Improved radiation discrimination and directional sensitivity
  – Unique monitoring of radiation environment from all directions of the celestial sphere
Application Concept: Full-Field Radiation Detector System

- Mapping of heavy ions > 100 MeV/amu
  - Integrated system with solid-state Cherenkov detector and large area detectors in surrounding wedges
- High radiation flux rates for 10+ year missions
  - Precision rad-hard, thermally stable wide band gap detectors used
- Low noise, multi-directional measurements at single locations
  - Compact, spherical detector system

**Space radiation detector with spherical geometry**

- Technology covered by U.S. Patents 7,872,750 (January 18, 2011) and 8,159,669 (April 17, 2012)
Application Concept: Full-Field Radiation Detector System

- Full-field ion detector system comprised of a spherical Cherenkov detector surrounded by stacked LET detectors
WBG LET Detectors

- Each stack of directional detectors has several Linear Energy Transfer (LET) detectors with layers of absorbers with a separate Trigger detector to initiate data collection
  - LET detectors measure $\frac{dE}{dx}$ as the ion moves through the stack
  - Based on the absorber geometry, the $\frac{dE}{dx}$ signal can be correlated to ion $Z$ and velocity
- The Wide Band Gap (WBG) semiconductor SiC selected for the LET detectors
  - Resistance to radiation damage
  - Insensitivity to changes in temperature
  - Demonstrated performance in the ETDP dosimeter
- Detectors up to 450 mm$^2$ required – Fabrication Options:
  - Large area array of 4 mm$^2$ diodes as used in the dosimeter
  - Large area detector from a single-crystal SiC wafer
Fast Solid-State Cherenkov Detector

• With the trigger of data collection from the stacks, the signal from the central Cherenkov detector is collected via fast UV photodetectors
  – The collected Cherenkov light emitted by particles over 200 MeV/amu can be correlated to ion Z and velocity

• Requires solid-state fast UV detectors in place of PMTs
  – Typically photomultiplier tubes (PMTs) are used for their sensitivity and fast response; no room for that in this application
  – Investigated solid-state UV detectors, both COTS & custom

Proof-of-Concept ZnO UV Detector (GRC, patent pend.)
SG01L-18 SiC UV Photodiode (©sglux)
FGAP71 GaP UV Photodiode (©Thorlabs)
Solid-State UV Detector Investigation

• Fabricated a 2 mm² active area ZnO detector and compared to COTS SiC and GaP photodiodes at 254 nm and 370 nm light sources
  – ZnO detector most sensitive at both wavelengths
  – GaP diode better than SiC at 370 nm
  – SiC diode as good as GaP at 254 nm

<table>
<thead>
<tr>
<th>Diode</th>
<th>ZnO (per Volt bias)</th>
<th>SiC (-10V bias)</th>
<th>GaP (-10V bias)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Area</td>
<td>2 mm²</td>
<td>0.96 mm²</td>
<td>4.8 mm²</td>
</tr>
<tr>
<td>Average Dark Current</td>
<td>1.8 ± 0.2 nAmps</td>
<td>&lt; 50 pAmps</td>
<td>100 ± 20 pAmps</td>
</tr>
<tr>
<td>Relative Output to Hg lamp (254 nm)</td>
<td>58.7 ± 3.8</td>
<td>0.196 ± 0.029</td>
<td>1</td>
</tr>
<tr>
<td>Relative Output to LED source (370 nm)</td>
<td>14.99 ± 5.6</td>
<td>0.041 ± 0.0024</td>
<td>1</td>
</tr>
<tr>
<td>Relative Output to Hg lamp (254 nm) per unit area (mm⁻²)</td>
<td>14.09 ± 0.91</td>
<td>0.981 ± 0.147</td>
<td>1</td>
</tr>
<tr>
<td>Relative Output to LED source (370 nm) per unit area (mm⁻²)</td>
<td>3.6 ± 1.3</td>
<td>0.207 ± 0.012</td>
<td>1</td>
</tr>
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Solid-State UV Detector Investigation

- ZnO detector with 20 µm electrode spacing, low resistance should have a response time of ~1 ns
  - Package not developed
- GaP strong response at 370 nm makes it an excellent candidate for use in scintillator trigger/veto counters
- SiC diode can be a backup to the ZnO detector assuming a fast response time can be achieved
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<thead>
<tr>
<th>Component</th>
<th>Technology Challenge</th>
<th>Approach</th>
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<tbody>
<tr>
<td>Fast Cherenkov Detector</td>
<td>ZnO UV detector packaging</td>
<td>GRC Harsh Environment Packaging expertise; Examine SiC diode back-up</td>
</tr>
<tr>
<td>Trigger/Veto Scintillator Counters</td>
<td>GaP photodiodes with fiber scintillators</td>
<td>Compare COTS to custom packaging</td>
</tr>
<tr>
<td>Large Area WGB LET Detectors</td>
<td>SiC Diode array</td>
<td>GRC Harsh Environment Packaging expertise; Examine single-crystal option</td>
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<tr>
<td>Signal Conditioning Electronics</td>
<td>Space available</td>
<td>GRC Space Electronics expertise</td>
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<tr>
<td>Detector Integration</td>
<td>Mass limit</td>
<td>More reliance on lower density metals (Al, Ti); Higher fidelity models</td>
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Summary

• Radiation detector issues impact a variety of missions in both air and space
• GRC is leveraging expertise in harsh environment thin films, SiC devices & harsh environment packaging, micro-optics, and space-based instrumentation to advance radiation detector technology
• Application concept system for a compact, full-field space radiation detector system outlined
• Detector development proceeding in WBG devices for LET and Cherenkov detectors
• Technology challenges identified and are being addressed
Acknowledgements

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  Michael Krasowski (GRC/RHI)
  – SiC dosimeter diode detector fabrication

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  Dr. Stephen P. Berkebile (ORAU)
  – General semiconductor and shielding studies for space radiation
    protection