National Aeronautics
and Space Administration

Wide Bandgap Working Group

Presented by Megan Casey

A Collaboration of
Goddard Space Flight Center,
Jet Propulsion Laboratory, and
Glenn Research Center

To be presented by Megan Casey at the NASA Electronic Parts and Packaging Program (NEPP) Electronics Technology Workshop (ETW), NASA Goddard Space Flight Center in Greenbelt, MD, June 11-13, 2012 and published on nepp.nasa.gov.

Collaborators and Areas of Focus

- JPL: Gallium Nitride (GaN) radiation performance and overall reliability
  - Leif Scheick (Working Group Chair)
  - Rick Harris
  - Steve McClure
  - Doug Sheldon
- GSFC: Silicon Carbide (SiC) radiation performance
  - Megan Casey (GSFC Task Lead)
  - Jean-Marie Lauenstein
  - Ken LaBel
  - Mike Sampson
- GRC: Thermal ruggedness
  - Dick Patterson
  - Ahmad Hammoud

Working Group Purpose

- **Explore opportunities for collaboration to leverage strengths of different Centers**
- **Share test data between Centers and avoid duplicative efforts**
- **Assist in test planning and analyzing test data**
- **Identify devices of interest and assist with vendor contacts**
- **Increase Technology Readiness Level of devices to foster use by flight projects**

SiC and GaN at a Glance

- Silicon MOSFETs are approaching their theoretical limits for both on-resistance and gate charge
- SiC and GaN have for several years found use in RF amplifiers
- Both SiC and GaN power transistors have significantly higher figures of merit (measured as the on-resistance times the gate charge), especially at high blocking voltages, than those of Si MOSFETs
- SiC FETs shine at 1000V and higher, whereas GaN devices are currently at 200V and below (with 600V devices under development)

Conner, Margery. "GaN and SiC: on track for speed and efficiency." Electronics Design, Strategy, News. 25 Aug. 2011. Ed. Electronics Design, Strategy, News. 15 Dec 2011. <http://www.edn.com/article/519172-GaN_and_SiC_on_track_for_speed_and_efficiency.php>

Why SiC?

- **Advantages of SiC Power MOSFETs (compared to Si)**
  - **Low on-state drain to source voltage due to low R_{DSon}**
  - **Low total gate charge**
  - **R_{DSon} changes little as temperature increases**
  - **Higher maximum junction temperature**

- **Disadvantages**
  - **Gate drive requires greater voltage for full enhancement, and slightly negative values for reliable cutoff**
  - **Thoughtful consideration of parasitic layout parameters required due to very fast switch transitions**
  - **Likely to generate greater emissions due to rapid switch transitions**
  - **Cost**

Stowe, Bob. "Tutorial: Power Semiconductor Switches | Power MOSFETs and Schottky Diodes." True Power Research. 20 Mar. 2011. Ed. True Power Research. 4 Nov 2011. <http://www.truepowerresearch.com/2011/03/tutorial-power-semiconductor-switches-power-mosfets-and-schottky-diodes/>

Why GaN?

- **Advantages of GaN Power MOSFETs (compared to Si)**
  - **Very low total gate charge**
  - **Low R_{DSon} resulting in lower conduction losses**
  - **R_{DSon} changes less as temperature increases**
  - **Device is fully enhanced with a V_{gs} of 5 V**

- **Disadvantages**
  - **Thoughtful consideration of parasitic layout parameters required due to very fast switch transitions**
  - **Likely to generate greater emissions due to rapid switch transitions**

Stowe, Bob. “Tutorial: Power Semiconductor Switches | Power MOSFETs and Schottky Diodes.” True Power Research. 20 Mar. 2011. Ed. True Power Research. 4 Nov 2011. <http://www.truepowerresearch.com/2011/03/tutorial-power-semiconductor-switches-power-mosfets-and-schottky-diodes/>

