Thermal Cycling and High Temperature Reverse Bias testing of Control and Irradiated Gallium Nitride Power Transistors

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

NEPP 5th Electronics Technology Workshop
NASA Goddard Space Flight Center
June 17 – 19, 2014
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

- Thermal cycling of 2nd generation GaN power FETs
- High temperature reverse bias (HTRB) testing of EPC2014 GaN FETs
### Second Generation GaN FETs

- EPC GaN transistors grown on Si wafer, passivated-die form with solder bumps; [http://www.epc-co.com](http://www.epc-co.com)
- Irradiated by JPL at TAMU with 25 MeV/amu Xe (LET=40 MeV.cm²/mg)

<table>
<thead>
<tr>
<th>EPC2015 (40V, 33A, 4mΩ)</th>
<th>EPC2014 (40V, 10A, 16mΩ)</th>
<th>EPC2012 (200V, 3A, 100mΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td><strong>Irradiated</strong></td>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>K7301</td>
<td>K7303</td>
<td>K6985</td>
</tr>
<tr>
<td>K7302</td>
<td>K7305</td>
<td>K6986</td>
</tr>
<tr>
<td>K7304</td>
<td></td>
<td>K7333</td>
</tr>
<tr>
<td>K7306</td>
<td></td>
<td>K7336</td>
</tr>
<tr>
<td>K7311</td>
<td></td>
<td>K7346</td>
</tr>
<tr>
<td>K7312</td>
<td></td>
<td>K7072</td>
</tr>
</tbody>
</table>

|               |                          |                          |                          |                          | K7396                    |
|               |                          |                          |                          |                          | K7399                    |
|               |                          |                          |                          |                          | K7364                    |
Thermal Cycling

- Cycling Profile:
  - Total # of Cycles 1000
  - Temperature rate of change: 10 °C/min
  - Temperature range: -55 ºC to +125 ºC
  - Soak time at extreme temperatures: 10 min
- Repeat measurements on devices during cycling
- Perform measurements after conclusion of cycling activity
**Parameters Investigated:**

- I-V Output Characteristics
- Gate Threshold Voltage, $V_{TH}$
- Drain-Source On-Resistance, $R_{DS(on)}$
- Pre, during, & post-cycling, measurements at selected temperatures

**Equipment Used:**

- SONY/Tektronix 370A Curve Tracer
- Keithley 238, 237, 2400 Source-Measure-Units
- LN-cooled Sun Systems Chamber
# EPC2015 Enhancement Mode GaN Power FET

<table>
<thead>
<tr>
<th>Control Parts</th>
<th>Irradiated Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>K7301</td>
<td>K7303</td>
</tr>
<tr>
<td>K7302</td>
<td>K7305</td>
</tr>
<tr>
<td>K7304</td>
<td></td>
</tr>
<tr>
<td>K7306</td>
<td></td>
</tr>
<tr>
<td>K7311</td>
<td></td>
</tr>
<tr>
<td>K7312</td>
<td></td>
</tr>
</tbody>
</table>
I-V Curves for K7301 (control)

EPC2015 GaN FET

Pre-Cycling

After 500 Cycles

After 1000 Cycles
I-V Curves for K7305 (irradiated)

EPC2015 GaN FET

After 500 Cycles

After 1000 Cycles
EPC2015 GaN FET
GATE THRESHOLD VOLTAGE, $V_{TH}$

Number of Thermal Cycles

$V_{TH}$ (V)

0.0 0.5 1.0 1.5 2.0 2.5

0 200 400 600 800 1000

K7301 Un-irradiated
K7302 Un-irradiated
K7304 Un-irradiated
K7306 Un-irradiated
K7311 Un-irradiated
K7312 Un-irradiated
K7303 Irradiated
K7305 Irradiated
EPC2015 GaN FET
Drain-Source On Resistance, $R_{DS(ON)}$

Number of Thermal Cycles

$R_{DS}$ (Normalized)

0.0 0.5 1.0 1.5 2.0

K7301 Un-irradiated
K7302 Un-irradiated
K7304 Un-irradiated
K7306 Un-irradiated
K7311 Un-irradiated
K7312 Un-irradiated
K7303 Irradiated
K7305 Irradiated

