

Power Device Qualification Methods

Leif Scheick

**Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, Ca**

**This Research Was Carried Out In Part by the Jet Propulsion Laboratory, California
Institute of Technology, Under Contract With the National Aeronautics and Space
Administration Under the NASA Electronic Parts and Packaging Program (Code AE).
Other data was collected from NASA flight projects.**

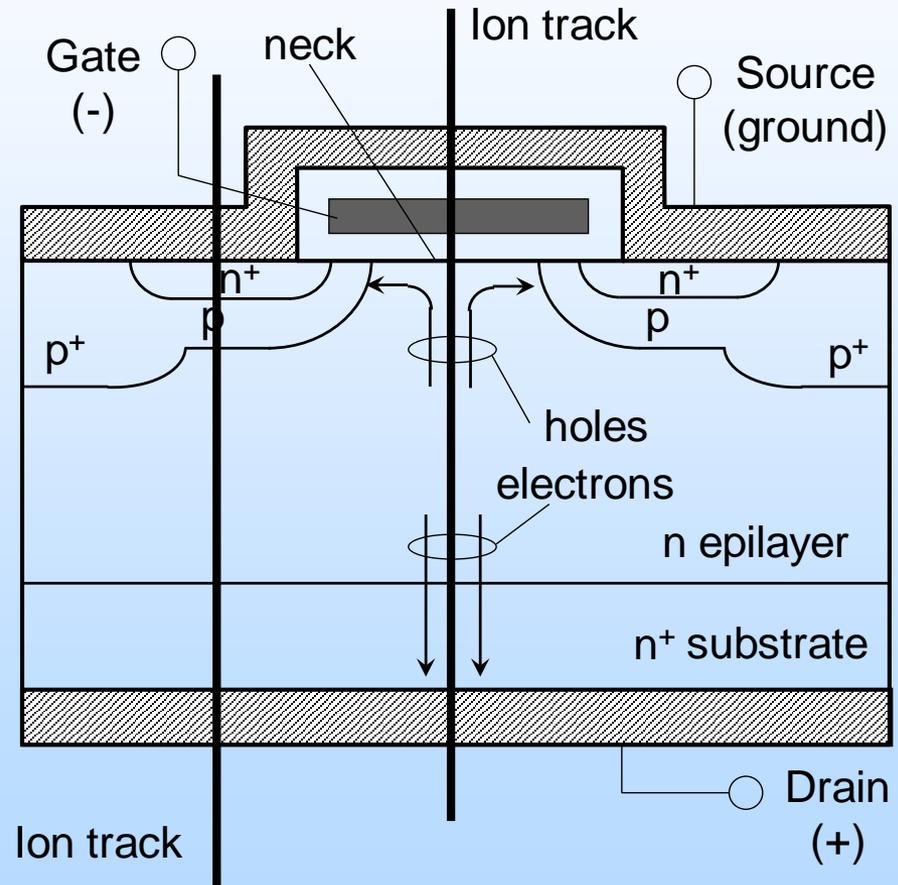


Introduction

- **Radiation effects in semiconductors**
 - Power devices are no exception
- **Space community is dominated by rad-hard vertical power MOSFETs**
 - Little concern about TID effects up to now
 - SEE effects are the current focus
- **Facts about SEE in power MOSFETs**
 - Shorten lifetime and reduce Safe Operating Area (SOA), i.e., derating or added design margin
 - Ability to block voltage and limit current is most susceptible to SEE effects
 - New designs, application, and requirements are a challenge
 - Very few actual failure in space due to conservative design and low rate