Current Test Devices

Center	Tech.	Vendor	PN	Voltage	Desc.
GSFC	SiC	Cree	CMF20120D	1200	Power MOSFET
GSFC	SiC	TranSiC	BT1206AA-P1	1200	BJT
GSFC	SiC	SemiSouth	SJEP120R100	1200	JFET
GSFC	SiC	SemiSouth	SDA10S120	1200	Schottky Diode
GSFC	SiC	STMicro	STPSC806D	600	Schottky Diode
GSFC	SiC	STMicro	STPSC1006D	600	Schottky Diode
GSFC	GaN	EPC	EPC2010	200	Power MOSFET
GSFC	SiC	STMicro	TBD	1200	Power MOSFET
GRC	SiC	Cree	CSD01060	600	Schottky Diode
GRC	SiC	SemiSouth	SJEP120R063	1200	JFET
GRC	GaN	National	LM5113	100	FET Driver

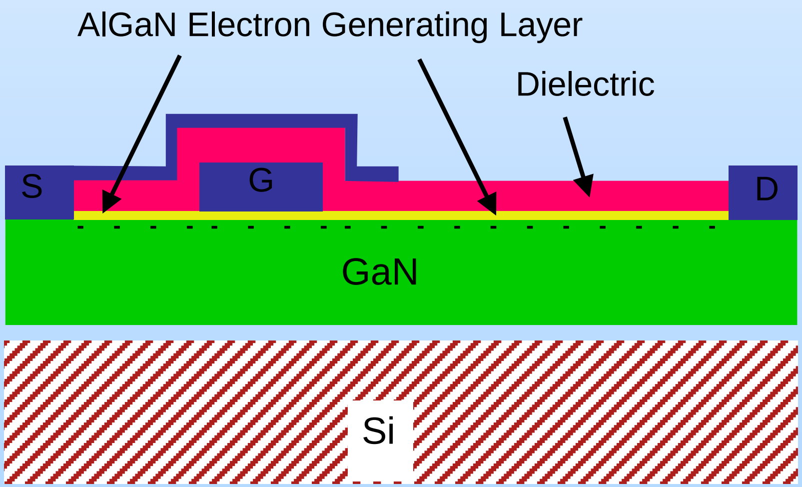
Current Test Devices (cont'd)

Center	Tech.	Vendor	PN	Voltage	Desc.
JPL	GaN	Cree	CGH40010	120	HEMT
JPL	GaN	Cree	CGH40120F	120	HEMT
JPL	GaN	Sumitomo	EGNB010MK	84	HEMT
JPL	GaN	Sumitomo	EGNB045MK	84	HEMT
JPL	GaN	RFMD	RF3934	120	Power Amplifier
JPL	GaN	EPC	EPC1015	40	Power MOSFET
JPL	GaN	EPC	EPC1005	60	Power MOSFET
JPL	GaN	EPC	EPC1001	100	Power MOSFET
JPL	GaN	EPC	EPC1014	40	Power MOSFET
JPL	GaN	EPC	EPC1011	150	Power MOSFET
JPL	GaN	EPC	EPC1010	200	Power MOSFET
JPL	GaN	EPC	EPC1009	60	Power MOSFET
JPL	GaN	EPC	EPC1007	100	Power MOSFET
JPL	GaN	EPC	EPC1013	150	Power MOSFET
JPL	GaN	EPC	EPC1012	200	Power MOSFET
JPL	GaN	IR	iP2010		
JPL	GaN	IR	IP2011		
JPL	GaN	IR	TBD	600	Power MOSFET
JPL	GaN	Transphorm	TBD	600	

