GaN HEMT Power Applications: The road to space qualification

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.

Program scope

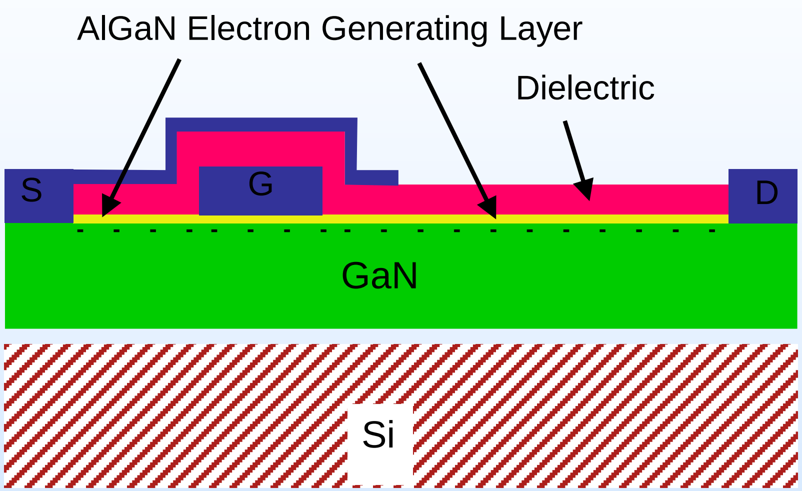
- Working group discusses best methods for evaluating new wide band gap technologies for infusion into space
  - GRC, JPL, JSC, GSFC, AFRL
  - Monthly meeting to share data and resources for radiation effects testing and reliability analyses
  - Analysis of current commercial efforts
- Previous efforts have been broad stroke testing
  - Mostly heavy ion testing
  - Dose effects secondary since GaN HEMT has no oxide
  - Survey of purchasable devices
- On going and future efforts
  - Continues radiation testing and analysis
  - Reliability test screens for new devices
  - Guidelines for implementation and testing
- All major providers have been tested so…
  - Deep dive on GaN Systems (E2V), Panasonic (Infineon), EPC (Freebird Semi)
  - Pivot to drill down on assurance approaches of “Big Three”
  - “Keep them honest” testing

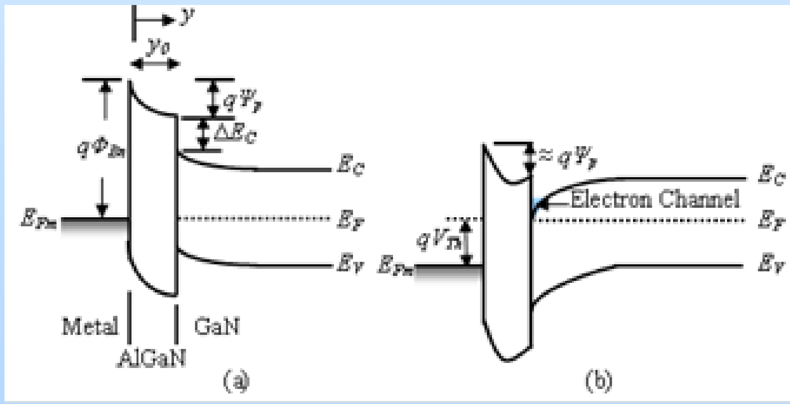
Accomplishments to date

- Have tested four different manufactures
- EPC (Gen 1 and 2), GaN Systems, Panasonic and Transphorm
- All have similar failure modes but with many small differences
  - Catastrophic SEE associate with drain edge of gate
- Dose effects are secondary since the device has not gate oxide
  - There are isolation oxides that may contribute
  - Hydrogen poisoning has been postulated to be a possible failure mode
- Book of knowledge draft is in review and should be released
- EPC Gen 5 devices are in testing this year

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**
  - **Thermal effects and aging are under study at GRC**