SEE in High-Voltage Power MOSFETs

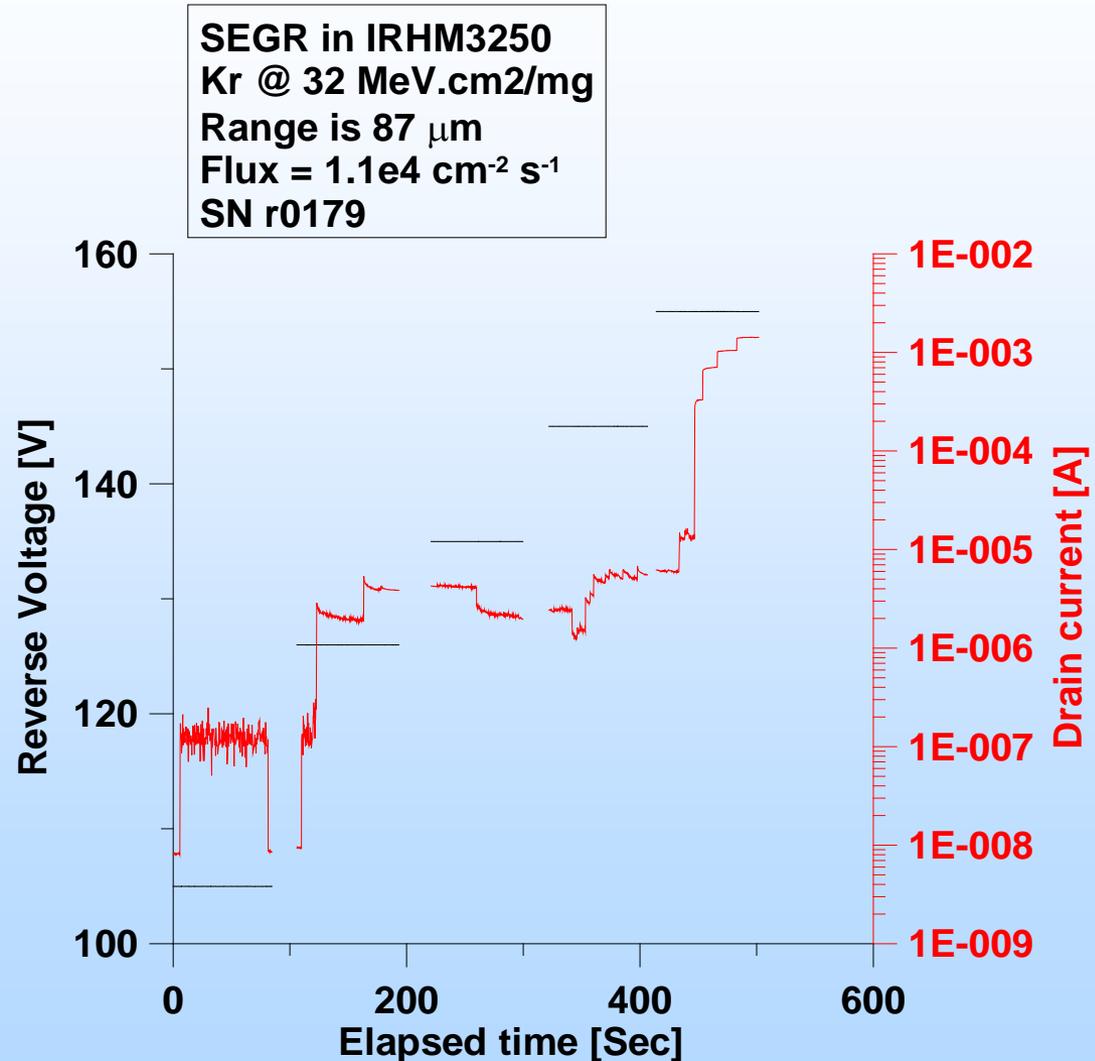
- **Caused by ion strike**
 - More important for higher-voltage devices
 - Even hardened power MOSFETs are susceptible to SEGR
- **SEGR from two effects:**
 - Direct interaction with gate
 - Increase in electric field from drain
 - Large fraction of voltage in the epi-region is coupled to the gate by the ion strike
 - Dependent on ion angle
 - Failure is high gate leakage
- **SEB from activation of parasitic bipolar transistor under source contact**
 - Temperature dependent
 - Current limitable
 - Failure is high drain-to-source leakage





SEE in High-Voltage Power MOSFETs

- Testing always occurs in situ
- Essentially testing is force a voltage and read a current
- Prompt spike in current signifies a SEE effect
 - Careful distinction must be made from TID effects
 - Small events may not effect parameters





Radiation Effects in Power MOSFETs - FY10 (Continuing)

Description:

- NASA missions have driven interest in a realistic derating for power MOSFETs. These missions expose devices to long missions in harsh radiation environments like Geosynchronous, Solar and Jovian missions. The requirements for power management have grown in current and voltage limits while the technology has not advanced, so the need to precisely derate the available devices has increased. Recent work has shown that SEGR is susceptible to dose history, and long and/or harsh missions will reduce the safe operating area of power devices.
- Device types from previous studies that show important phenomena, like atypical proton-gamma correlation, low dose instability in SEE response and hyper-dependence on device architecture, will be chosen for extensive studies to resolve and understand the observations. This will result in a definite derating guideline for the gamut of NASA missions.

FY10 Plans:

- **Select two parts that demonstrate the strongest dose-SEGR dependence**
 - **Procure test devices (IR)**
- **Test devices with various stressors, including but not limited to**
 - **proton and gamma irradiation**
 - **biased and unbiased total dose irradiations**
 - **SEE testing, SEM and spreading resistance**
- **Correlated difference with irradiation variable**
 - **protons vs. gamma**
 - **biased vs. unbiased**
- **Provide de-rating guideline**

Schedule:

Power MOSFET - Radiation	2009			2010											
	O	N	D	J	F	M	A	M	J	J	A	S			
procure devices	[Bar]							◇							
plan radiation tests			[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	◇						
perform radiation testing				[Bar]	◇										
report on test results					[Bar]	◇									
final report delivery								[Bar]	[Bar]	[Bar]	[Bar]	◇			
propose follow-on tests								[Bar]	[Bar]	[Bar]	[Bar]	◇			

Deliverables:

- Report on the SEE failure mode investigation (FY10)
 - Updated SEGR test guideline, if needed (FY10)
- Provide a revised voltage de-rating scheme for power MOSFETs with prior dose history (FY10)

Lead Center/PI: JPL/Selva

Co-Is: JPL/Scheick

Contributors: IR

Center Funding Split: 100%



Radiation Effects in Newly Available Power MOSFETs - FY10 (NEW)

Description:

• Available power devices to NASA missions have decreased due to fabrication challenges at the manufacturer, but new devices are coming onto the available market. Very little radiation test data applicable to NASA mission is available on these devices. Upcoming NASA missions have driven interest in a better catalogue of parts available to NASA designers and contractors with adequate mission assurance data.