GALLIUM NITRIDE POWER DEVICES

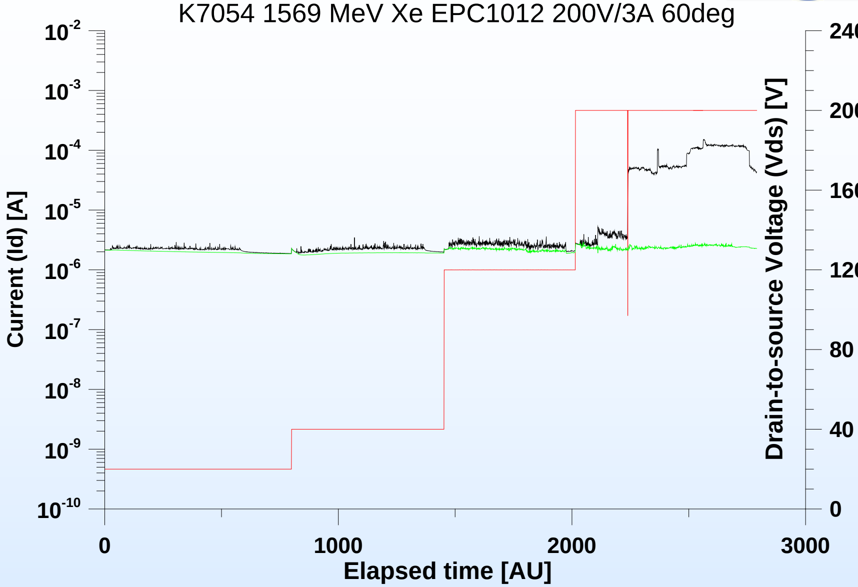
Gallium Nitride

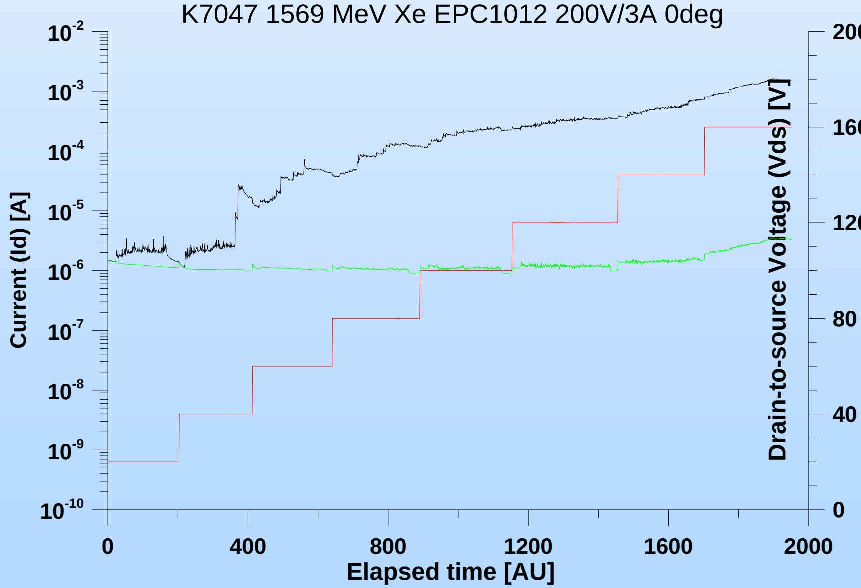
- **Devices are becoming available**
  - **Efficient Power Conversion (EPC) is primary power supplier**
  - **Cree is primary RF supplier**
  - **Neither available in hi-rel or rad hard form**
- **Reliability effects are a concern**
  - **Gate stress is lethal (abs max of Vgs +/-5 V!)**
  - **Thermal effects and aging are under study at GRC**



Gallium Nitride

- Radiation effects have been mostly positive
  - Single Event Effects (SEE)
    - RF HEMTs exhibit small damage
    - EPC HEMT result in SEDR to isolation oxide which has been hardened to near full compliance
    - SEE in RF mode may result in gate overstress
  - Total Ionizing Dose (TID) is very robust
    - >1 Mrad(Si)
    - No oxides to damage
    - Proton testing scheduled

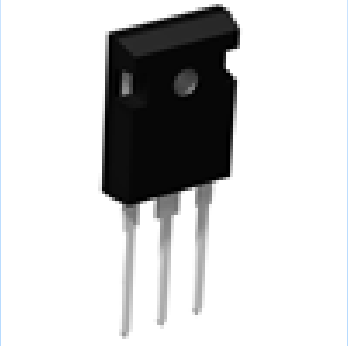




SILICON CARBIDE POWER DEVICES

Goals and Expected Impact

- **Evaluation of SiC power devices for space applications**
  - Research new and emerging manufacturers
  - Develop relationships with SiC device suppliers
  - Investigate SEE and TID susceptibility of currently available commercial products
- **Identify possible TID tolerant power MOSFET alternatives for the space environment**
- **Strengthen existing and foster new relationships with industry**