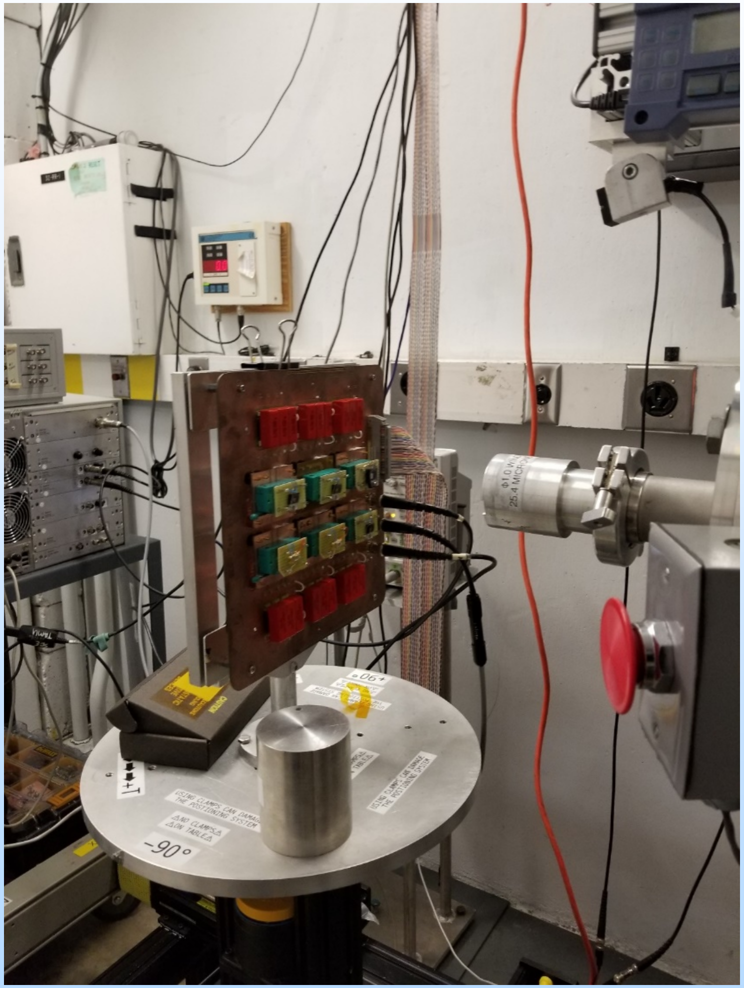


Panasonic PGA26E19BA, Transporm THX320X, and EPC EPC2046 and EPC2045

RECENT TESTING ACTIVITIES

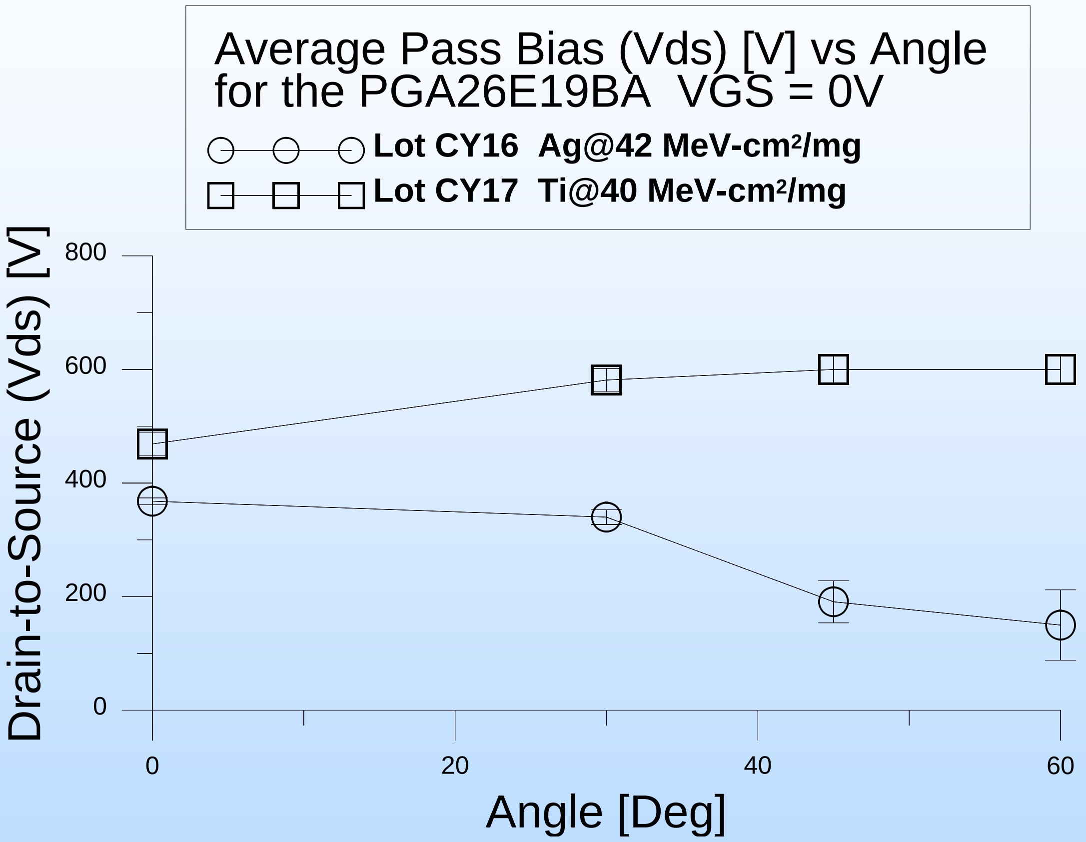
SEE testing with GaN

- **GaN devices are very thin (~10 nm) so TAM beamline at 15 MeV/u is fine**
- **Devices are lateral so angle is an issue**
- **Most devices have a dead layer of some soft**
- **Device are tested in static mode so far**



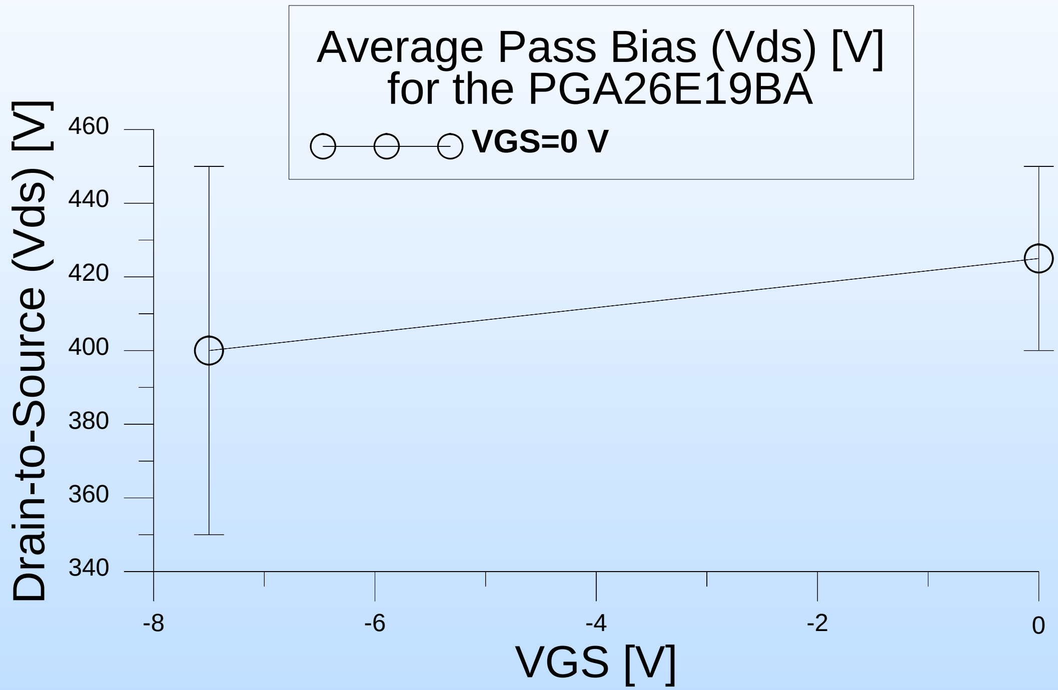
Panasonic angle SEE dependence

- **Angular response for SEE shows lot-to-lot variance**
- **All other variables the same**
- **No change in foundry**