• Device types for an emerging manufacture (Fuji) will be procured pro bono to test to NASA standards (Testing Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs). Applicability to NASA mission will be assessed with any derating guidelines.

FY10 Plans:

- Acquire parts
 - Pro-bono test hi-rel test devices from Fuji
 - 500V from Fuji is in works
 - 3 other part types expected
- Perform radiation testing
 - SEGR and TID/DDD
- Analyzed data
 - Side by side comparison with IR
 - FIT and SER estimates
 - Any circuit application anomalies

Schedule/Costs:

Power MOSFET - Radiation	2009			2010											
	O	N	D	J	F	M	A	M	J	J	A	S			
procure devices	[Bar]						◇								
plan radiation tests			[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	◇						
perform radiation testing				[Bar]	◇										
report on test results					[Bar]	◇									
final report delivery								[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	◇		
propose follow-on tests								[Bar]	[Bar]	[Bar]	[Bar]	[Bar]	◇		

Deliverables:

- Report on the SEGR results for new device types (FY10)

Lead Center/PI: JPL/Selva

Co-Is: JPL/Scheick

Contributors: STM, IR

Center Funding Split: 100%

NASA and Non-NASA Organizations/Procurements:

Test devices: \$0K

Equipment upgrade: \$0K

Radiations Effects in Power Devices

Timeline



- **Proactive and reactive response to technology challenges**
 - Proactive in qualifying device ahead of missions
 - Reactive in concerns of upcoming missions
- 2004 – Technology overview
- 2005 – Test method development
- 2006 – Latent damage investigation
- 2007 – Test method publication
- 2008 – Dose damage investigation
- 2009 – Qualify emerging part vendors
- 2010 – Test guide update and IR requal
- 2011 – Emerging vendors and technology



Goals

- **Test emerging devices that are usable to community**
 - IR, Microsemi, Semicoa, STM, Fuji
 - GaN MOSFETs
- **Investigate observed radiation anomalies in power MOSFETs**
 - Latent damage, dose effects, lifetime effects
- **Develop testing methods and technology to meet new emerging project needs**
 - Extremes in current and voltage measurement
 - Specific environment testing
 - Thermal or radiation emulation
 - Enhanced predictive methods including
 - Predicted rate calculation and device modeling
- **Inform public on what methods are best**
 - NASA test guideline
 - Report latest testing (NSREC Data Workshops)



Expected Impact to Community

- **Mission Assurance**
 - **Improved test capabilities**
 - Both in NASA capabilities and exported in guidelines
 - **Improved mitigations and analysis**
 - Rate prediction is a continuing challenge
- **Design applications**
 - **Improved derating and part applications**
 - Less time spent on part selection
 - **Part selection based on known data**
- **Product development**
 - **Better data**
 - Prompt feed back to vendors



