Status of the Wide Bandgap Working Group – Gallium Nitride

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Current activities

• Working group discusses best methods for evaluating new wide band gap technologies for infusion into space
  – GRC, JPL, JSC, GSFC, AFRL
  – Monthly meeting to share data and resources for radiation effects testing and reliability analyses

• Previous efforts have been broad stroke testing
  – Heavy ion testing
    • Gallium Nitride HEMTs (JPL)
    • Silicon Carbide MOSFETs (JPL)
  – Reliability screening
    • Temperature cycling of GaN and SiC

• On going and future efforts
  – Continues radiation testing and analysis
  – Reliability test screens for new devices
  – Guidelines for implementation and testing
Previous body of knowledge on GaN

- Current silicon power solutions are at their innate limits for space applications
  - Silicon devices are at efficiency limit
  - Best hi-rel devices are less than ~400 V drain-to-source
- GaN devices are becoming available
  - Reliability effects are a concern
  - Gate stress is limited (abs max of Vgs +6, -5 V)
    - Integrated devices increase robustness (GaNSystems)
  - Thermal effects and aging are under study at GRC
Status of Radiation Effects in GaN
Previous body of knowledge on GaN

- SEE in GaN have been observed
- Used the NEPP guideline: The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs [JPL Publication 08-10 2/08]
  - No post irradiation stress tests between
  - Testing at angle required

To be presented at the 5th NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 23-26, 2014, NASA GSFC, Greenbelt, MD.
Previous body of knowledge on GaN

![Graphs showing VSee vs. Vgs and VSee vs. Cr for Xe @ 25 MeV/amu with data points for different wafer lots labeled as LDC1_EPC1, LDC2_EPC1, etc.]

Average VSee for Several Lots of GaN HEMTs
- EPC1 is EPC1012
- EPC2 is EPC2012

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Current investigations

- Gate to source interaction
  - Looking at shorting the gate to source
  - Parameterization of test circuits
  - Establishment of SEE operating area

- Angular Effects
  - Devices are lateral, and some effects have been seen

- Testing of emerging parts
  - GaNSystems
  - Fujitsu
  - Northup Grumman
GATE TO SOURCE
INTERACTION
EPC with SMU holding VGS=0 V

- This is a typical response – SEE occurred at 60 V
- SMU establish virtual ground
EPC with Gate Shorted to Source

- Gate current is high due to the sense line test
- No SEE until 200 V
- Irrelevant to space flight
Investigation of SET on gate

- The real time evolution of an SEE shows gate and drain transients
- Gate surges positive, then follows the drain in negative current
  - Possible coupling to the power supply
- Parameterization of test circuit (LRC etc) is next step

![Graph showing SEE of EPC1012 with Vds=200 V, Vgs=0 V, showing Drain Current and Gate Current over time.](image)
TESTING OF GANSYSTEMS PARTS
SEE in 100 V GS61008

- Irradiation with Ag at LBL
- Leakage increase
- One SEE out of eight devices below 100 V
- Confirmation at TAM
- Variety of failure modes
TID Results – GS61008

- HDR with 2 hr anneal
- No change in subthreshold behavior

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Conclusion

- **Gate to source interaction**
  - Gate shorted to source fails at 180 V
  - Gate and source at virtual ground fail at 60 V
  - Parametrization of test setup next step

- **Testing of GaNSystems parts**
  - Ion increases the drain leakage
  - Low cross-section for SEE (less than $10^{-7}$ cm$^2$)
  - TID looks good but more susceptible than EPC

- **Future plans**
  - Measurement of LRC circuit in testers
  - Development of an SOA
  - High voltage issues are becoming more visible
  - Continual search for GaN IGFET
Status of Reliability Effects in GaN
Reliability Assessment of Wide Bandgap Power Devices

Kristen Boomer, NASA GRC
Leif Scheick, JPL
Jean-Marie Lauenstein & Megan Casey, NASA GSFC
Ahmad Hammoud, Vantage Partners LLC

NEPP 6th Electronics Technology Workshop
NASA Goddard Space Flight Center
June 23 – 26, 2015
Scope of Work

• A NEPP collaborative effort among NASA Centers to address reliability of new COTS wide bandgap power devices

Approach

• Identify, acquire, and evaluate performance of emerging GaN (Gallium Nitride) & SiC (Silicon Carbide) power devices under the exposure to radiation, thermal cycling, and power cycling
• Document results and disseminate findings

Presentation

• Radiation & thermal cycling effects on GaN power FETs
• Wear-out board for dynamic power/thermal cycling
## Radiation & Thermal Cycling Effects on GaN Power FETs

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Part #</th>
<th>Parameters</th>
<th># Samples</th>
<th>Radiation</th>
<th>Cycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC</td>
<td>2012</td>
<td>200V, 3A, 100mΩ</td>
<td>15/26</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GaN Systems</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GS61008P</td>
<td>100V, 90A, 7.4mΩ</td>
<td>11/10</td>
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<td>✓</td>
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<tr>
<td></td>
<td>GS66508P</td>
<td>650V, 30A, 52mΩ</td>
<td>4/0</td>
<td>Planned</td>
<td>✓</td>
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</tbody>
</table>