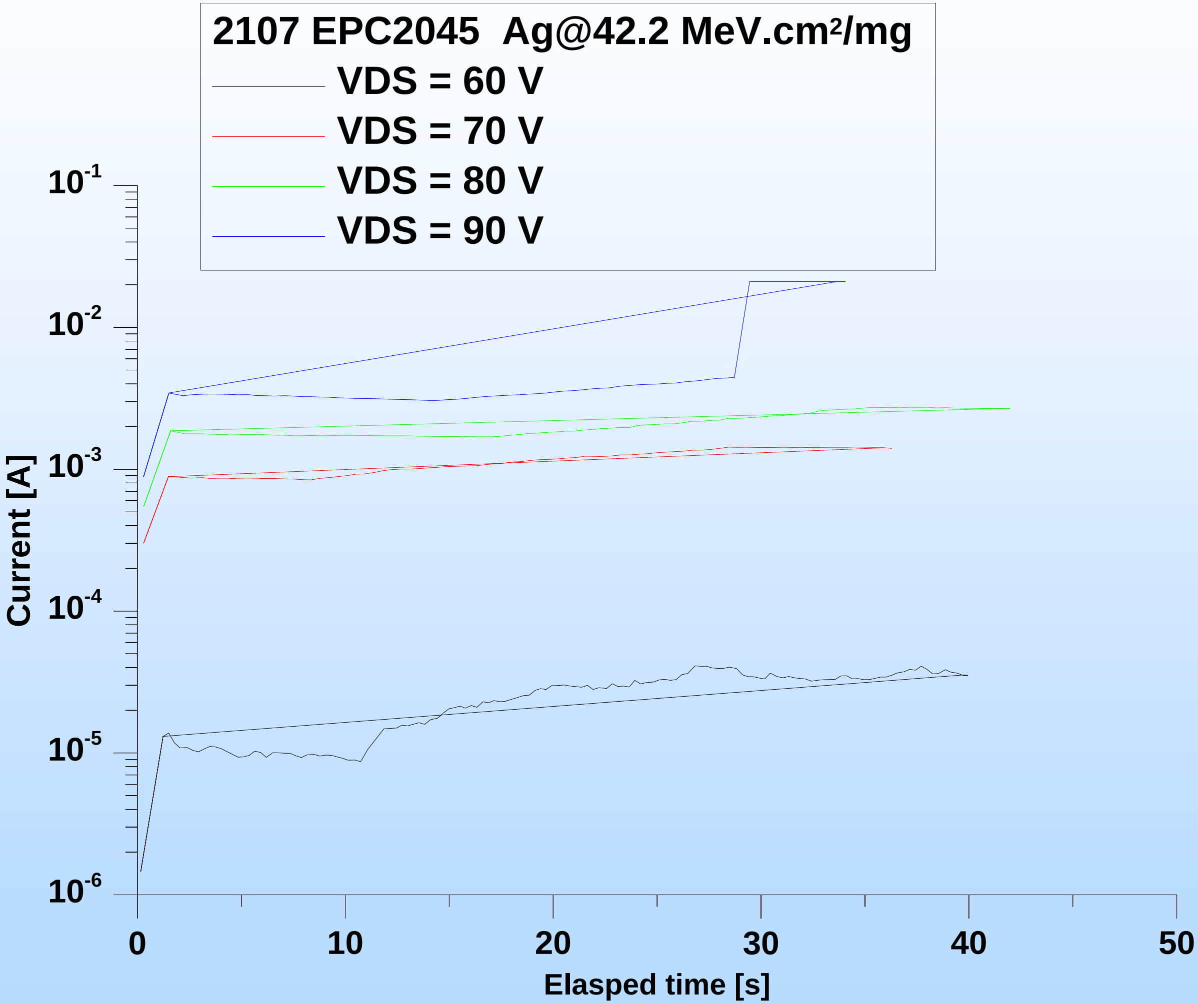
Effect of gate bias on SEE

- Previous testing show little effect of gate-to-source voltage on Vsee
- Later lots showed similar effect
- This is critical to power applications since negative VGS is used to turn devices off “hard” to meet lower leakages



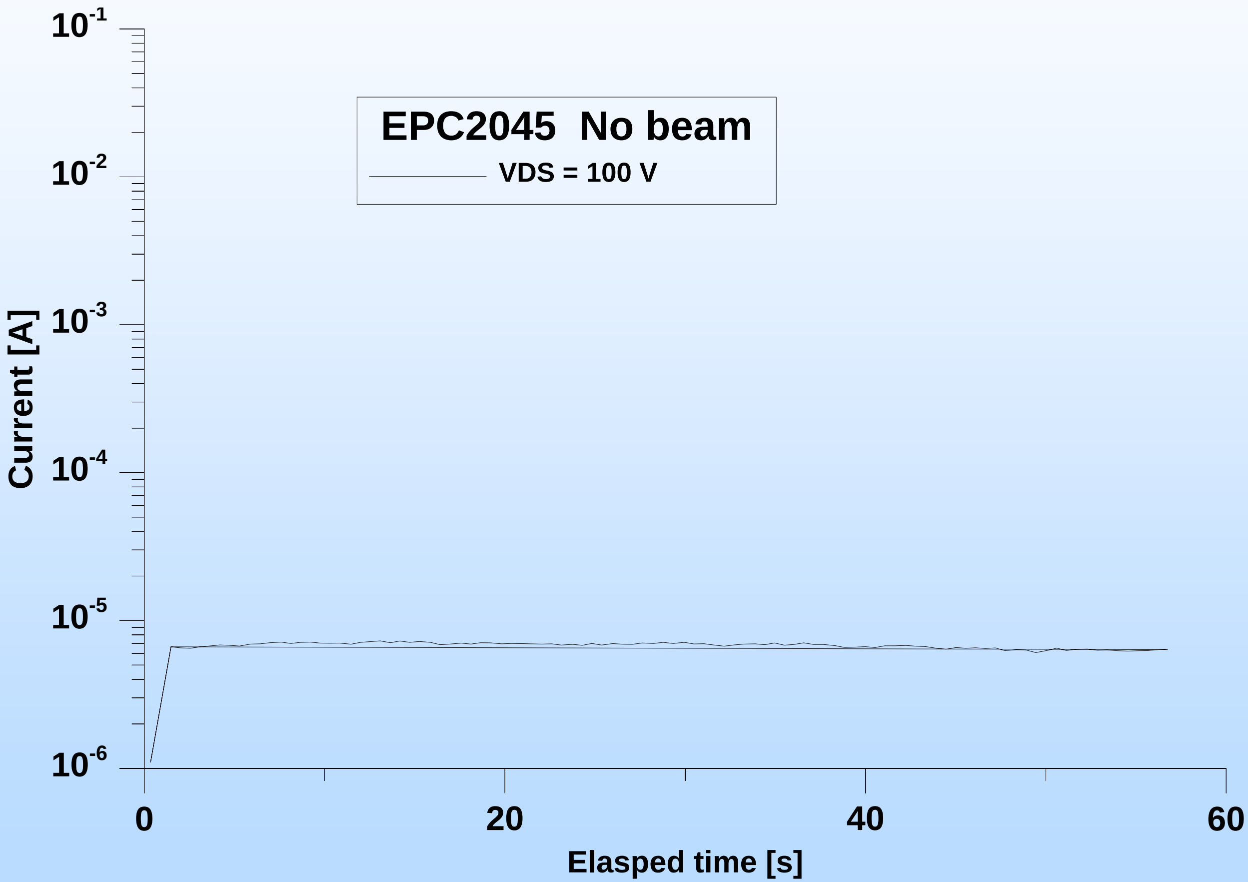
EPC Gen 5 100 V test results

- EPC Gen 5 devices get leak and accrue damage well below Vsee
- Maye damage to piezo-electric fields
- Fluence is always 10^7 cm^{-2}