Status/schedule

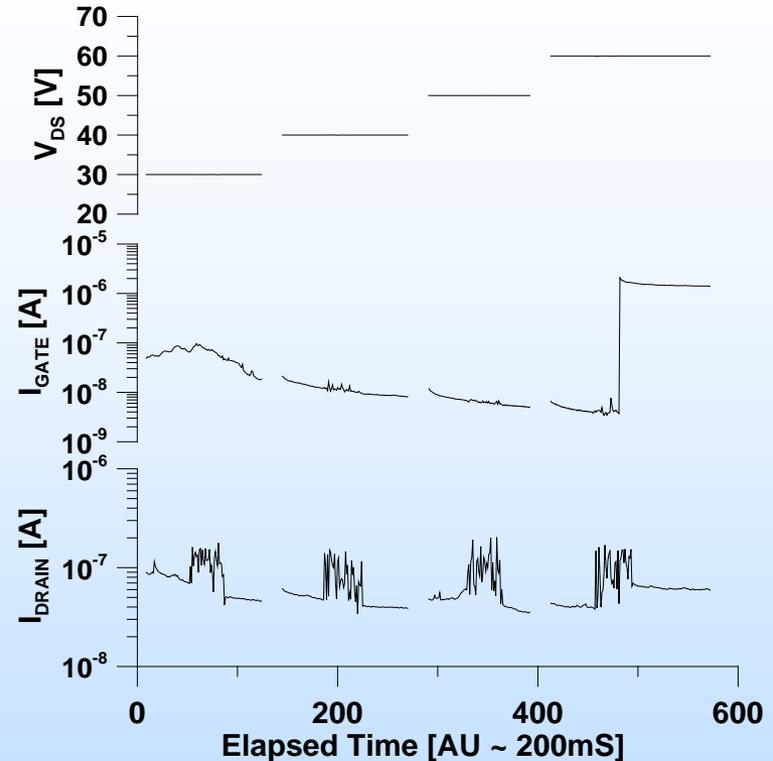
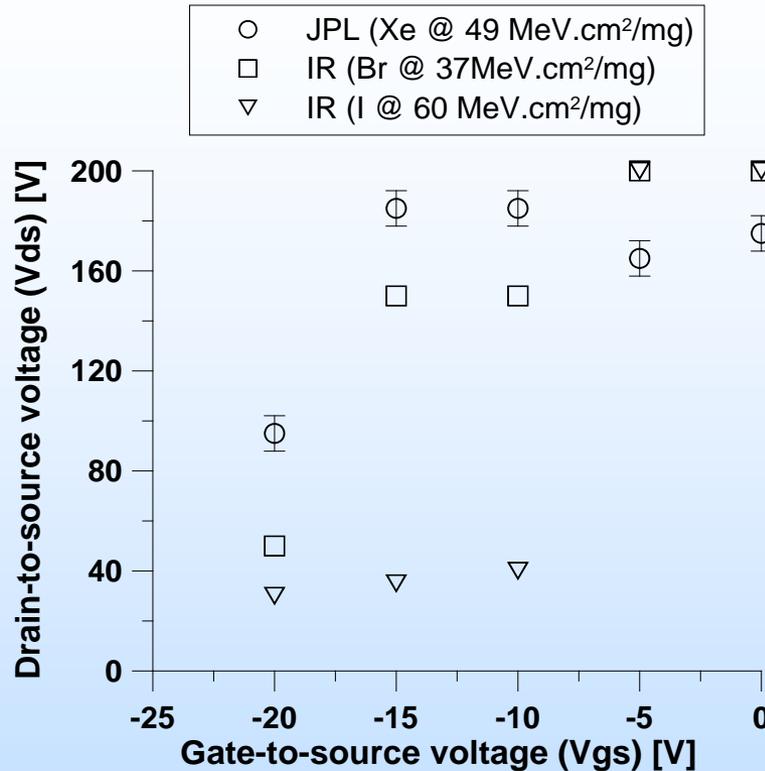
- **Updating latest test guideline**
 - **The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [JPL Publication 08-10 2/08].**
 - **Q3-FY10**
- **Publish ASTM guide for power device testing**
 - **Q4-FY11**
- **Qualify emerging parts**
 - **New IR line and other entries**
 - **Q4-FY11**
- **Technology readiness for emerging technology**
 - **GaN and SiC**



Highlights/Accomplishments

- **Part qualification**
 - Supported or partially supported testing of more than 30 power MOSFETs in 6 years
- **Anomaly investigations where risk to flight project was scoped**
 - Latent damage in power devices
 - Manageable risk
 - Effect of dose on SEE response
 - Minimal risk
 - Criticality of testing conditions on failure rate estimation
 - Significant risk
 - Effect of circuit on SEE response
 - Manageable risk

Highlight 1 – Gross SEE Data



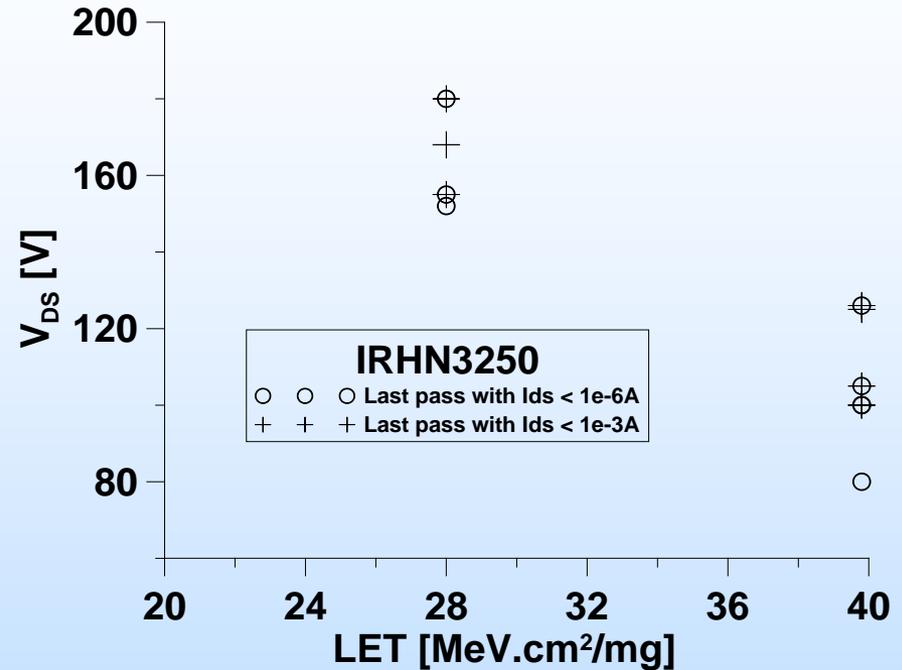
- **Data delivered to public**
 - SOA (left) to aid in part selection
 - Failure mode data (right) to aid in mitigation

