Status of the Wide Bandgap Working Group – Gallium Nitride

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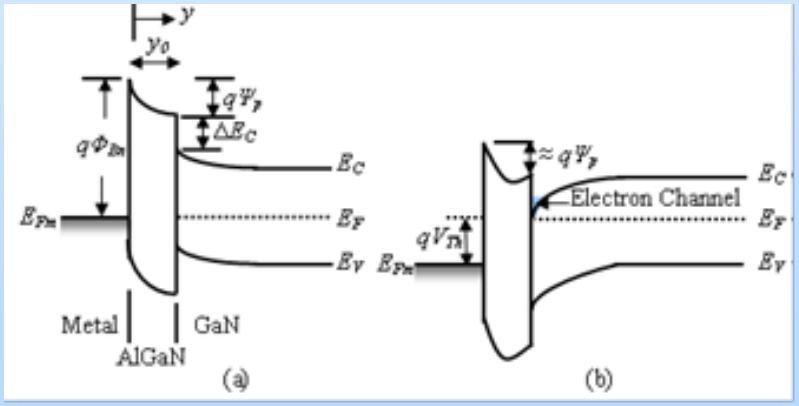
Current activities

- **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

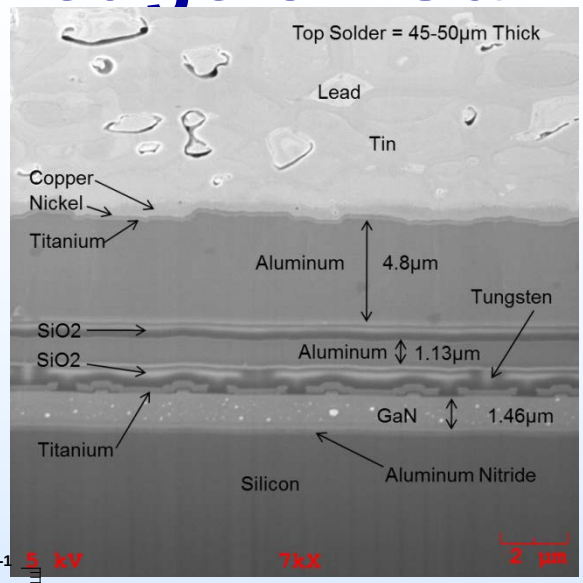
- **Current silicon power solutions are at their innate limits for space applications**
  - **Silicon devices are at efficiency limit**
  - **Best hi-rel devices are less then ~400 V drain-to-source**
- **GaN devices are becoming available**
  - **Reliability effects are a concern**
  - **Gate stress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