Number of Thermal Cycles

0 200 400 600 800 1000
EPC2015 GaN FET

OBSERVATIONS

• All eight EPC2015 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C

• Radiation seemed to affect steepness of the I-V curves as reflected by the increase in $V_{TH}$ & $R_{DS(ON)}$

• Insignificant changes in the I-V characteristics of control samples due to cycling

• Thermal cycling seemed to cause some recovery in the $V_{TH}$ & $R_{DS(ON)}$ properties of the irradiated parts

• No alteration in device packaging or terminations
## EPC2014 Enhancement Mode GaN Power FET

<table>
<thead>
<tr>
<th>Control Parts</th>
<th>Irradiated Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>K6985</td>
<td>K7325</td>
</tr>
<tr>
<td>K6986</td>
<td>K7328</td>
</tr>
<tr>
<td>K7333</td>
<td>K7347</td>
</tr>
<tr>
<td>K7336</td>
<td></td>
</tr>
<tr>
<td>K7346</td>
<td></td>
</tr>
<tr>
<td>K7072</td>
<td></td>
</tr>
</tbody>
</table>
I-V Curves for K7072 (control)

EPC2014 GaN FET

Pre-Cycling

After 500 Cycles

After 1000 Cycles
I-V Curves for K7347 (irradiated)

Pre-Cycling

After 500 Cycles

After 1000 Cycles

EPC2014 GaN FET
EPC2014 GaN Power FET
Drain-Source On Resistance, $R_{DS(ON)}$
EPC2014 GaN POWER FET

OBSERVATIONS

- All nine EPC2014 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C
- Slight changes in I-V curves of irradiated parts
- Thermal cycling seemed to slightly improve the I-V characteristics of both control and irradiated samples
- Part-to-part variation in output characteristics
- No alteration in device packaging or terminations
## EPC2012 Enhancement Mode GaN Power FET

### EPC2012
200V, 3A, 100mΩ

<table>
<thead>
<tr>
<th>Control Parts</th>
<th>Irradiated Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4754</td>
<td>K7348</td>
</tr>
<tr>
<td>A4755</td>
<td>K7353</td>
</tr>
<tr>
<td>A4756</td>
<td>K7354</td>
</tr>
<tr>
<td>A4757</td>
<td>K7359</td>
</tr>
<tr>
<td>A4758</td>
<td>K7370</td>
</tr>
<tr>
<td>A4759</td>
<td>K7395</td>
</tr>
<tr>
<td></td>
<td>K7396</td>
</tr>
<tr>
<td></td>
<td>K7399</td>
</tr>
<tr>
<td></td>
<td>K7364</td>
</tr>
</tbody>
</table>
I-V Curves for A4755 (control)

EPC2012 GaN FET
I-V Curves for K7396 (irradiated)

Pre-Cycling

After 500 Cycles

VGS = 2.0 V
1.9 V
1.8 V
1.7 V
1.6 V
1.5 V

I0 (A)

VDS (V)

0.0 0.4 0.8 1.2 1.6 2.0

K7396.pdw

EPC2012 GaN FET

After 1000 Cycles

VGS = 2.0 V
1.9 V
1.8 V
1.7 V
1.6 V
1.5 V

I0 (A)

VDS (V)

0.0 0.4 0.8 1.2 1.6 2.0
EPC2012 GaN POWER FET
GATE THRESHOLD VOLTAGE, $V_{TH}$

Number of Thermal Cycles

$V_{TH}$ (V)

Un-irradiated

Irradiated

A4754 Un-irradiated
A4755 Un-irradiated
A4756 Un-irradiated
A4757 Un-irradiated
A4758 Un-irradiated
A4759 Un-irradiated
k7348 Irradiated
k7353 Irradiated
k7354 Irradiated
k7359 Irradiated
k7370 Irradiated
k7395 Irradiated
k7396 Irradiated
k7399 Irradiated
k7364 Irradiated
EPC2012 GaN POWER FET