• **Risk on each part is manageable**



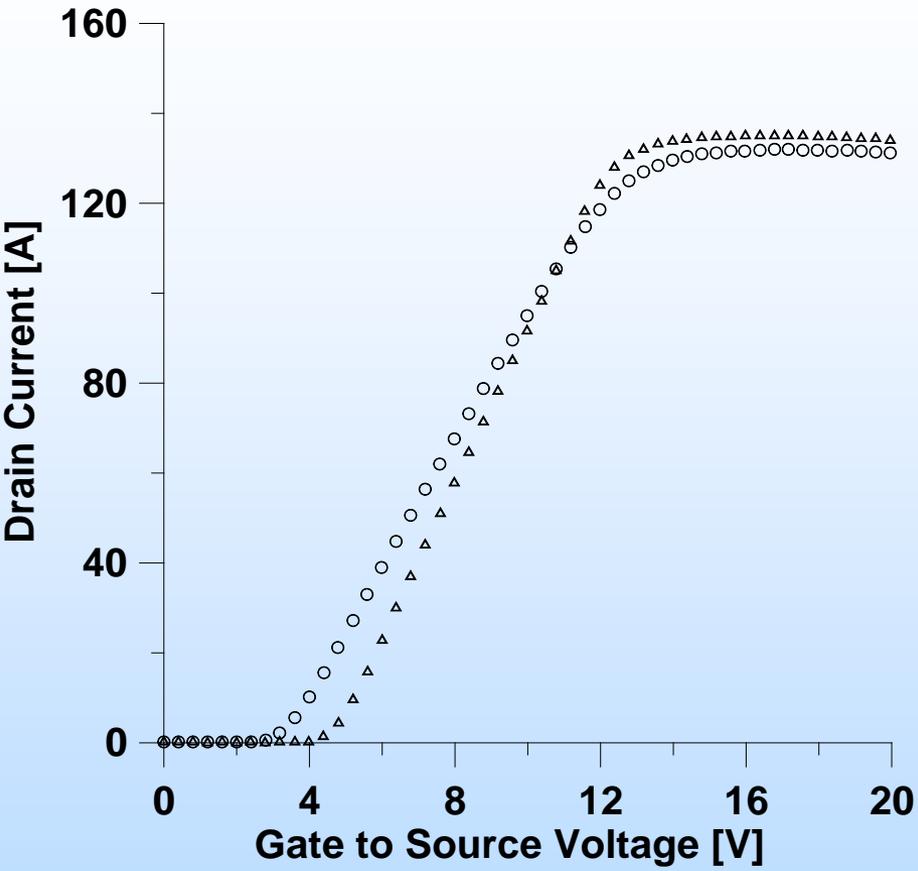
Highlight 2 – Latent damage

- 200V Power MOSFET used at limit of SOA
- Range of test ion an issue
- Additional testing revealed non-catastrophic breaks within SOA
- Question of the resulting risk of “walking wounded” devices was issue
- Further analysis would estimate that the risk of enough incremental damage was low
- Reduction in life not known