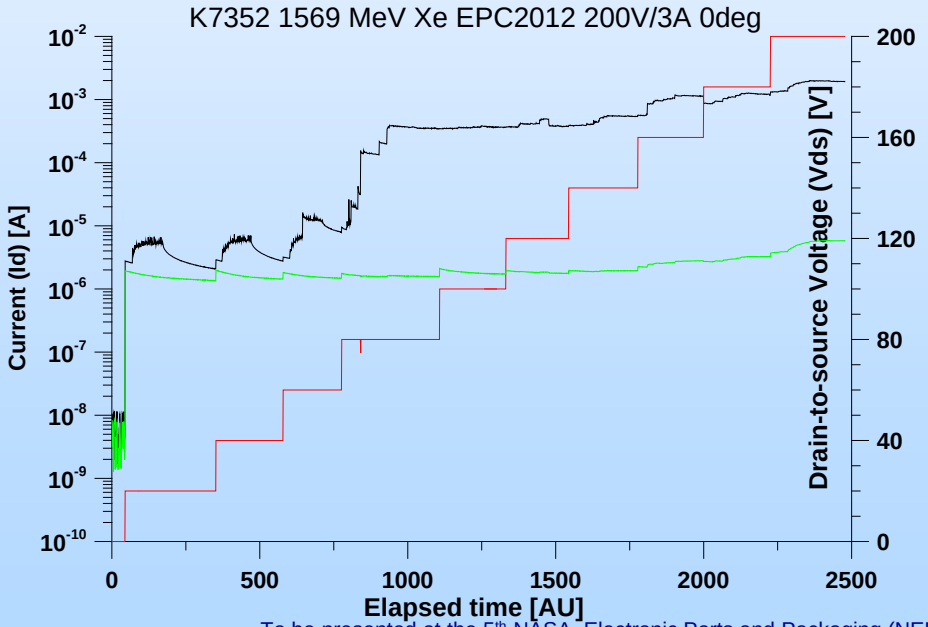


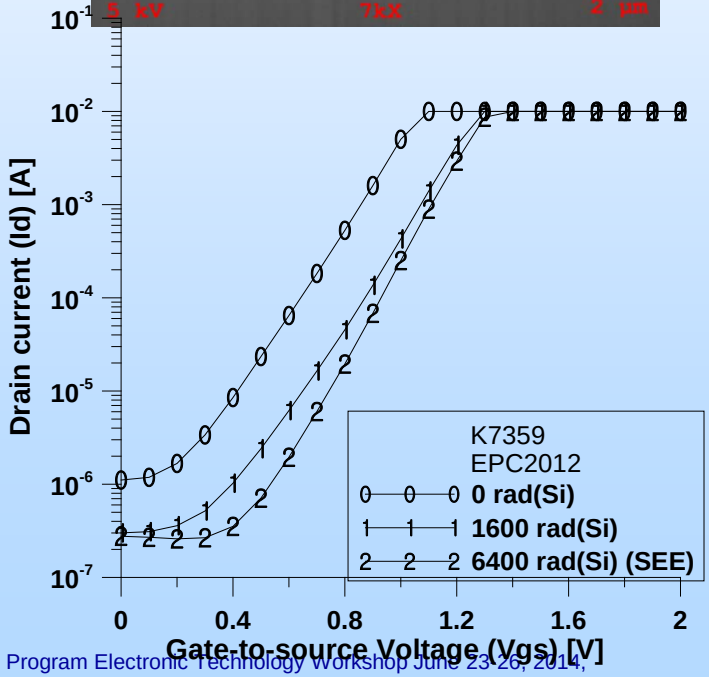
Status of Radiation Effects in GaN

Previous body of knowledge on GaN

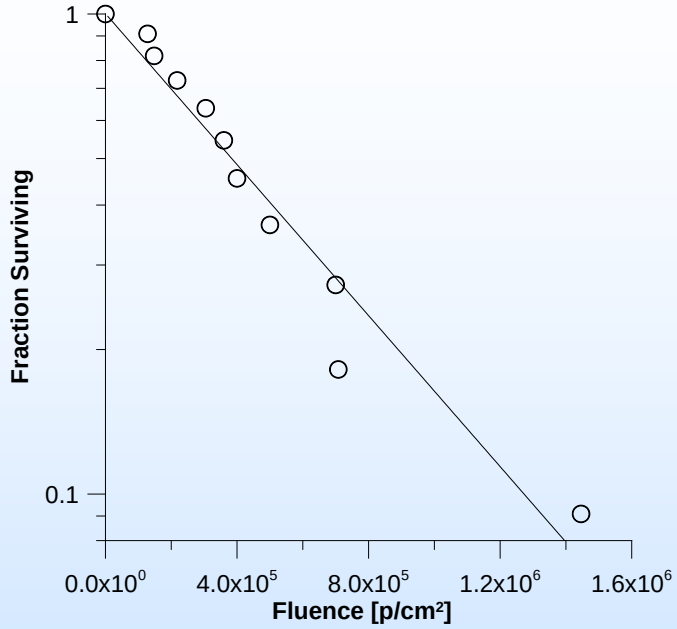
- **SEEs in GaN have been observed**
- **Used the NEPP guideline: The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs [JPL Publication 08-10 2/08]**
  - **No post irradiation stress tests between**
  - **Testing at angle required**