OBSERVATIONS

• All fifteen EPC2012 GaN transistors, control & irradiated, remained functional after exposure to radiation followed by 1000 thermal cycles between -55 & +125 °C

• Radiation seemed to affect steepness of the I-V curves as reflected by the increase in $V_{TH}$ & $R_{DS(ON)}$

• Thermal cycling seemed to influence characteristics of control as well as irradiated samples:
  - While $V_{TH}$ of control parts increased slightly with cycling, those of the irradiated parts exhibited a decrease
  - No effect on $R_{DS(ON)}$ of majority of control parts but a decrease in this property was observed for the irradiated counterparts

• Part-to-part variability apparent in output characteristics

• No alteration in device packaging or terminations
HIGH TEMPERATURE REVERSE BIAS (HTRB) TEST (Ongoing)

- EPC2014 GaN Power FET
- Duration: 1000 hours
- Temperature: 125 °C
- Bias: 80 % rated \(BV_{DSS}, V_{GS} = 0\) V
- Parameters:
  - Gate threshold voltage
  - Drain leakage current
  - Gate forward leakage current
  - Gate reverse leakage current
  - I-V characteristic curves
- Measurements performed at high temperature at intervals
High Temperature Reverse Bias Test Board
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE THRESHOLD VOLTAGE

Threshold Voltage, $V_{th}$ (V)

Hours

<table>
<thead>
<tr>
<th>Threshold Voltage, $V_{th}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
</tr>
<tr>
<td>2.5</td>
</tr>
</tbody>
</table>

Legend
- k6985
- k6986
- k7336
- k7346
- k7072
- k7325 Irradiated
- k7328 Irradiated
- k7347 Irradiated
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
DRAIN-SOURCE LEAKAGE

Legend
- k6985
- k6986
- k7336
- k7346
- k7072
- k7325 Irradiated
- k7328 Irradiated
- k7347 Irradiated

Drain-Source Leakage, I_{ds} (μA)

Hours
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE-SOURCE FORWARD LEAKAGE

Gate-Source Forward Leakage, \( I_{gss} \) (\( \mu \)A)

Legend

- k6985
- k6986
- k7336
- k7346
- k7072
- k7325 Irradiated
- k7328 Irradiated
- k7347 Irradiated

Hours

0 200 400 600 800 1000

0 1000 2000 3000 4000 5000

Gate-Source Forward Leakage, \( I_{gss} \) (\( \mu \)A)
EPC2014 GaN Power FET
HIGH TEMPERATURE REVERSE BIAS TEST (Ongoing)
GATE-SOURCE REVERSE LEAKAGE

Legend
- k6985
- k6986
- k7346
- k7336
- k7325 Irradiated
- k7072
- k7347 Irradiated
- k7328 Irradiated

Hours
0 200 400 600 800 1000
Gate-Source Reverse Leakage, Igss (µA)
0
2000
4000
5000

Legend
- k6985
- k6986
- k7336
- k7346
- k7072
- k7325 Irradiated
- k7328 Irradiated
- k7347 Irradiated
I-V Curves for K6986 (Control)

K6986 pre HTRB

K6986 after 100 hrs HTRB

K6986 after 260 hrs HTRB

EPC2014 GaN FET HIGH TEMPERATURE REVERSE BIAS TEST
I-V Curves for K7325 (Irradiated)

EPC2014 GaN FET HIGH TEMPERATURE REVERSE BIAS TEST
Prototype Transistor Test Board for Thermal Cycling and Other Tests
Planned Work

- Continue multi-stress tests on control and irradiated GaN & SiC power devices
- High Temperature Gate Bias (HTGB) Test
  - Bias: 80 % rated $V_{GS}$, $V_{DS} = 0$ V
- Power Cycling
  - Static (Gate DC voltage)
  - Dynamic (Gate AC voltage)
ACKNOWLEDGMENT

This collaborative work was performed in support of the NASA Electronic Parts and Packaging Program. Guidance and funding provided by the Program’s co-managers Michael Sampson and Kenneth LaBel are greatly appreciated. Part of this work was done at the NASA Glenn Research Center under GESS-3 Contract # NNC12BA01B.