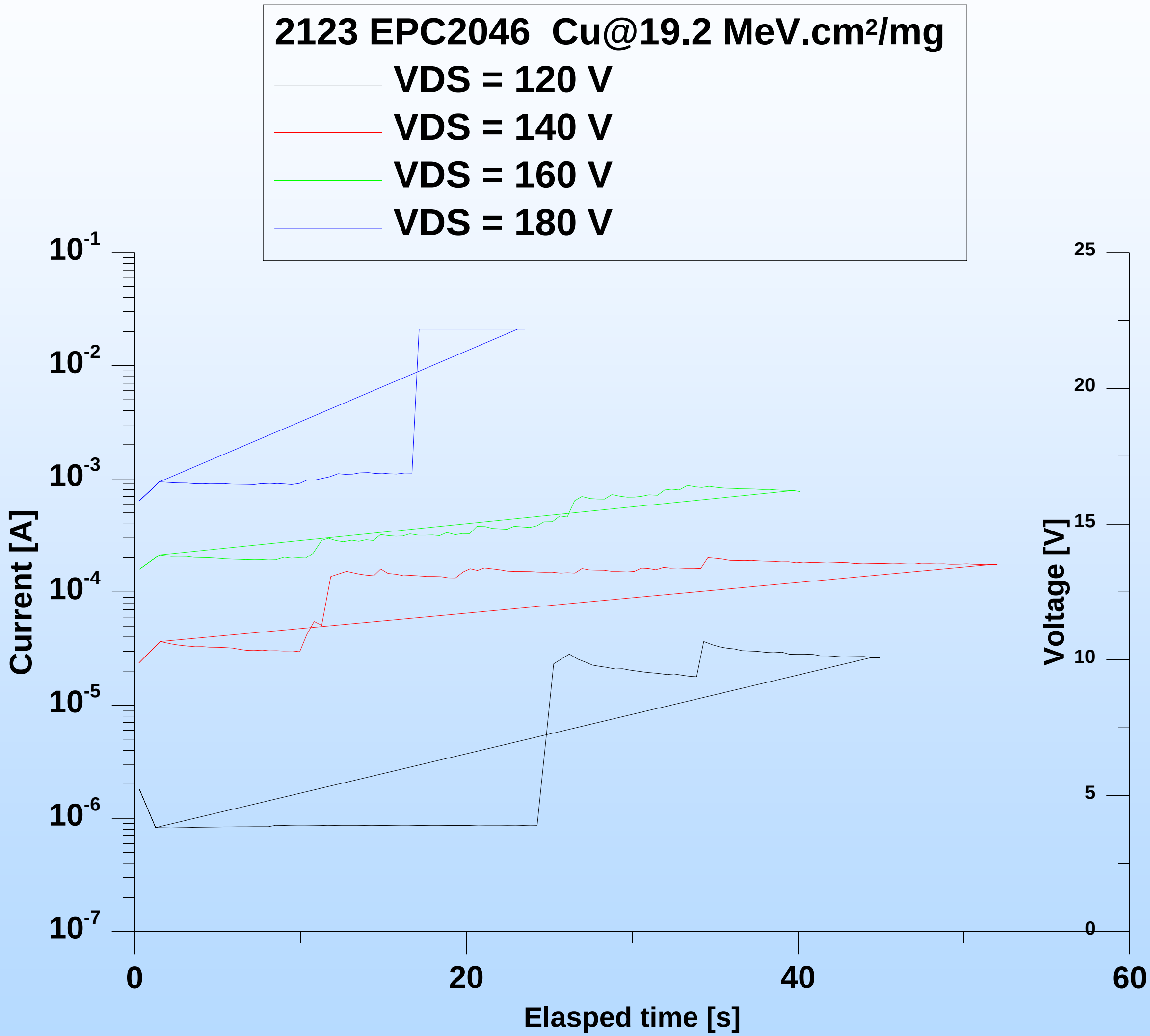
EPC Gen 5 100 V No beam

- **Dry run data with no beam shows no increased leakage**



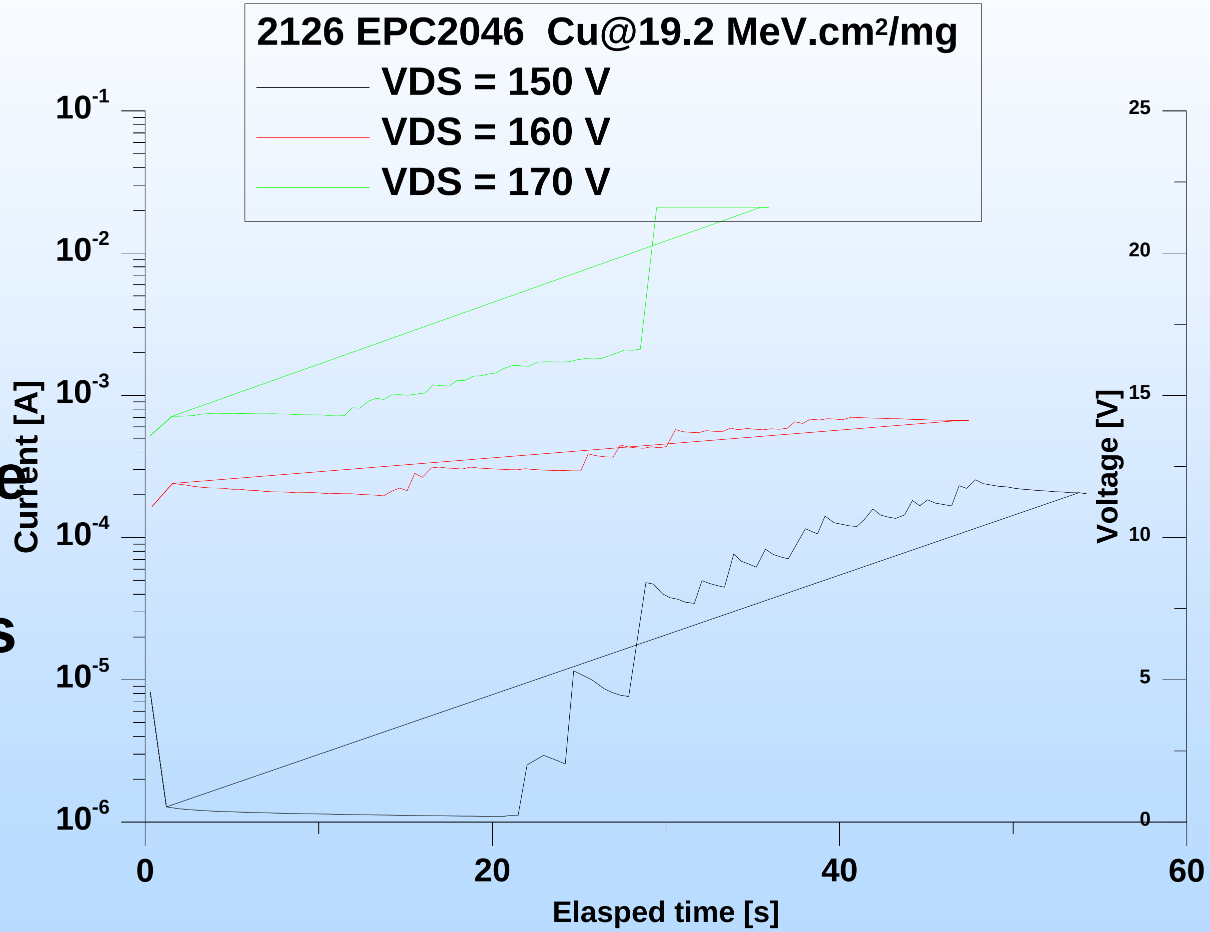
EPC Gen 5 200 V test results

- **EPC Gen 5 devices get leak and accrue damage well below Vsee**