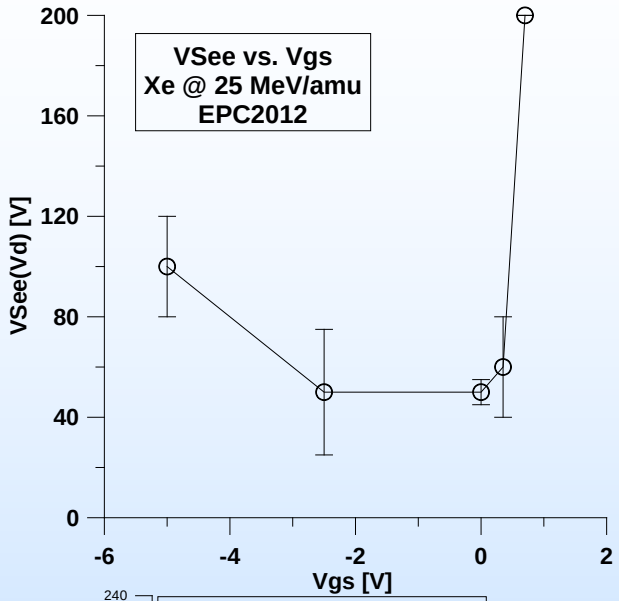


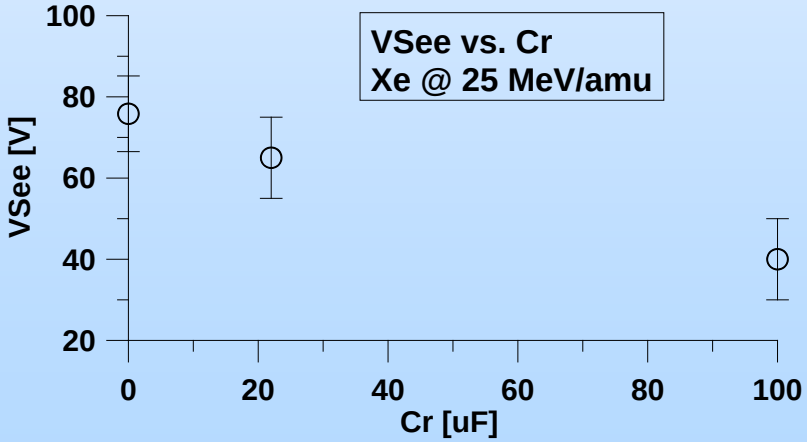


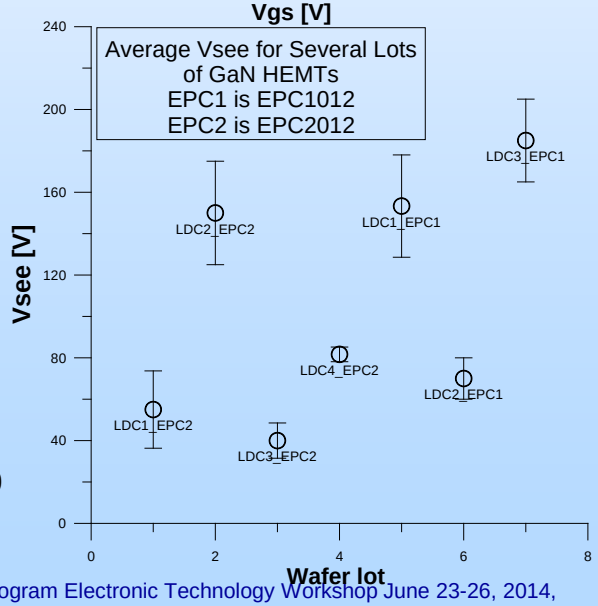


Previous body of knowledge on GaN









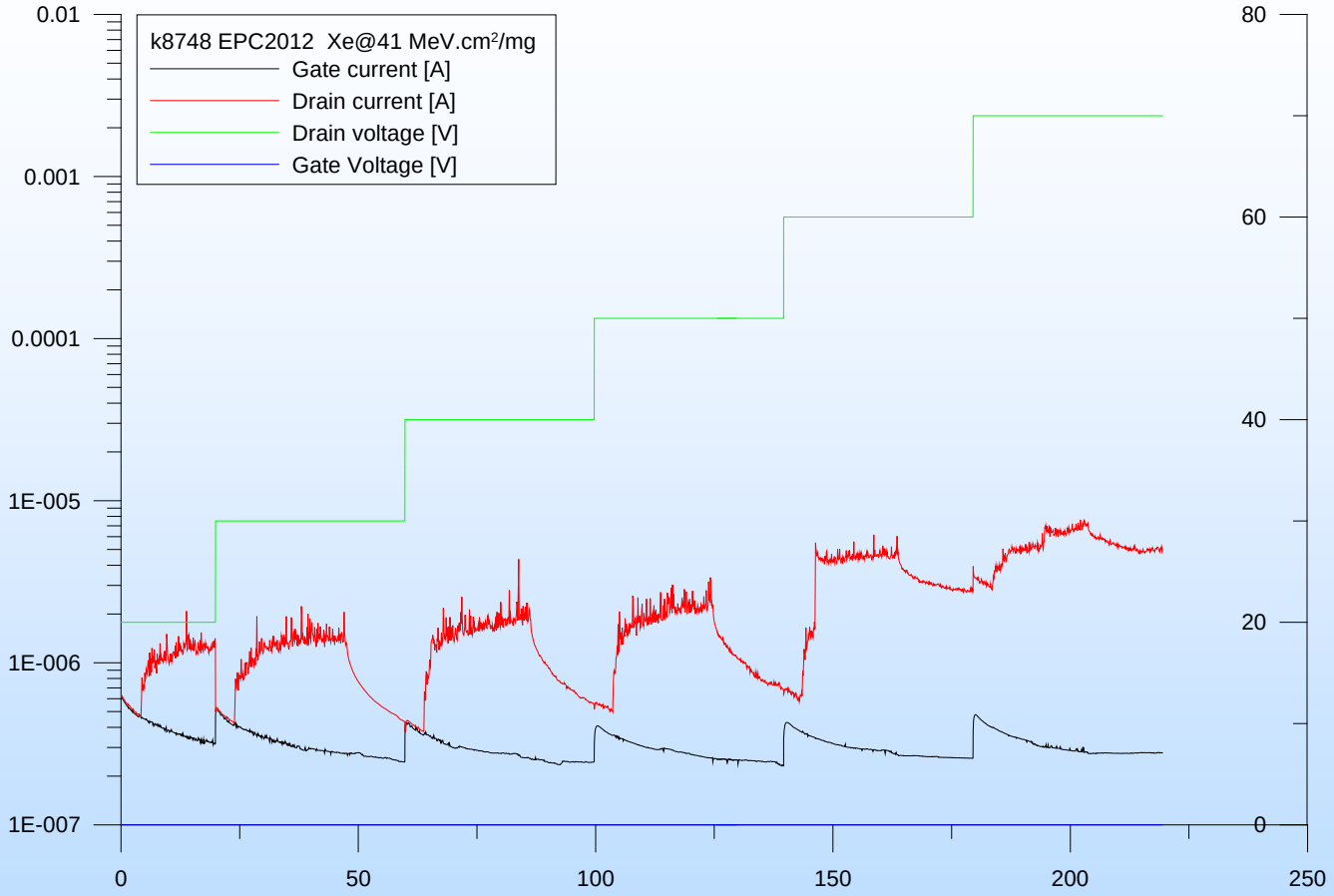
Current investigations

- 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

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

EPC with SMU holding VGS=0 V



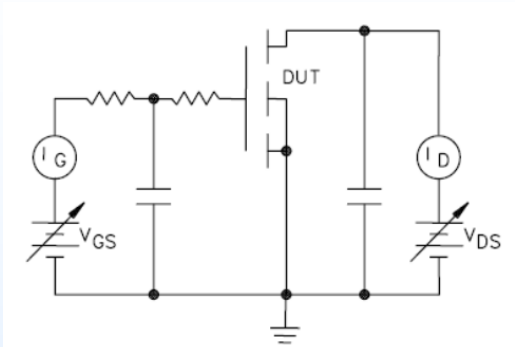
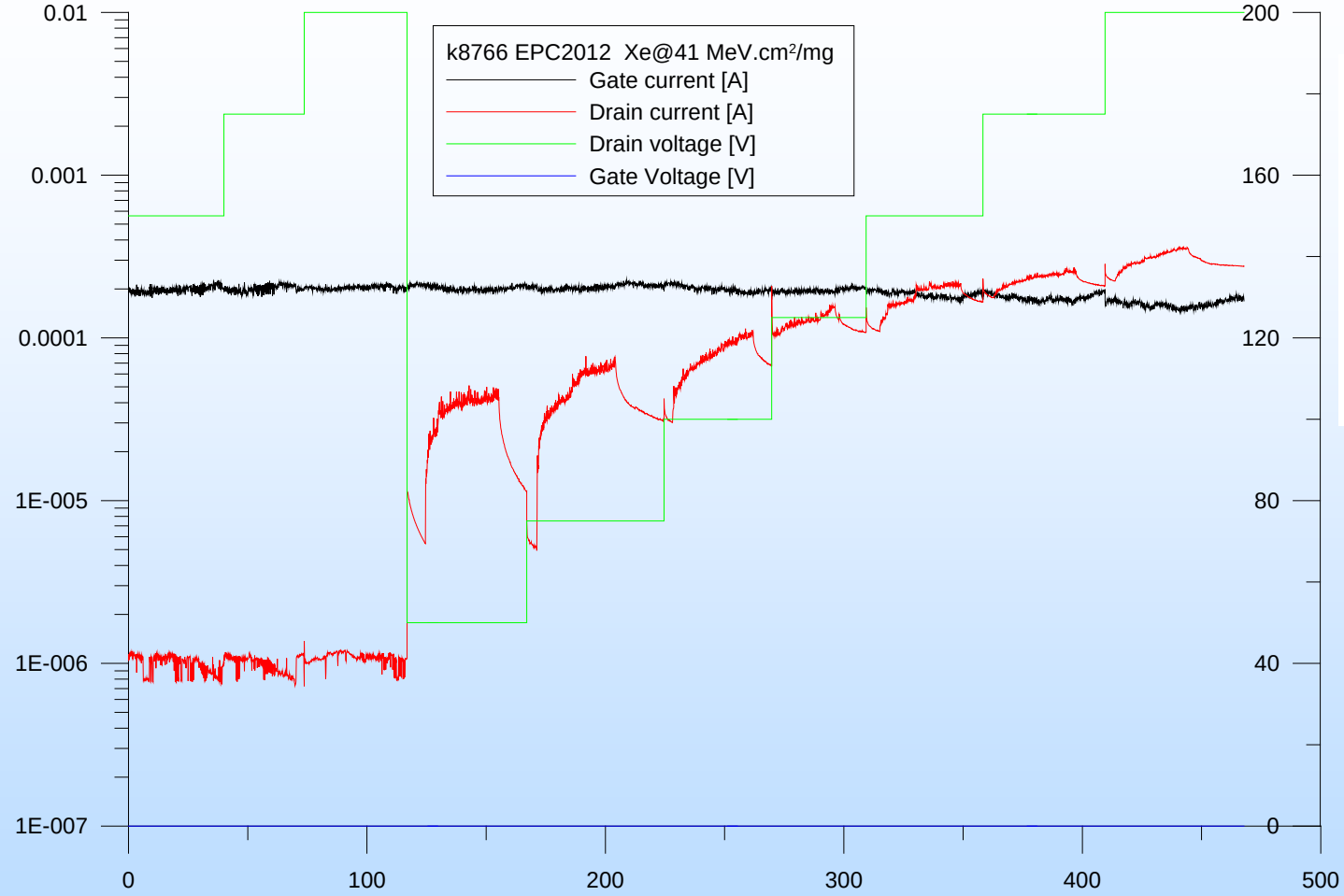


FIGURE 1080–1. Basic SEB/SEGR test circuit.