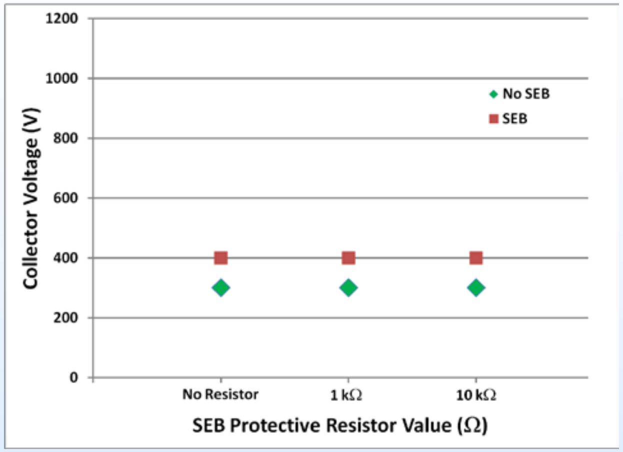
Rohm

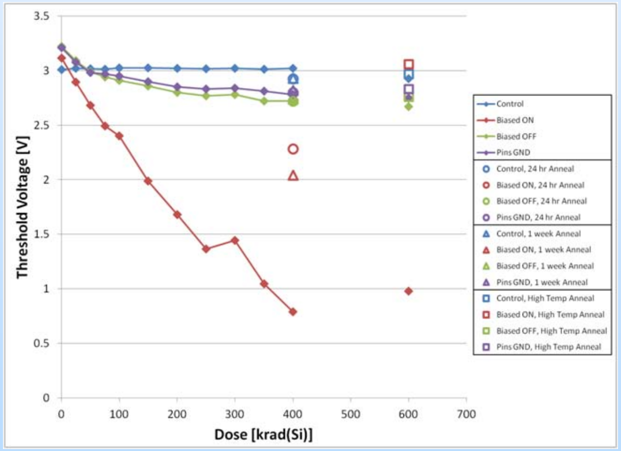
Micross

Cree

SEE and TID Testing

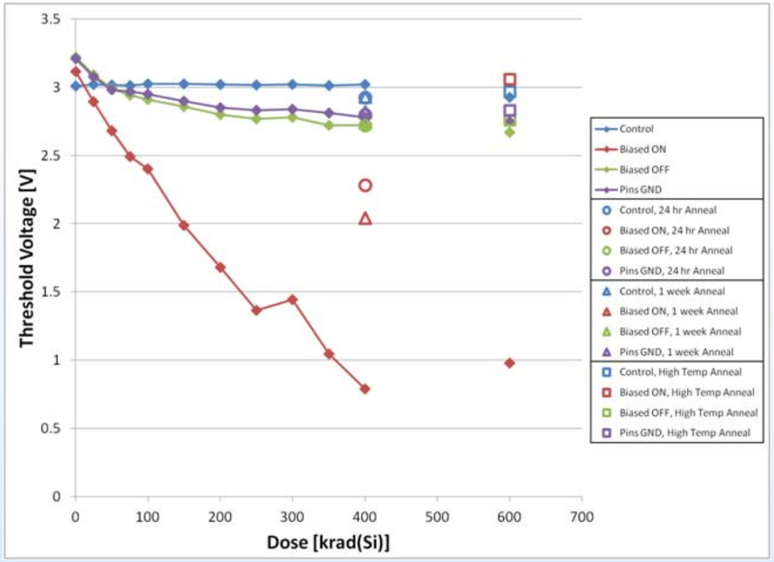
- **Test dates:**
  - SEE
    - TranSiC 1200V BJT: Mar 24, 2012; June/July, 2012
    - Cree 1200V VDMOS: June/July, 2012
    - Micross 1200V JFET: June/July, 2012
    - Micross 1200V Schottky Diode: 4th Qtr
  - TID
    - Cree 1200V VDMOS: June 29, 2011
    - Micross 1200V JFET: 4th Qtr
- **Alternative sources of SiC power MOSFETs for future evaluation:**
  - ST Micro
  - Rohm