- **Maybe damage to piezo-electric fields**
- **Fluence is always 10^7 cm^{-2}**



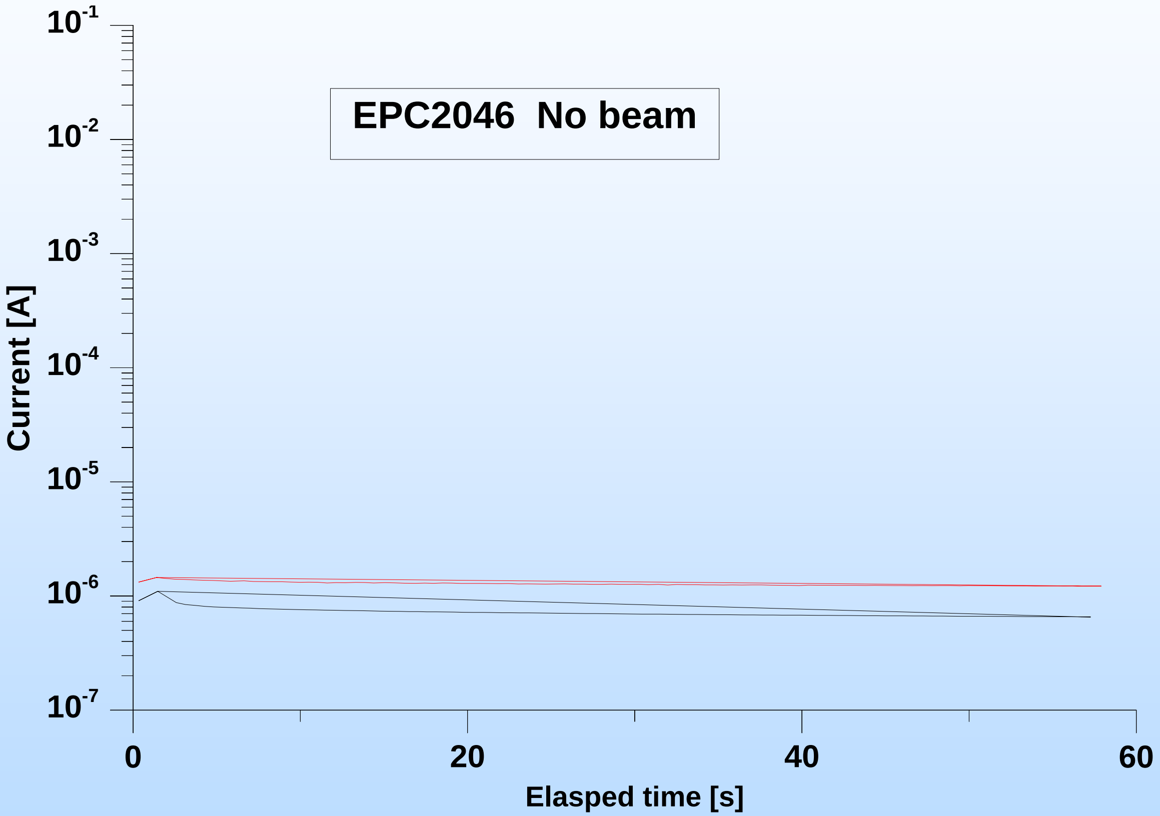
EPC Gen 5 200 V test results

- EPC Gen 5 devices get leak and accrue damage well below Vsee
- Maye damage to piezo-electric fields
- Fluence is always 107 cm^{-2}