- **This is a typical response – SEE occurred at 60 V**
- **SMU establish virtual ground**

EPC with Gate Shorted to Source



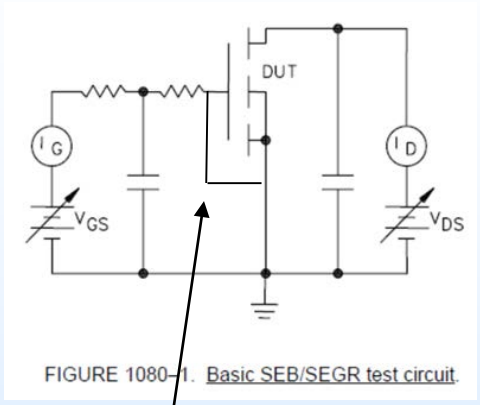


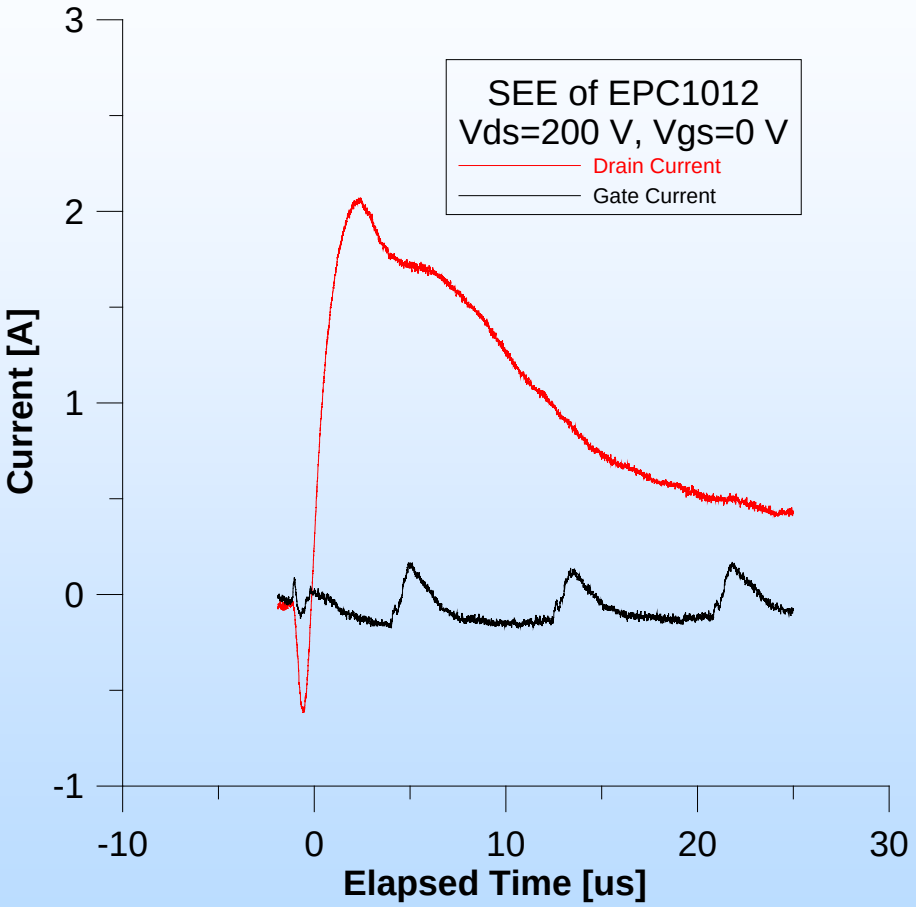
FIGURE 1080–1. Basic SEB/SEGR test circuit.