### Radiation Exposure

<table>
<thead>
<tr>
<th>Device</th>
<th>Ion</th>
<th>Energy (MeV)</th>
<th>LET</th>
<th>Range (μm)</th>
<th>Dose (rads)</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC</td>
<td>Xe</td>
<td>1569</td>
<td>40</td>
<td>124.5</td>
<td>8719.6</td>
<td>TAMU</td>
</tr>
<tr>
<td>GaN Systems</td>
<td>Ag</td>
<td>1569</td>
<td>41</td>
<td>121</td>
<td>6634</td>
<td>LBL</td>
</tr>
</tbody>
</table>

### Thermal Cycling:

- 120 cycles (Ongoing)
- Rate: 10 °C/min
- Range: -55 °C to +125 °C
- Soak time: 10 min
Parameters Investigated:

- I-V Output Characteristics
- Gate Threshold Voltage, $V_{TH}$
- Drain-Source On-Resistance, $R_{DS(on)}$
- Drain Leakage Current, $I_{DSS}$
- Gate Leakage current, $I_{GSS}$
EPC2012 Enhancement Mode Power FET

<table>
<thead>
<tr>
<th>EPC2012</th>
<th>Pre-cycling</th>
<th>Post-cycling</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cont</td>
<td>Irrad</td>
<td>Cont</td>
</tr>
<tr>
<td>$V_{TH} (V)$</td>
<td>1.21</td>
<td>0.90</td>
<td>1.02</td>
</tr>
<tr>
<td>$I_{GSSF} (\mu A)$</td>
<td>0.69</td>
<td>0.84</td>
<td>0.71</td>
</tr>
<tr>
<td>$I_{GSSR} (n A)$</td>
<td>540</td>
<td>779</td>
<td>664</td>
</tr>
<tr>
<td>$I_{DSS} (\mu A)$</td>
<td>0.17</td>
<td>383</td>
<td>0.19</td>
</tr>
<tr>
<td>$R_{DS(on)}$ Normalized</td>
<td>1.0</td>
<td>1.33</td>
<td>1.06</td>
</tr>
</tbody>
</table>

**Graphs:**
- Control
- Irradiated
- Post-cycling
# GaN Systems Enhancement Mode Power FET

## GS61008P

<table>
<thead>
<tr>
<th></th>
<th>Pre-cycling</th>
<th>Post-cycling</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cont</td>
<td>Irrad</td>
<td>Cont</td>
</tr>
<tr>
<td>$V_{TH}$ (V)</td>
<td>1.21</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>$I_{GSSF}$ (µA)</td>
<td>58.8</td>
<td>35.9</td>
<td>35</td>
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<tr>
<td>$I_{GSSR}$ (nA)</td>
<td>1.54</td>
<td>1.41</td>
<td>1.21</td>
</tr>
<tr>
<td>$I_{DSS}$ (µA)</td>
<td>1.40</td>
<td>1.24</td>
<td>4.94</td>
</tr>
<tr>
<td>$R_{DS(on)}$ Normalized</td>
<td>1.0</td>
<td>1.33</td>
<td>1.02</td>
</tr>
</tbody>
</table>

### Remarks
- Control & irradiated parts remained functional after exposure to radiation & thermal cycling.
- Slight reduction in threshold voltage & modest increase in drain-source resistance with radiation; 1 device had significant increase in leakage current.
- Insignificant effects of cycling on properties.
- Part-to-part variation in output characteristics.
- No alteration in device packaging or terminations.

## Graphs

### Control

- $V_{GS}$ = 2.0V
- Current ($I$) vs. $V_{DS}$

### Irradiated

- $V_{GS}$ = 2.0V
- Current ($I$) vs. $V_{DS}$

### Post-cycling

- $V_{GS}$ = 2.0V
- Current ($I$) vs. $V_{DS}$
# GaN Systems Enhancement Mode Power FET

<table>
<thead>
<tr>
<th>GS66508P</th>
<th>Pre-cycling</th>
<th>Post-cycling</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>$V_{TH}$ (V)</td>
<td>1.59</td>
<td>1.41</td>
<td>• Parts remained functional after exposure to thermal cycling with no significant changes in properties</td>
</tr>
<tr>
<td>$I_{GSSF}$ (µA)</td>
<td>471.5</td>
<td>465.7</td>
<td>• Part-to-part variation in output characteristics</td>
</tr>
<tr>
<td>$I_{GSSR}$ (nA)</td>
<td>0.41</td>
<td>0.33</td>
<td>• No alteration in device packaging or terminations</td>
</tr>
<tr>
<td>$I_{DSS}$ (µA)</td>
<td>6.37</td>
<td>5.53</td>
<td></td>
</tr>
<tr>
<td>$R_{DS(on)}$ Normalized</td>
<td>1.0</td>
<td>1.08</td>
<td></td>
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**Graphs:**
- Pre-cycling
- Post-cycling

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<th>$V_{GS}$ = 2.5V</th>
<th>$I_{D}$ (A)</th>
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<tr>
<td>2.4V</td>
<td>0.00</td>
<td>1.8V</td>
</tr>
<tr>
<td>2.3V</td>
<td>1.9V</td>
<td>2.0V</td>
</tr>
<tr>
<td>2.2V</td>
<td>2.1V</td>
<td>2.3V</td>
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<td>2.4V</td>
<td>2.0V</td>
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**Graphs:**
- Pre-cycling
- Post-cycling
Wear-out board for dynamic power/thermal cycling
Planned Work

- Continue multi-stress tests on control and irradiated GaN & SiC power devices
- Power Cycling
  - Static (Gate DC voltage)
  - Dynamic (Gate AC voltage)

ACKNOWLEDGMENT

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