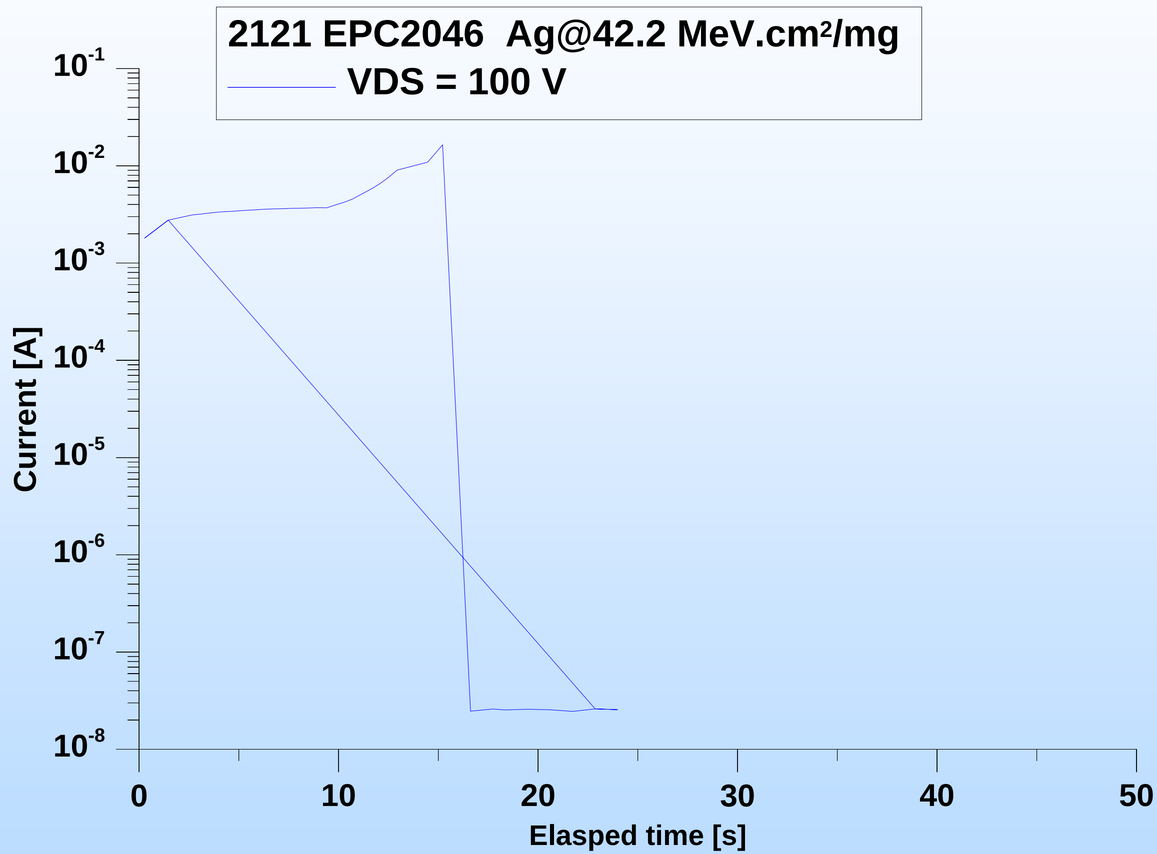
EPC Gen 5 200 V No beam

- Dry run data with no beam shows no increased leakage



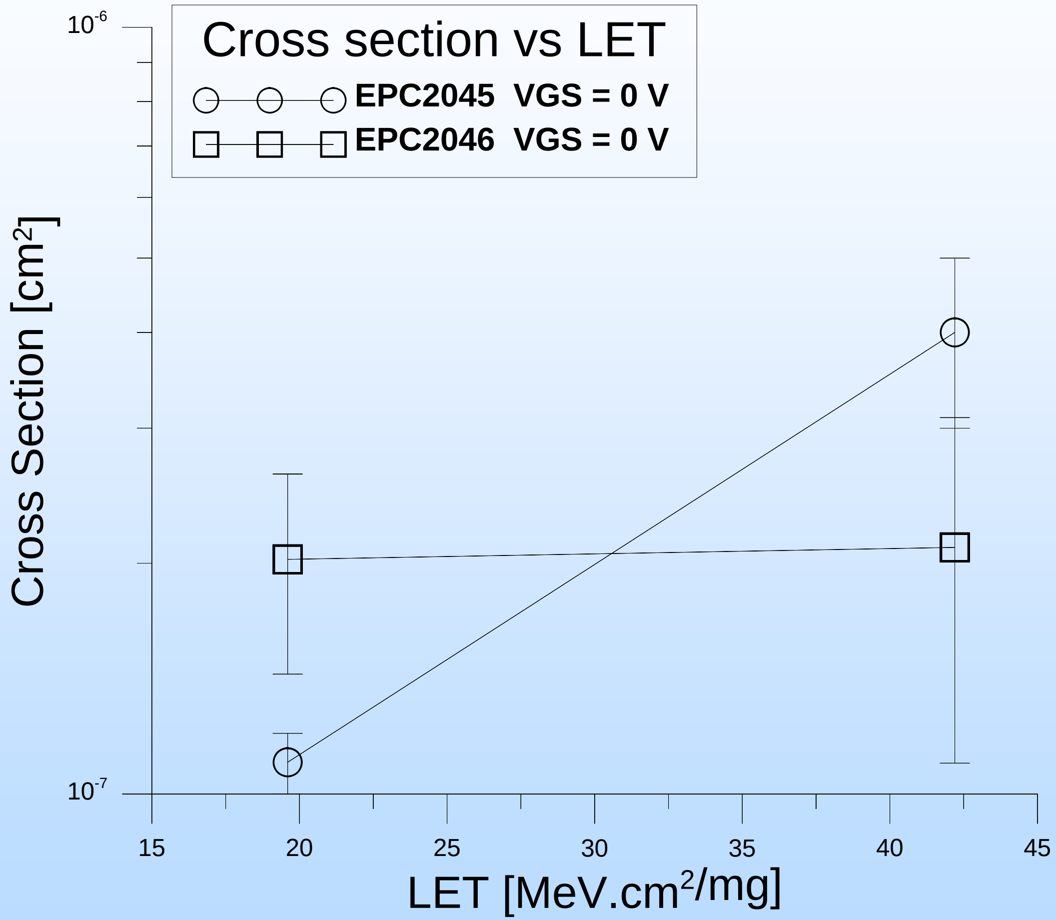
EPC Ge5 200 V parts blown open

- Usual failure mode is highcurrent failure
- This device blew open
- Under FA analysis currently