Shorted gate 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

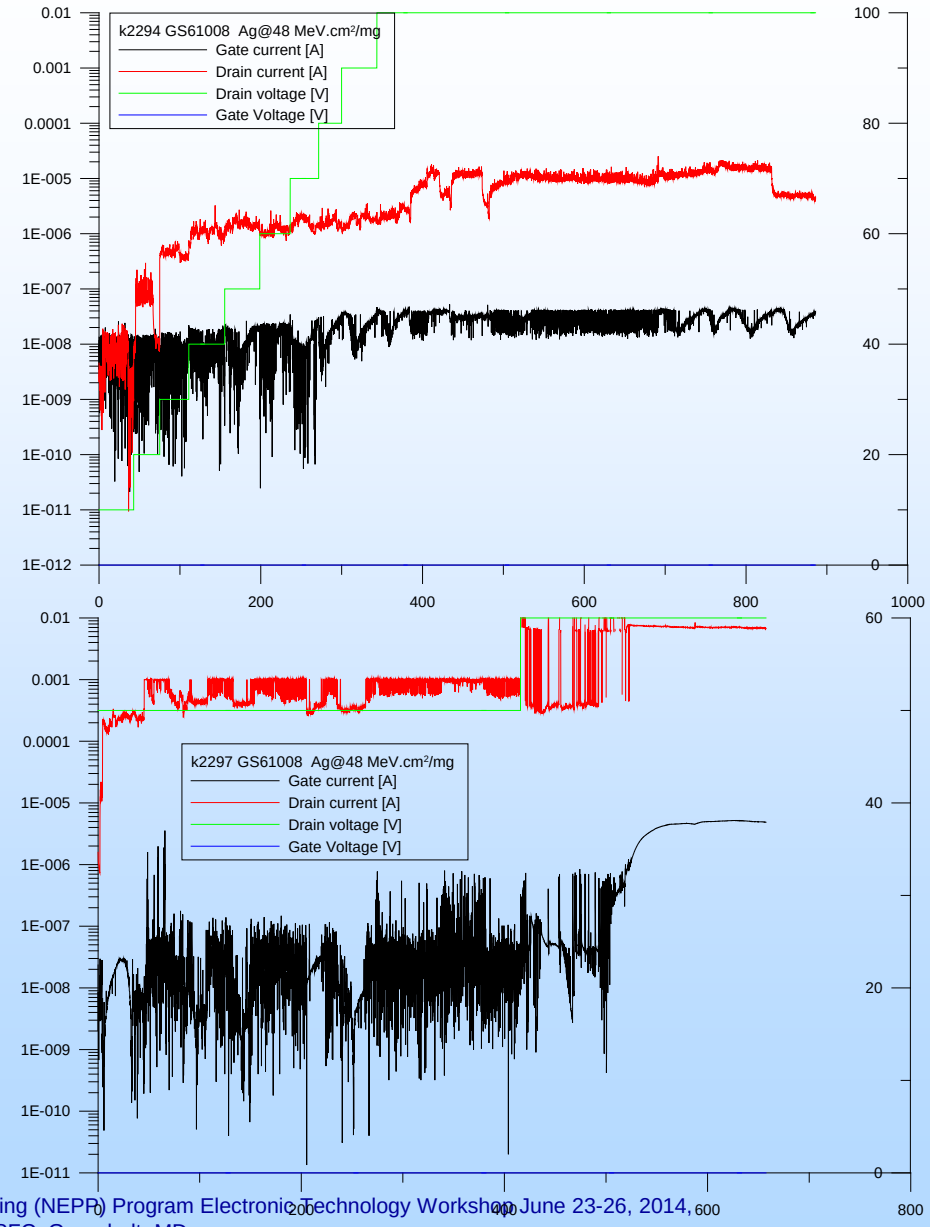


TESTING OF GANSYSTEMS PARTS

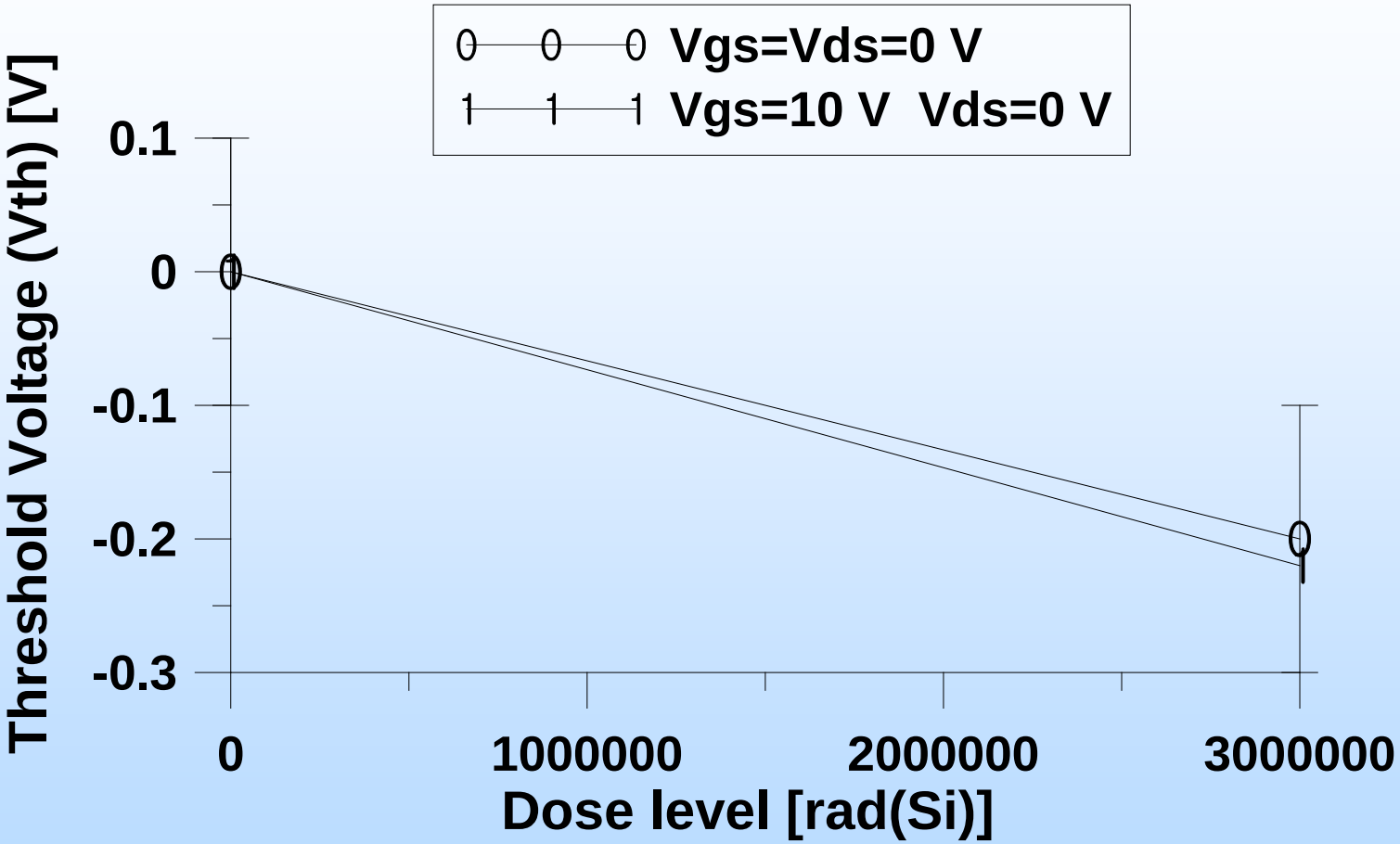
To be presented at the 5th NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 23-26, 2014, NASA GSFC, Greenbelt, MD.

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

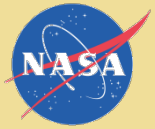


- HDR with 2 hr anneal
- No change in subthreshold behavior

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 then 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

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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

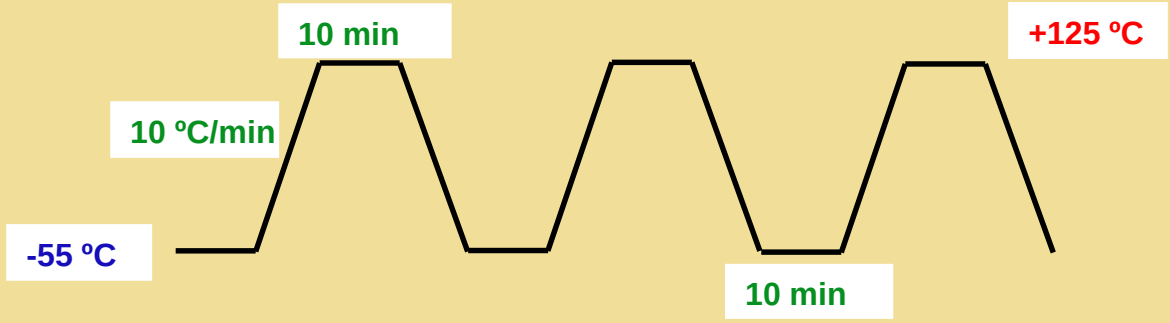
Radiation & Thermal Cycling Effects on GaN Power FETs