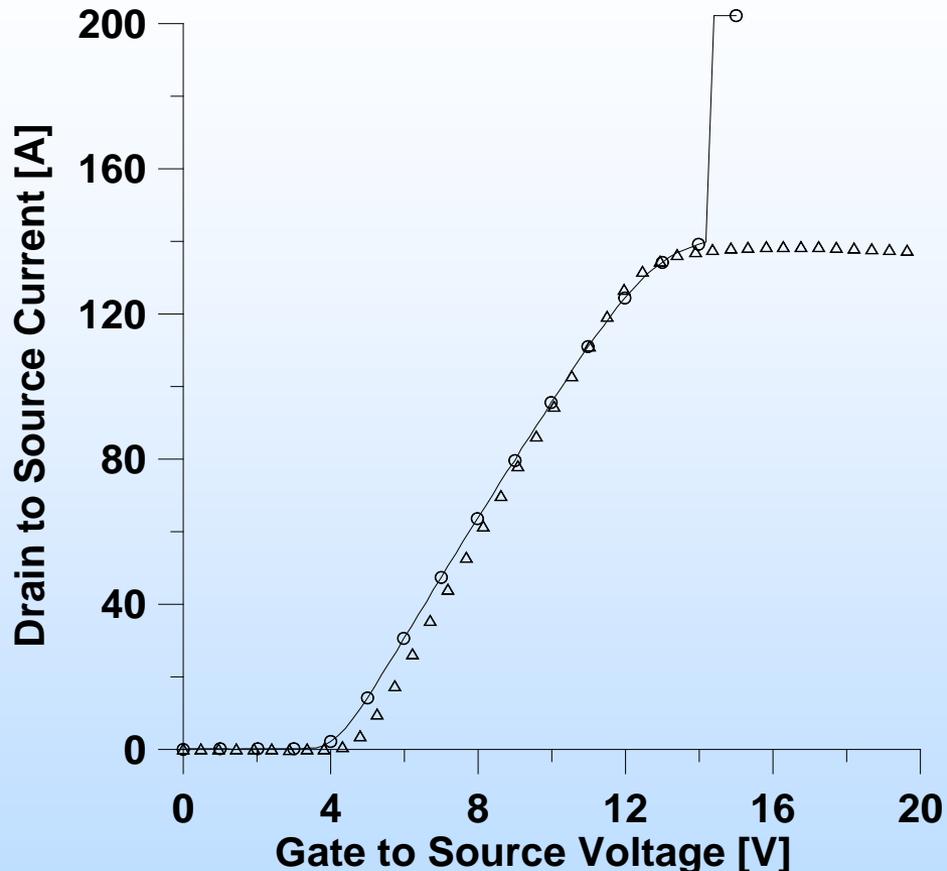


SEGR in a 200-V Hardened Power MOSFET

Highlight 2 – Latent damage – Fatal stress



Walking Wounded



KIA

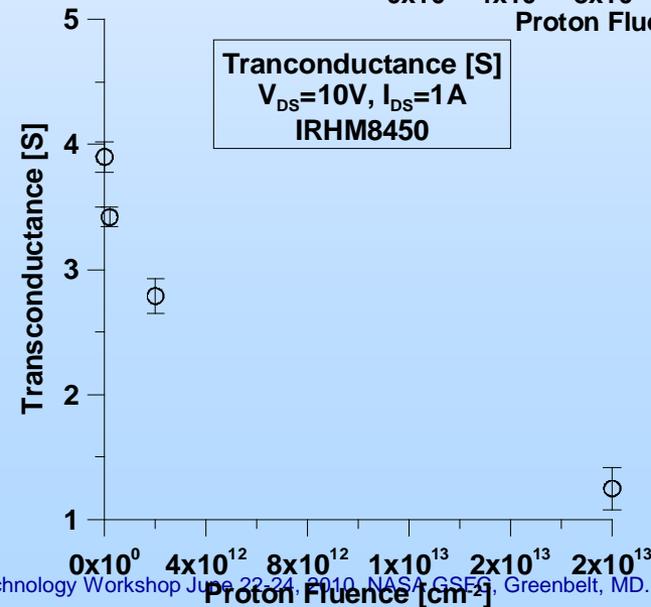
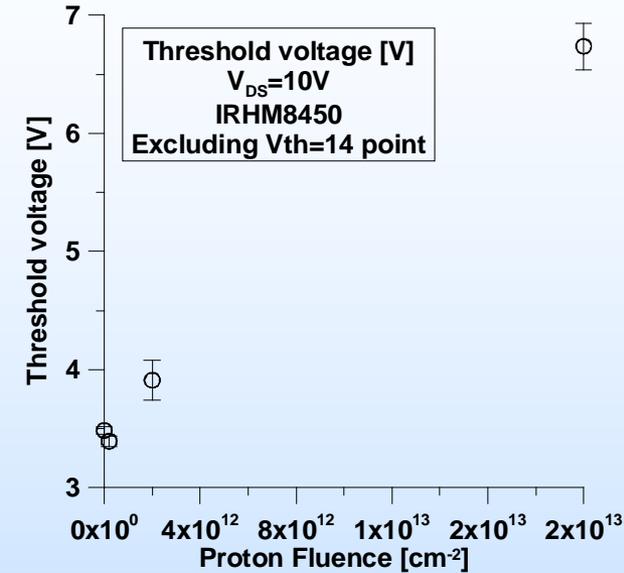
The combination of bias, current, and thermal stress induce failure. Applications are advised to avoid even small order events.

Risk is **manageable**.