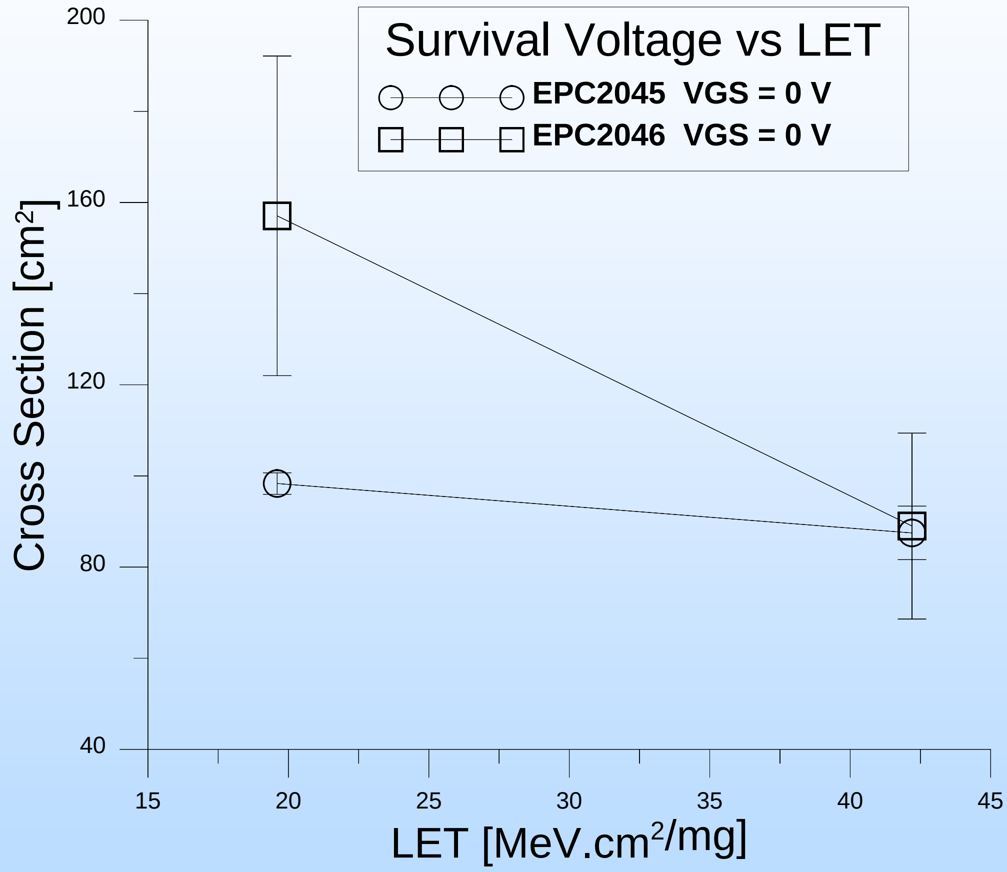
Cross section of Vsee

- **Cross section is routinely ~2x10^{-6} cm^2**
- **This is approximately the area of the drain edge of the gate**



Vsee dependence on LET

- **Two hundred volt rated parts are more sensitive to SEE**
- **Similar behavior to Gen 1 and Gen 2**



COMMERCIAL QUALIFICATION EFFORTS

Reviewing the “Big Three”

- Three entities have emerged to sate the appetite for GaN power system applications
- GaN Systems with E2V, Panasonic with Infineon, EPC with Freebird Semiconductor
- All three rushing to “fill the gaps” on qualification – radiation, reliability and packaging
- EEE part qualification is almost exclusively based on silicon “lessons learned”
  - MIL-PRF-19500, MIL-PRF-38584, MIL-PRF-38535
- Using these as a basis of GaN qualification overlooks possible escapes
  - E.g.: Current collapse, dynamic RDSon, channel hot carrier stress, inverse piezoelectric effect, electromigration

GaN devices are still widely varied

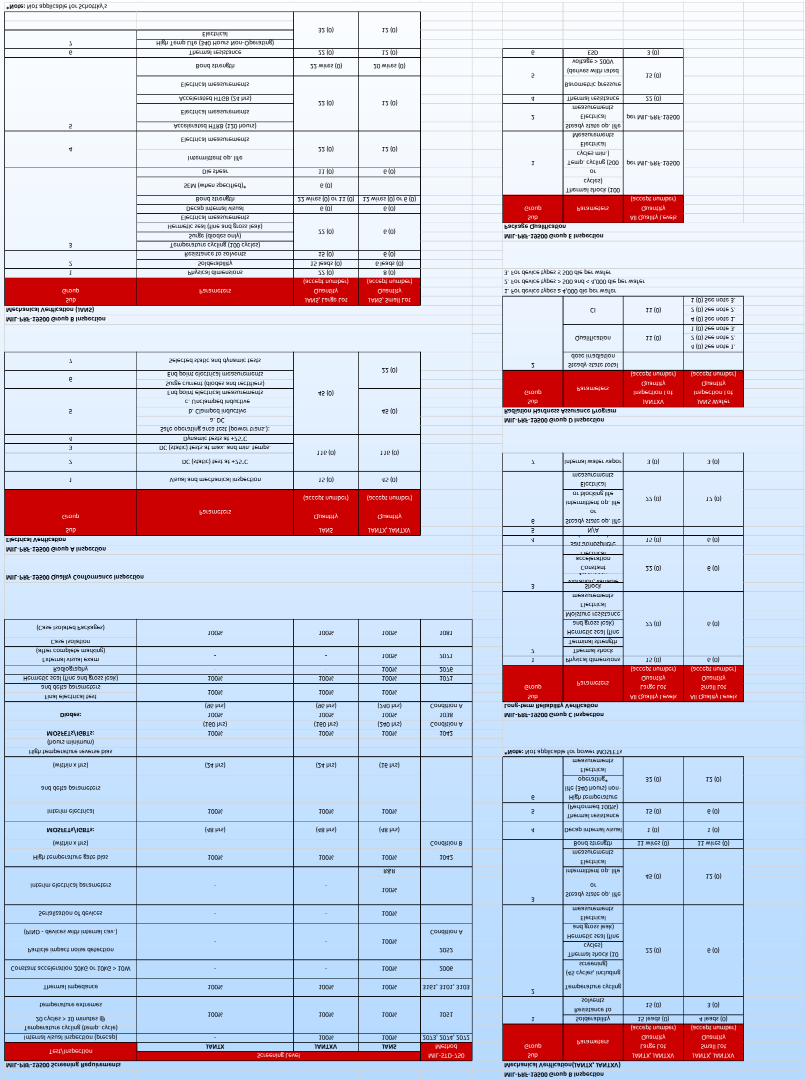
Aspect*	Panasonic X-GaN	Infineon SJ-MOS IPL60R065C7	Transphorm TPH3212PS	GaN System GS66508P
Type	Normally Off GIT	MOS	Cascode	Normally Off Insulated Gate
Package	SMD DFN 8x8	SMD DFN 8x8	TO-220	SMD GaNPX 10x8.7
BVDS	600V	650V	650V	650V
IDSS (150°C)	1uA (100uA)	1uA (10uA)	3uA (12uA)	2u (400uA)
Ron (150°C)	56mΩ (110mΩ)	56mΩ (125mΩ)	72mΩ (148mΩ)	50mΩ (129mΩ)
Vth	1.2V	3.5V	2.1V	1.7V
Qg	5nC	68nC	14.6nC	5.8nC
Ciss	405pF	2850pF	1130pF	260pF
Co(er)	87pF	101pF	142pF	88pF
Qrr diode	0C	6uC	90nC	0C
Qoss	45nC	-	-	57nC

Large variation in some parameter mean reliability data will be as varied

*source Panasonic

MIL-STD-19500 is extensive

- The initial urge is to use 19500 as the standard for qualification
  - MIL-STD-883 is also used
- Followed by MIL-STD-750 TM1019 and 1080 for radiation
- Proper qualification needs to identify the gaps



Birds eye view

Manufacturer	Reliability flow	Relibity TM	RHA reference	Gap Analysis
Panasonic	Own	Own	None	Case-by-case
Freebird (EPC)	MIL-PRF-19500	MIL-STD-750	MIL-STD-750	Case-by-case
E2V (GaN Systems)	Own	MIL-STD-883 5011, etc	Own	Case-by-case

Qualification efforts vary widely between vendors
"Secret sauce" requires NDAs to reveal process
Concern is fixing one issue (e.g., current collapse) will result in a new failure mode!