Manufacturer	Part #	Parameters	# Samples (control/Irradiated)	Radiation	Cycling
EPC	2012	200V, 3A, 100mΩ	15/26	✓	✓
GaN Systems	GS61008P	100V, 90A, 7.4mΩ	11/10	✓	✓
	GS66508P	650V, 30A, 52mΩ	4/0	Planned	✓

Radiation Exposure						
Device	Ion	Energy (MeV)	LET	Range (μm)	Dose (rads)	Facility
EPC	Xe	1569	40	124.5	8719.6	TAMU
GaN Systems	Ag	1569	41	121	6634	LBL

Thermal Cycling:

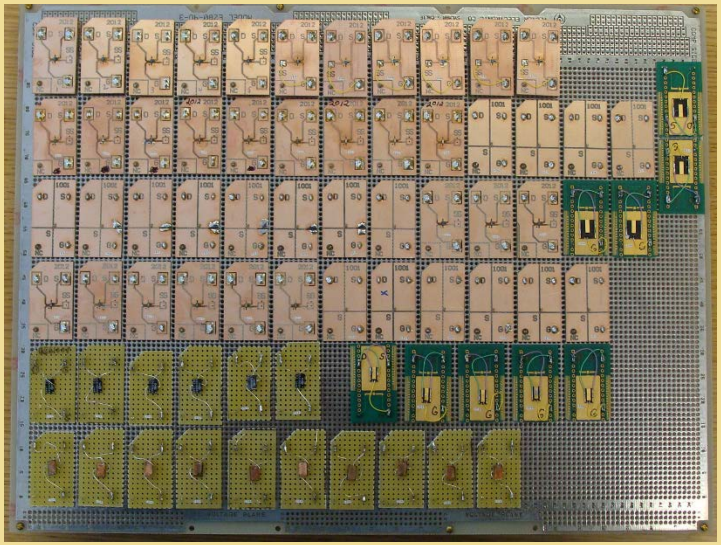
- 120 cycles (Ongoing)
- Rate: 10 ºC/min
- Range: -55 ºC to +125 ºC
- Soak time: 10 min

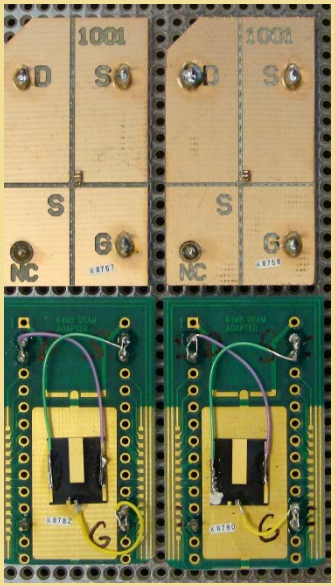


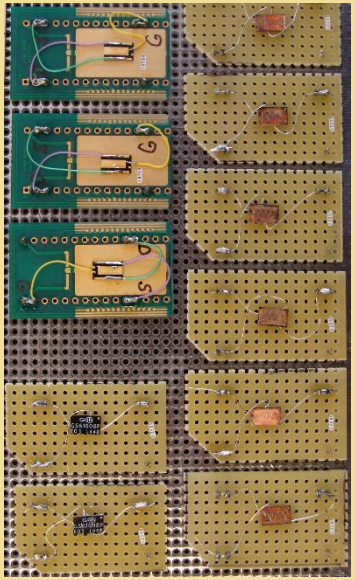
Test Setup

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}

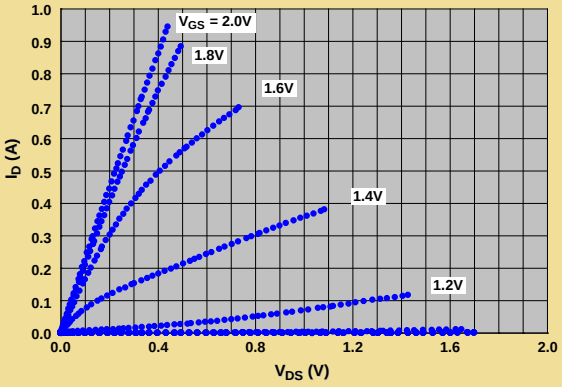




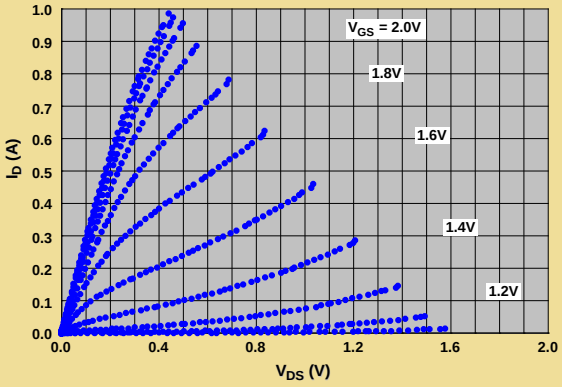


EPC2012 Enhancement Mode Power FET

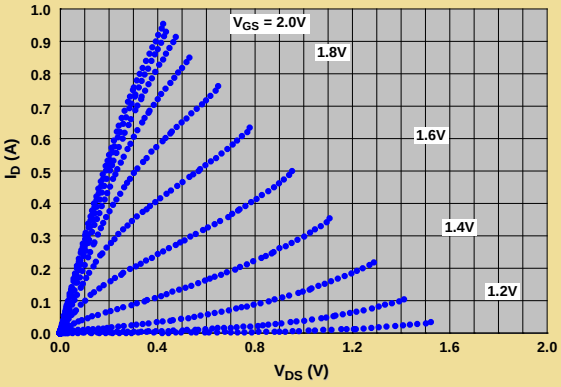
EPC2012	Pre-cycling		Post-cycling		Remarks
	Cont	Irrad	Cont	Irrad	• Control & irradiated parts remained functional after exposure to radiation & thermal cycling • Slight reduction in threshold voltage, modest increase in drain-source resistance & varying increase in leakage current with radiation • Insignificant effects of cycling on properties • Part-to-part variation in output characteristics • No alteration in device packaging or terminations
V_{TH} (V)	1.21	0.90	1.02	0.84	
I_{GSSF} (μA)	0.69	0.84	0.71	0.85	
I_{GSSR} (nA)	540	779	664	881	
I_{DSS} (μA)	0.17	383	0.19	440	
$R_{DS(on)}$ Normalized	1.0	1.33	1.06	1.04	