Highlight 3 – Environment Stress effect on SEGR



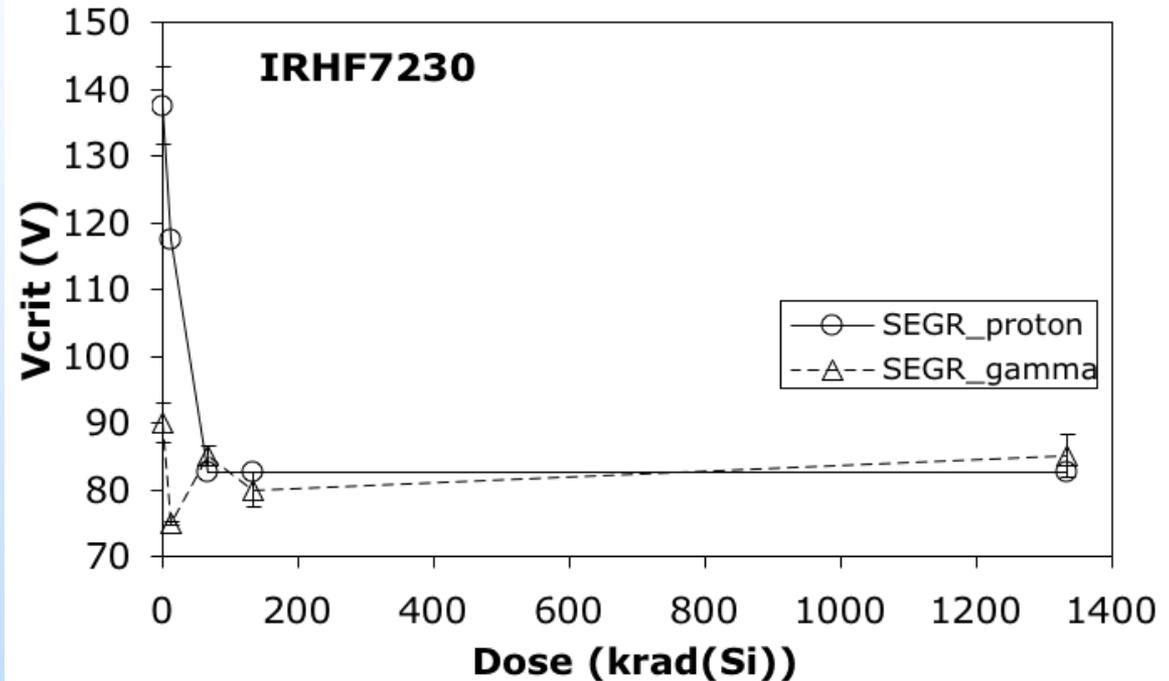
- Missions currently in design
 - Greater than 10 year duration
 - Mission dose over 10 krad(Si)
 - High power and voltage requirements
 - Power devices not used in these instances
- Question has come up (repeatedly) of any synergy from these factors
- Dose and stress change device parameter that affect SEGR



Highlight 3 - Environment Stress effect on SEGR



- The reduction in SOA due to damage from radiation is observable
 - However decrease for rad hard device is contained in normally used derating



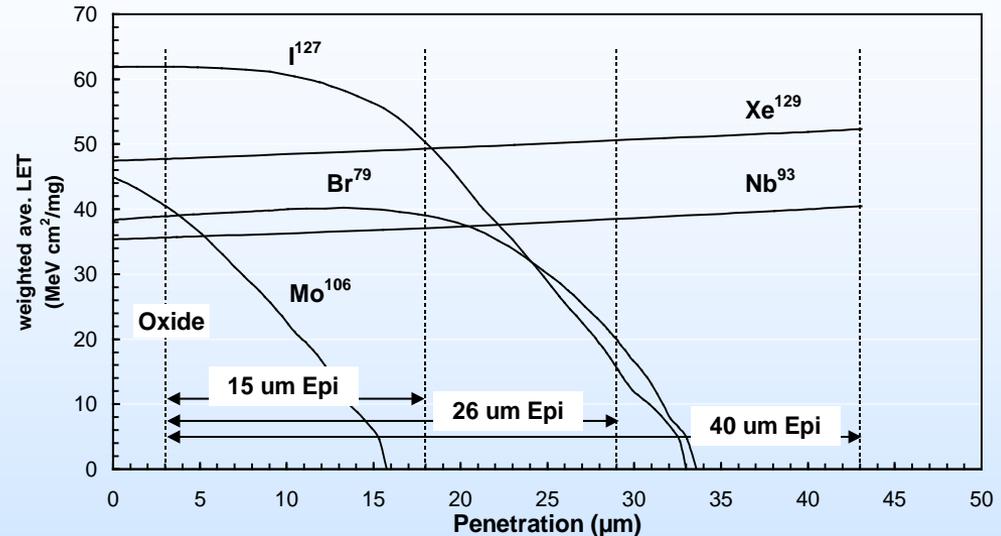
Normally used derating envelops margin from effect.

Risk is minimal.

