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

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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>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>Irradiated</td>
<td>Control</td>
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<tr>
<td>K7301</td>
<td>K7303</td>
<td>K6985</td>
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Thermal Cycling

- Cycling Profile:
  - Total # of Cycles 1000
  - Temperature rate of change: 10 °C/min
  - Temperature range: -55 °C to +125 °C
  - 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

**EPC2015**  
40V, 33A, 4mΩ  

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

Pre-Cycling

After 500 Cycles

After 1000 Cycles

EPC2015 GaN FET
I-V Curves for K7305 (irradiated)

Pre-Cycling

After 500 Cycles

After 1000 Cycles

EPC2015 GaN FET
EPC2015 GaN FET
GATE THRESHOLD VOLTAGE, $V_{TH}$
EPC2015 GaN FET
Drain-Source On Resistance, $R_{DS(ON)}$

Number of Thermal Cycles

$R_{DS}$ (Normalized)

- K7301 Un-irradiated
- K7302 Un-irradiated
- K7304 Un-irradiated
- K7306 Un-irradiated
- K7311 Un-irradiated
- K7303 Irradiated
- K7312 Un-irradiated
- K7303 Irradiated
- K7305 Irradiated
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>EPC2014 40V, 10A, 16mΩ</th>
<th>Control Parts</th>
<th>Irradiated Parts</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>K6985</td>
<td>K7325</td>
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<tr>
<td></td>
<td>K7072</td>
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</tr>
</tbody>
</table>
I-V Curves for K7072 (control)

Pre-Cycling

EPC2014 GaN FET

After 500 Cycles

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

- **Pre-Cycling**

  - **VGS = 2.0 V**
    - 1.9 V
    - 1.8 V
    - 1.7 V
    - 1.6 V
    - 1.5 V
    - 1.4 V
    - 1.3 V

- **After 500 Cycles**

  - **VGS = 2.0 V**
    - 1.9 V
    - 1.8 V
    - 1.7 V
    - 1.6 V
    - 1.5 V
    - 1.4 V
    - 1.3 V

- **After 1000 Cycles**

  - **VGS = 2.0 V**
    - 1.9 V
    - 1.8 V
    - 1.7 V
    - 1.6 V
    - 1.5 V
    - 1.4 V
    - 1.3 V

**EPC2014 GaN FET**
EPC2014 GaN POWER 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

k6985 Un-Irradiated
k6986 Un-Irradiated
k7333 Un-Irradiated
k7336 Un-Irradiated
k7346 Un-Irradiated
k7072 Un-Irradiated
k7325 Irradiated
k7328 Irradiated
k7347 Irradiated
EPC2014 GaN Power FET
Drain-Source On Resistance, $R_{DS(ON)}$

Number of Thermal Cycles

$R_{DS}$ (Normalized)

- k6985 Un-irradiated
- k6986 Un-irradiated
- k7333 Un-irradiated
- k7336 Un-irradiated
- k7346 Un-irradiated
- k7072 Un-irradiated
- k7325 Irradiated
- k7328 Irradiated
- k7347 Irradiated
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

<table>
<thead>
<tr>
<th>Control Parts</th>
<th>Irradiated Parts</th>
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</thead>
<tbody>
<tr>
<td>A4754</td>
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<td></td>
<td>K7399</td>
</tr>
<tr>
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<td>K7364</td>
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</tbody>
</table>

**EPC2012**

200V, 3A, 100mΩ
I-V Curves for A4755 (control)

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

EPC2012 GaN FET
EPC2012 GaN POWER FET
GATE THRESHOLD VOLTAGE, $V_{TH}$

Number of Thermal Cycles

$V_{TH}$ (V)

0 400 800 1200 1600

0.0 0.5 1.0 1.5 2.0

Irradiated

Un-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

Drain-Source On Resistance, $R_{DS(ON)}$

Number of Thermal Cycles

$R_{DS} \text{ (Normalized)}$

Un-irradiated

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

(On-going)

- 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

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

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

Gate-Source Reverse Leakage, Igss (uA)

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

Hours
0 200 400 600 800 1000
I-V Curves for K6986 (Control)

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

K7325 pre HTRB

VGS = 2.0 V

1.9 V

1.8 V

1.6 V

1.4 V

K7325 after 100 hrs HTRB

VGS = 2.0 V

1.9 V

1.8 V

1.7 V

1.5 V

K7325 after 260 hrs HTRB

VGS = 2.0 V

1.9 V

1.8 V

1.7 V

1.5 V

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.