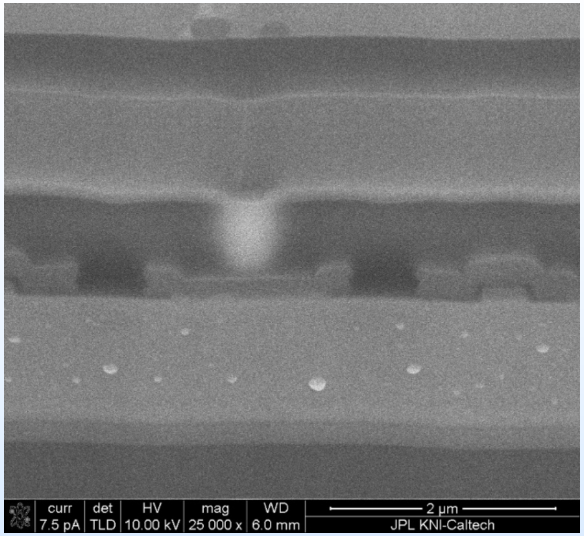
NASA QUALIFICATION GUIDELINE

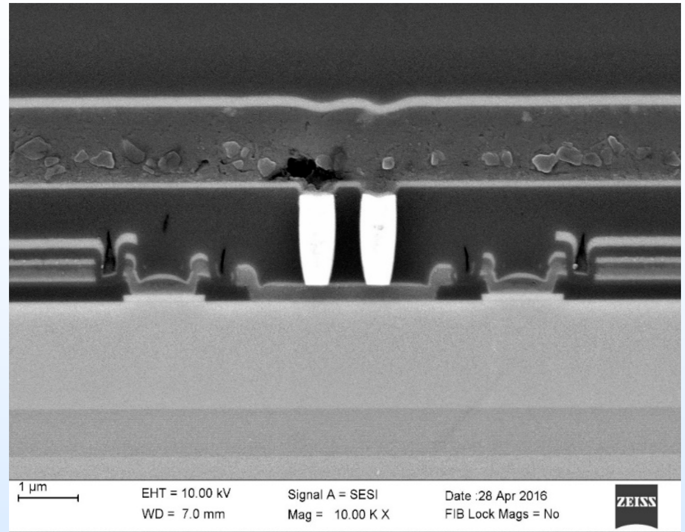
To be presented at the 9[9h] NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 20, 2018, NASA GSFC, Greenbelt, MD.

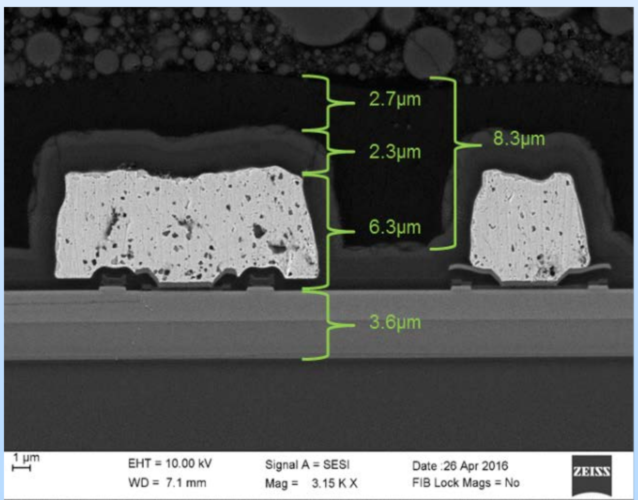
Radiation qualification

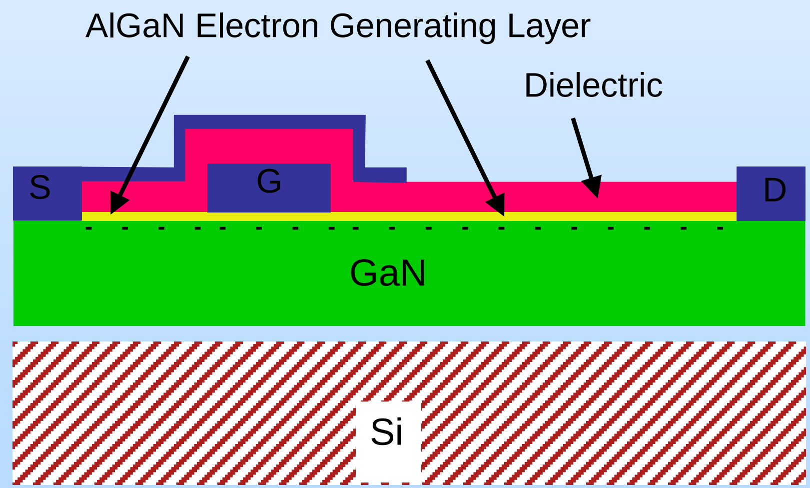
- What we know so far
  - SEE risk associated with the drain edge of the gate in higher bias
  - Total dose risk is minimal
- What we need to know to have an efficient testing campaign
  - What temperature is worst case for SEE testing?
  - What are the latent damage effects of ion testing?
  - What is the best approach for PIGS and PIDS testing?
  - What is the effect of burn-in on the testing?
  - Is there a synergistic effect between dose and SEE?
  - What is the worst case ion condition for SEE testing?
  - Does gate stress exacerbate dose or ion effects?
  - What is worst case – static or dynamic?
  - What is the effect of dynamic RDSon on dose or SEE effects?
  - Are there any device specifications that could indicate radiation effects?
- Until these trends are analytically known
  - Test early and test often

Case in point – three difference manufactures









In contrast, silicon power MOSFETs almost all look the same

Future work

- **More testing**
  - **Panasonic parts**
  - **Transphorm**
  - **EPC Gen 5**
- **Testing guideline**
  - **Modeling data is the best bet**
- **Leverage off flight projects**
  - **Power design engineers can’t take there eyes off of the efficiency number**