Highlight 4 – Test conditions effect on failure rate calculations



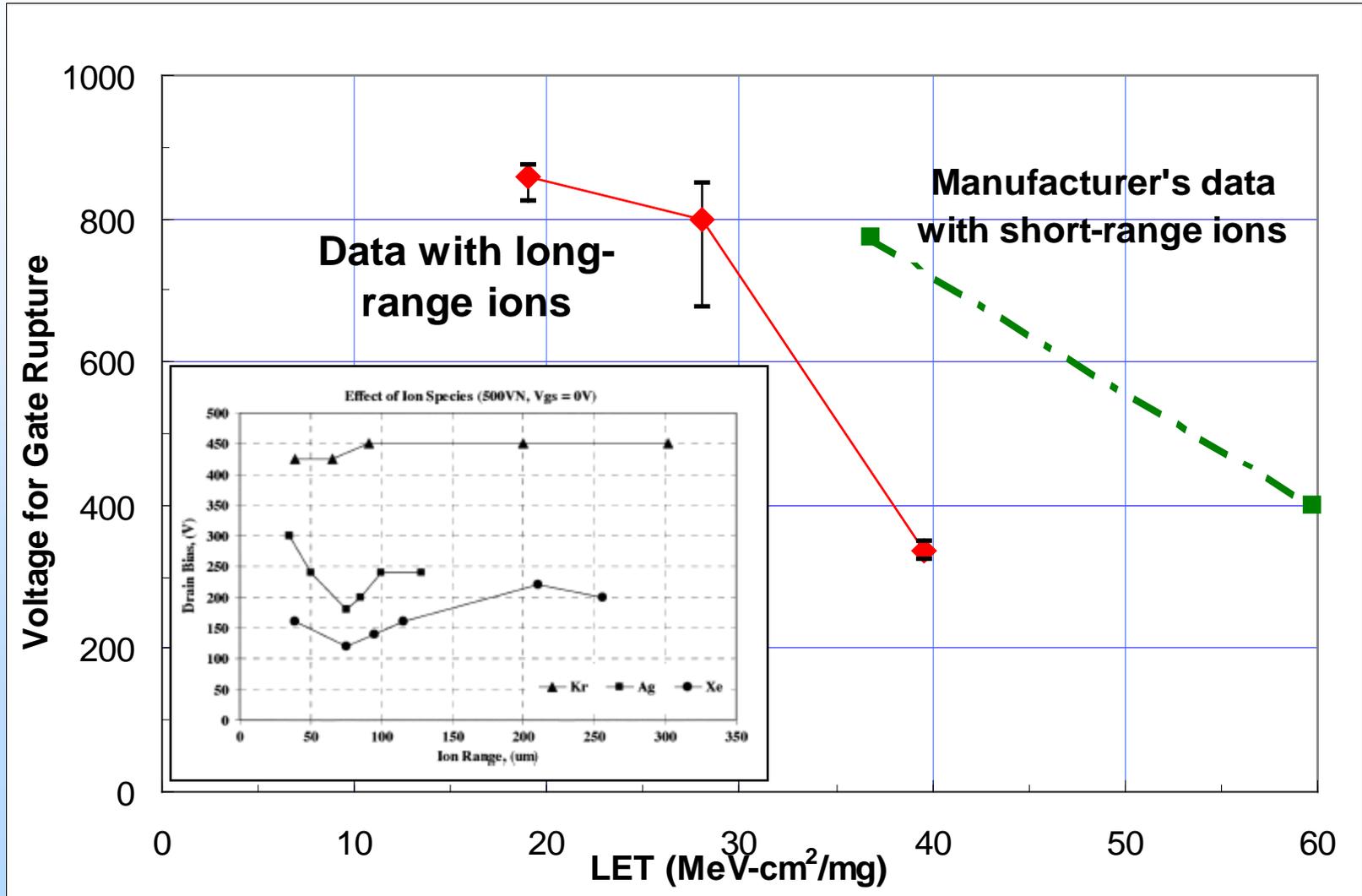
- **Manufacturers data on 1000V MOSFET underestimated SEGR due to lack of ion range in tested devices**
- **Retesting resulted in significantly reduced safe operation area (SOA)**
- **Redesign of application was costly**
- **Ion energy key in testing**
- **Question of what derating or weighting function must be applied to low energy ion to offset energy**



Weighted average LET (MeV cm²/mg) for swift heavy ions traveling through a virtual power MOSFET composed of 3 µm of metallization over 75 Å of SiO₂ and a Si epitaxial layer of various depths, i.e., 15, 26 and 40 µm. The ions used in this study are similar to the short range ions from Brookhaven National Laboratory and the long range ions from Texas A&M.



Highlight 4 – Test conditions effect on failure rate calculations





Highlight 4 – Test conditions effect on failure rate calculations

- The experimental conditions have a considerable effect on the expected failure rate
- Table shows a rate from Xenon failures for 200V part operated at 150V and zero gate bias for four testing conditions
- Data show a minimum in V_{crit} with ion energy

Ion Energy [MeV/amu]	Ion LET [MeV.cm ² /mg]	Ion range in Si [um]	Rate* [per day]
3.64	69	~40	6.5x10 ⁻⁹
10.6	57.5	~100	3x10 ⁻⁷
3.64<E<10.6	57.5<E<69	~40-100	3x10 ⁻⁷
>10.6	<57.5	>100	<10 ⁻⁹

*Rate is per unit cross-section.

Risk in using the wrong test data is significant.



Conclusion

- **Power device technologies still suffer from growing pains in regards to radiation effects**
 - Higher rated parts may be limited by radiation effects
 - Alternates are scarce
 - SiC, IGBTs, SCRs all have liabilities
 - Derating (Design margin) on the SOA is the most used approach
- **Lesson learned**
 - New applications yield uncovered effects
 - All radiation issue should be revisited after new design
 - Or new environment, technology, or mission profile