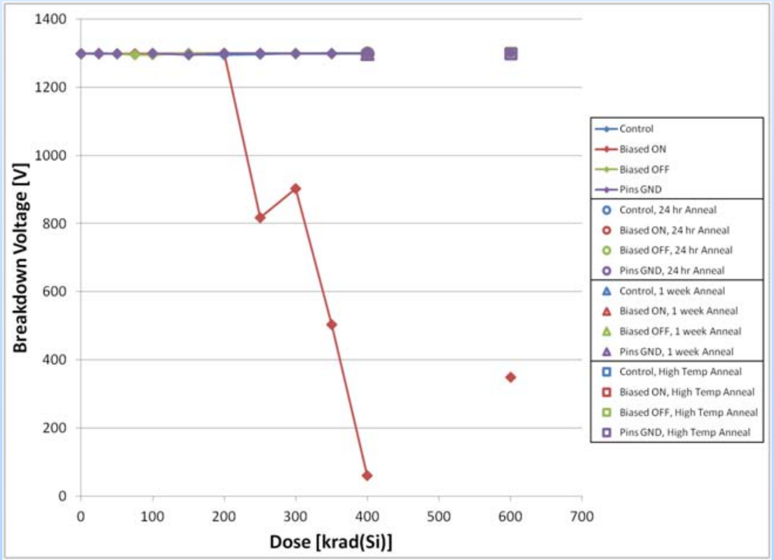


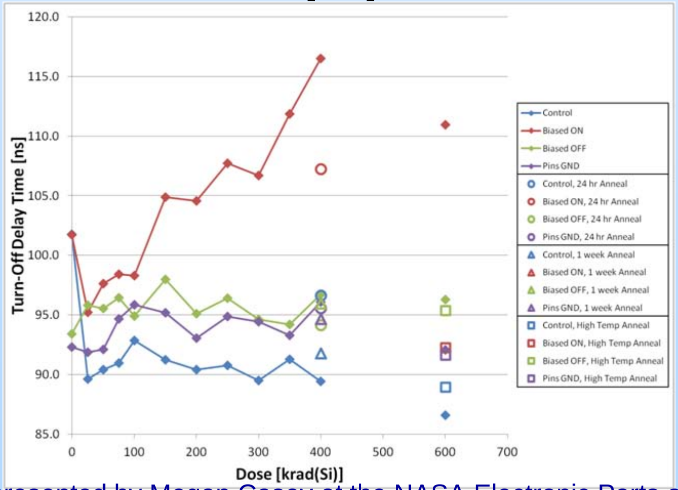


SiC TID Test Results

- **Small sample size and large part-to-part variability**
- **All parameters, except breakdown voltage, stayed within “specification” to 600 krad**
  - Most parameters list a typical value and do not have a minimum or maximum
- **There is a time-dependent dose effect (most evident between 250 and 300 krad steps)**

