Status of the Gallium Nitride High Electron Mobility Transistor Radiation Testing for the NEPP Program

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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 (GSFC)
  - 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
GaN Basics

- **Current silicon power solutions are at their innate limits for space applications**
  - Silicon devices are at efficiency limit
  - Best hi-rel devices are less then ~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)
  - Thermal effects and aging are under study at GRC

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To be presented at the 7th NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 16, 2016, NASA GSFC, Greenbelt, MD.
Destructive SEE have been seen in GaN HEMTs- RF GaN

- GaN substrate directly under gate experiences greatest electric field
  - Where 2DEG is reduced
- High electrical stress will exacerbate SEE
- SEE seen in RF devices
  - Tested in amplifier circuits
  - Depletion mode devices

M. Rostewitz / Trans. Nucl. Sci, 2013
Destructive SEE have been seen in GaN HEMTs- eGaN

- Failure seen in 200 V eGaN from 40 V to 200 V
- A. Lidow et al / Trans. Nucl. Sci, 2014 did not observe
- Process variation or test interaction is suspected
- TID and DD are not issues

C. Abbate et al. / Microelectronics Reliability 55 (2015) 1496–1500

L. Scheick / Trans Nucl Sci (2014) 1296–1300
SEE in GaN are Very Complicated

- **VSee vs. Vgs (Xe @ 25 MeV/amu)**
  - EPC1 is EPC1012
  - EPC2 is EPC2012

- **VSee vs. Cr (Xe @ 25 MeV/amu)**

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

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Effect of Test Circuit on $V_{\text{SEE}}$

Shorted gate to source

FIGURE 1080-1. Basic SEB/SEGR test circuit.
Work to be done

- Identification of SEE mechanism
- Establishment of SEE operating area
- Affect of local circuit on onset of SEE
  - Similar to SEB in power
  - Parameterization of test circuits
- Angular Effects
  - Devices are lateral, and some effects have been seen

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PGA26E19BA

TESTING OF PANASONIC PARTS
Optical Images

Front

Back

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The active region is very thin.
Cross Section Perpendicular to Gate

- 2.7 µm
- 2.3 µm
- 6.3 µm
- 3.6 µm

- 400 nm
- 317 nm
- 222 nm
- 249 nm
Heavy Ion Testing

- **PGA26E19BA Pr@60 MeV.cm²/mg**
  - VDS = 200 V
  - VDS = 300 V
  - VDS = 400 V

- **PGA26E19BA Ag@43.6 MeV.cm²/mg**
  - VDS = 300 V
  - VDS = 325 V
  - VDS = 600 V PIGS

- **PGA26E19BA Ag@43.6 MeV.cm²/mg**
  - VDS = 600 V

- **PGA26E19BA Cu@20 MeV.cm²/mg**
  - VDS = 550 V
  - VDS = 575 V

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$V_{\text{SEE}}$ as a Function of LET

Higher LET results in lower SEE $V_{\text{ds}}$. 

Average Pass Bias ($V_{\text{ds}}$) [V] for the PGA26E19BA

$V_{\text{GS}} = 0$ V
Cross-section as a Function of LET

Preliminary: Cross-section not dependent on LET.
VSEE as a Function of Incident Angle

Average Pass Bias ($V_{ds}$) [V] vs Angle for the PGA26E19BA

$V_{GS}=0$ V

Lateral devices like this HEMT are expected to have an angular dependence.
SEE Vds has a strong angular response.
TESTING OF GANSYSTEMS PARTS
Optical Images

Front

Back
Package Cross Section Overview

![Cross-section images with measurements]
Cross Section Perpendicular to Gate

Active contacts and gates

Active contact

Gate areas are small and more complex in newer devices.
Heavy Ion Testing

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V_{SEE} as a function of LET

Average pass voltage vs LET (15 MeV/n) for the GS66516T

Preliminary: Higher LET results in lower SEE Vds.
Cross-section as a function of LET

Cross section vs LET for the GS66516T

VGS=0 V

Preliminary: Cross-section not dependent on LET.
$V_{SEE}$ as a function of ion range

VSEE vs Ion Range (~40 MeV-cm$^2$/mg) for the GS66516T

VGS=0 V

Preliminary: Longer range ions are more damaging Xe versus Ag.
FUTURE WORK
More testing…

- Testing of emerging parts
  - GaNSystems
  - Freebird Semi
  - Panasonic
  - Northup Grumman

- Collaboration with other entities
  - NASA
  - DOE and DOD
  - Vendors

More GaN devices are becoming available every day.
EMMI and IR SEE site recovery

This will identify SEE location to establish trends and identify mechanism.
Conclusion

• SEE in GaN HEMTs are complex
  – Mechanisms and underlying device physics are still under study

• New devices show similar effects
  – Panasonic parts seem more robust
  – GaNSystems have more complicated SEE response

• Future plans
  – Measurement of LRC circuit in testers
  – Development of an SOA
  – High voltage issues are becoming more visible
  – Continual search for GaN IGFET