Control



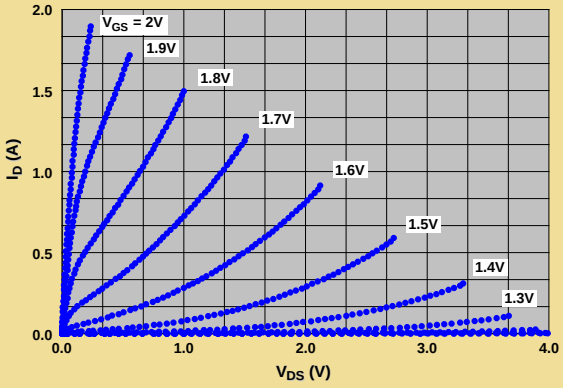
Irradiated



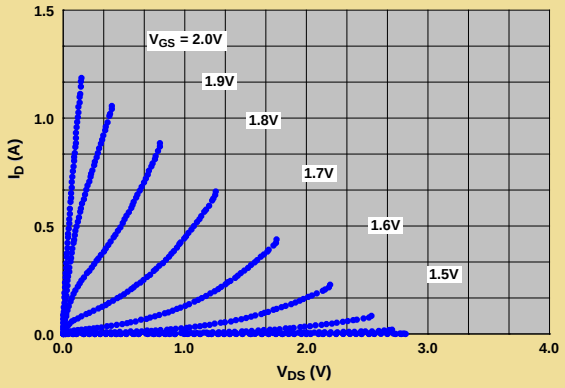
Post-cycling

GaN Systems Enhancement Mode Power FET

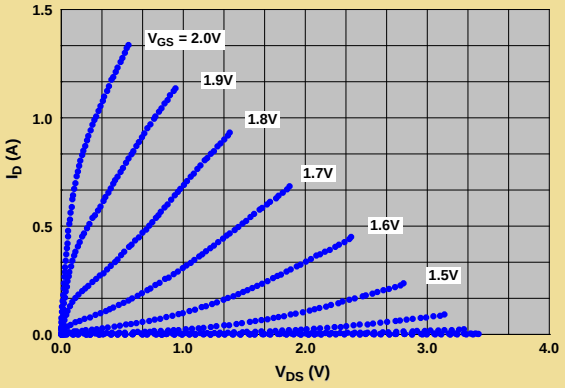
GS61008P	Pre-cycling		Post-cycling		Remarks
	Cont	Irrad	Cont	Irrad	• Control & irradiated parts remained functional after exposure to radiation & thermal cycling • Slight reduction in threshold voltage & modest increase in drain-source resistance with radiation; 1 device had significant increase in leakage current • Insignificant effects of cycling on properties • Part-to-part variation in output characteristics • No alteration in device packaging or terminations
V_{TH} (V)	1.21	0.95	0.97	1.04	
I_{GSSF} (μA)	58.8	35.9	35	68	
I_{GSSR} (nA)	1.54	1.41	1.21	1.31	
I_{DSS} (μA)	1.40	1.24	4.94	72.2	
$R_{DS(on)}$ Normalized	1.0	1.33	1.02	0.87	