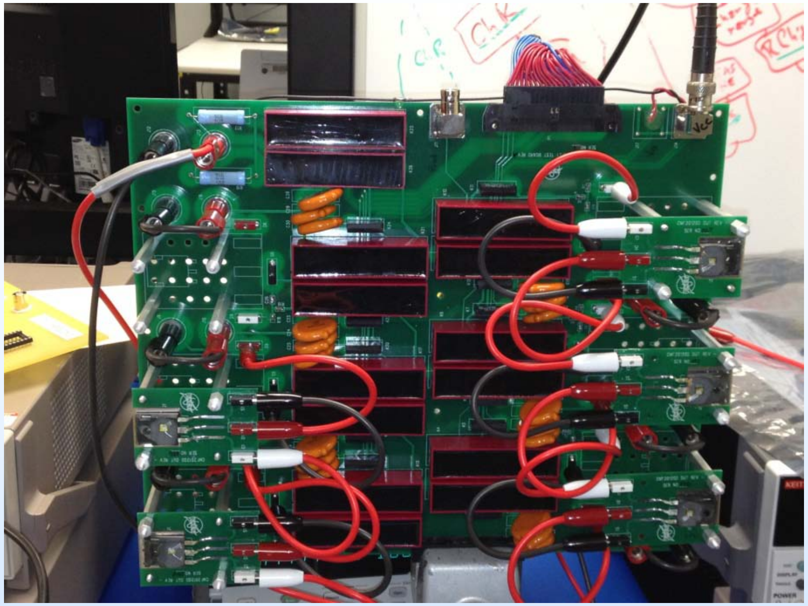


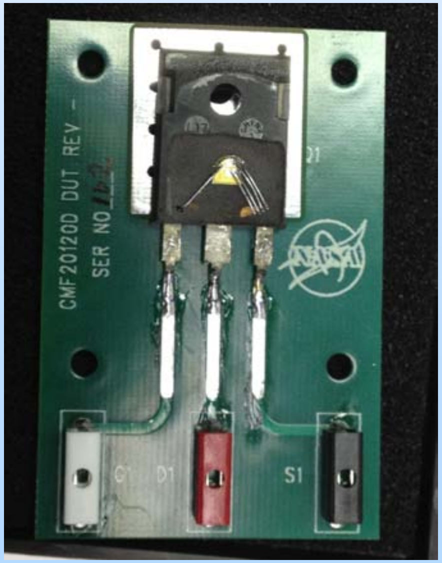




Status

- **Accomplishments**
  - Designed and implemented new motherboard for high-voltage SEE testing
  - Cree 1200 V power MOSFET testing included as featured part in 2012 TID Compendia paper
  - Completed preliminary SEB testing of TranSiC1200 V NPN BJTs at LBNL





- **Current Status**
  - JFETs, BJTs, and MOSFETs will be tested at TAMU in June/July 2012

Path Forward

- **SEE Tests**
  - Analyze data and write test reports
    - Depending on outcome, additional testing may be required
- **TID Tests**
  - SEE testing of BJTs is higher priority (based on limited number of parts)
  - Begin preparation for JFETs
  - Possibility for collaboration with CoolCAD on Cree devices
  - Identify and obtain MOSFETs from other vendors

WIDE BANDGAP THERMAL EFFECTS

Thermal Effects

Objective:

Perform long-term thermal cycling on control and irradiated GaN and SiC devices to assess their reliability for use under harsh environments in NASA missions

Test Plan:

Perform long-term thermal cycling on devices:

Repeat measurements on devices during cycling

Perform measurements after conclusion of cycling activity

Parts Tested:

CREE CGH40120F 120 W, RF Power GaN HEMT

- 2 irradiated with Kr, 7 unirradiated

CREE CMF20120D 150 W, SiC Power MOSFET

- 3 unirradiated

Results

CMF20120D SiC MOSFETs

- **All devices maintained functionality after 1000 cycles**
- **The three MOSFETs experienced a slight decrease in V_{TH} and in $R_{DS(ON)}$ upon cycling**

CGH40120F GaN HEMTs

- **All GaN HEMTs remained functional after 1000 cycles between -55C and +125C**
  - **No difference in effects for control and irradiated samples**
- **Changes due to cycling included variation in V_{TH}, increase in transconductance, and increased I_D values**

Future Work

- **Perform long-term thermal cycling on new control and irradiated SiC and GaN power devices as parts become available**

Conclusions

- **GaN and SiC devices show high TID tolerance**
  - **GaN HEMTs do show some SEEs, while SiC parts still need to be tested**
- **Parts show some degradation, but maintain functionality, after thermal cycling**
  - **No difference in irradiated versus unirradiated**

- **Working group is meeting monthly**
- **Solid collaboration between centers**
- **Look forward to continued success**