Control



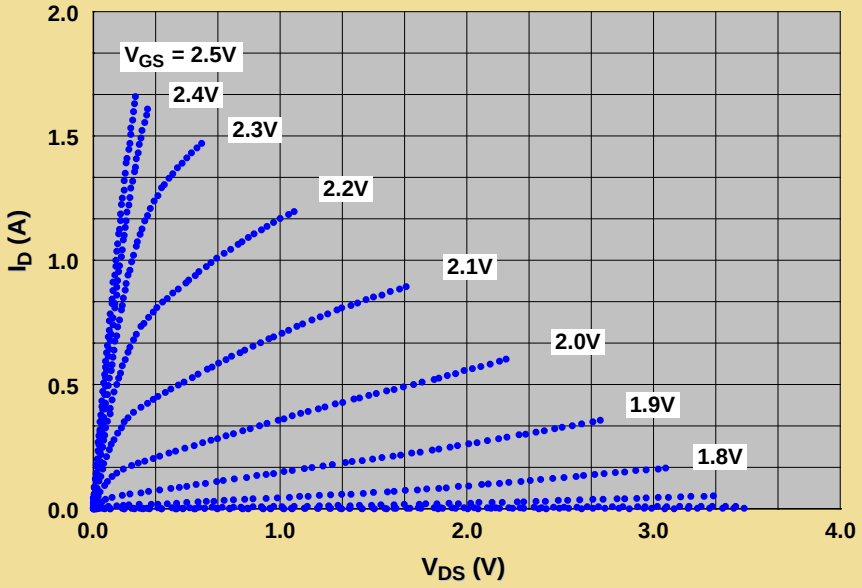
Irradiated



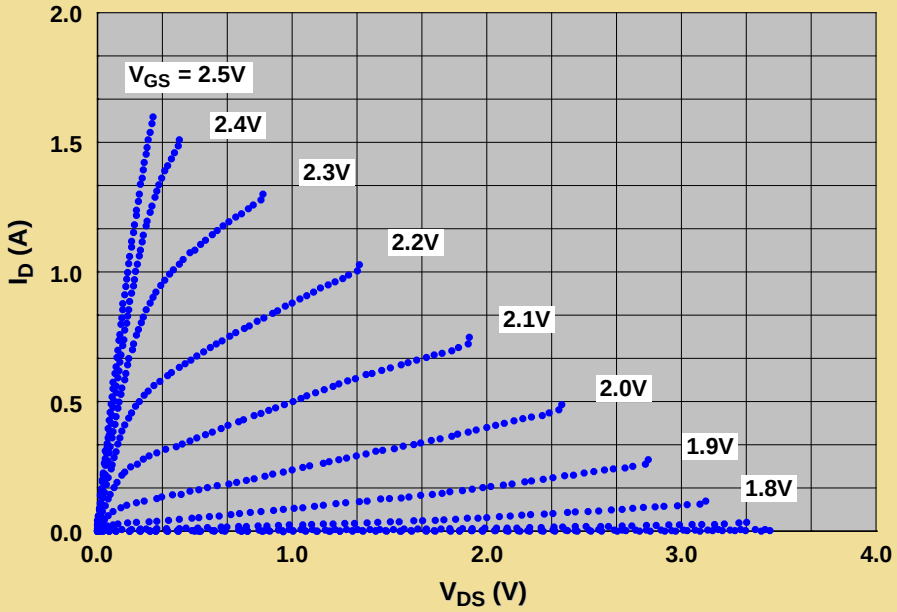
Post-cycling

GaN Systems Enhancement Mode Power FET

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

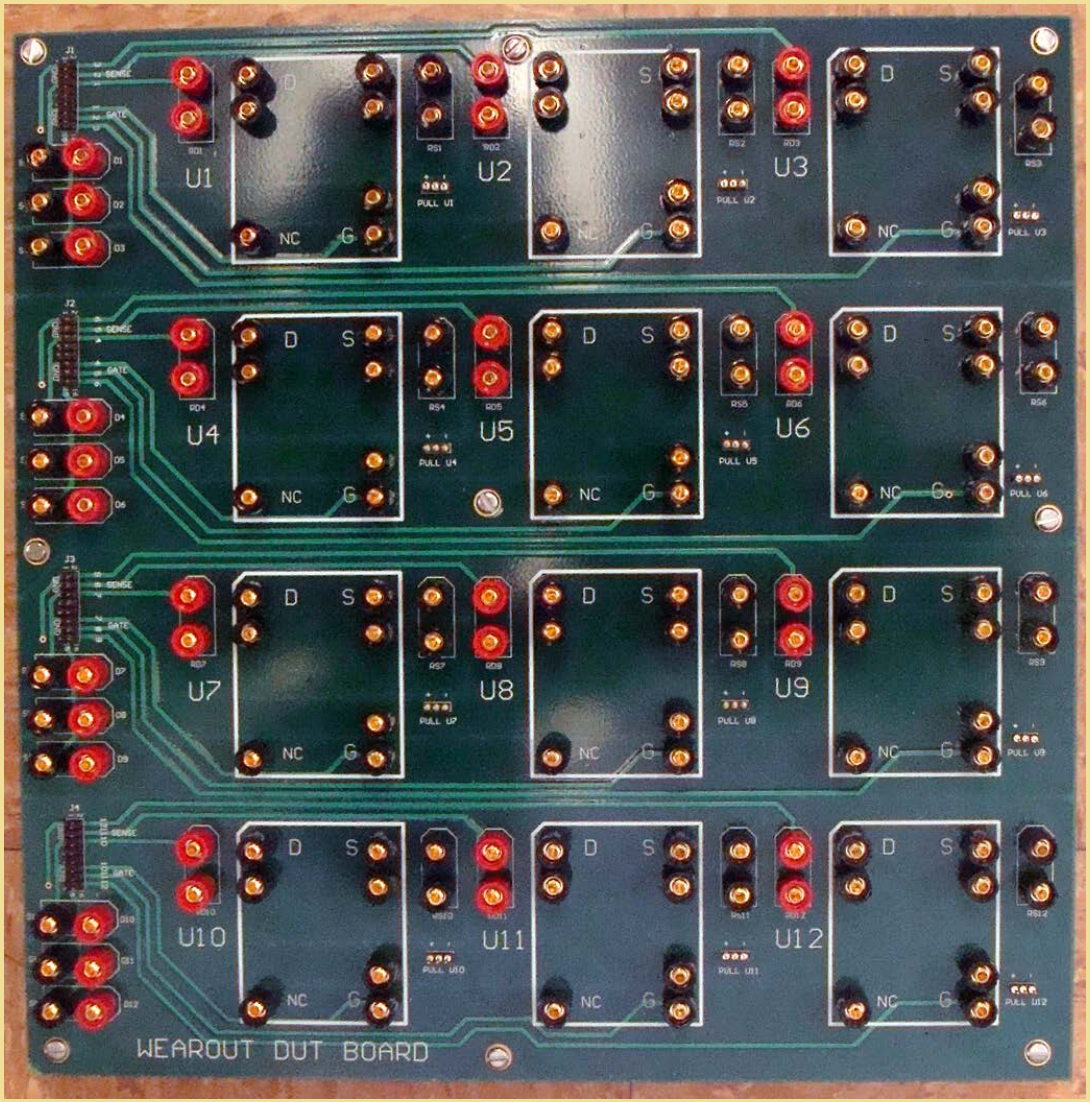


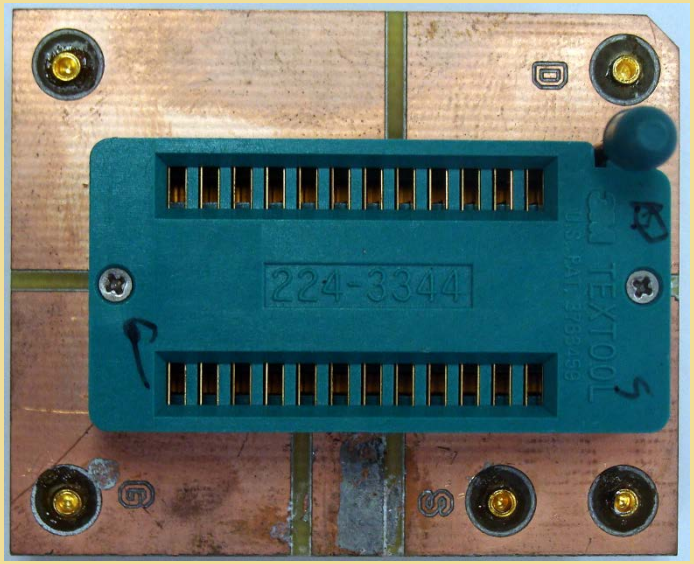
Pre-cycling

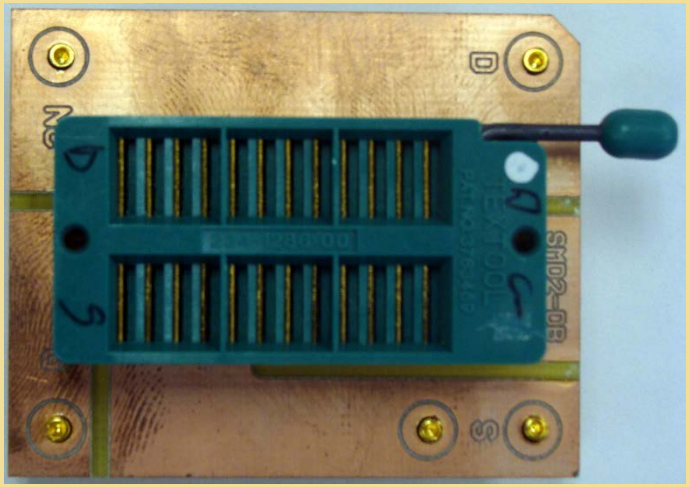


Post-cycling

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

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.