Rad Effects in Emerging GaN FETs

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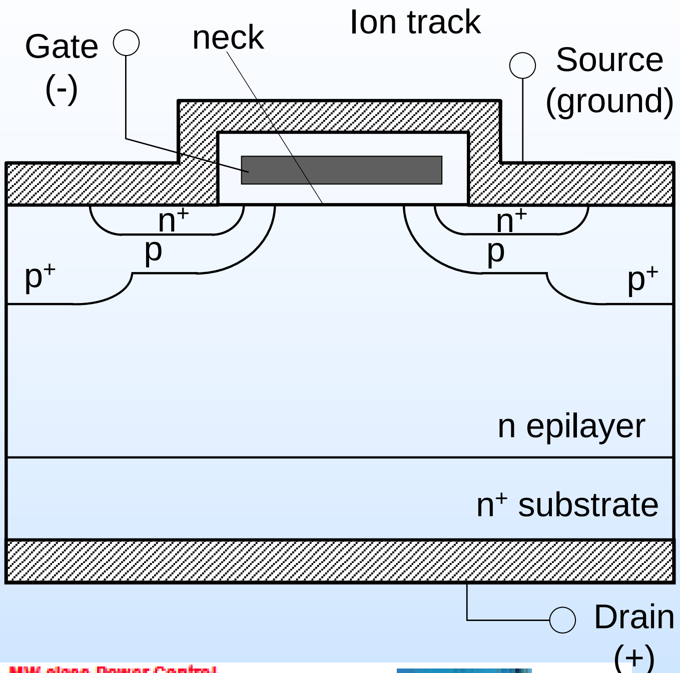
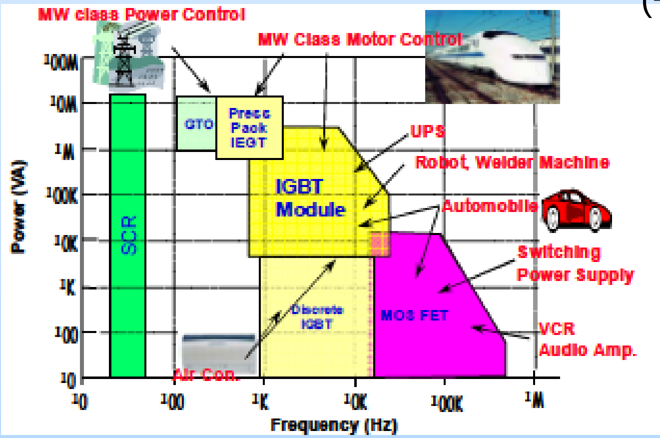
Motivation for alternative to silicon based power

- **Current silicon power solutions are at their innate limits for space applications**
- **Silicon devices are at efficiency limit**
  - **Thermal management is an issue**
  - **Low voltage – high power applications (POL converters for processors) are also limited**
- **Best hi-rel devices are less then ~400 V drain-to-source**
  - **Stacking devices have risks**
  - **High voltage applications (JIMO, Ion engines) are therefore limited**
  - **Poor efficiency also limits applicability**



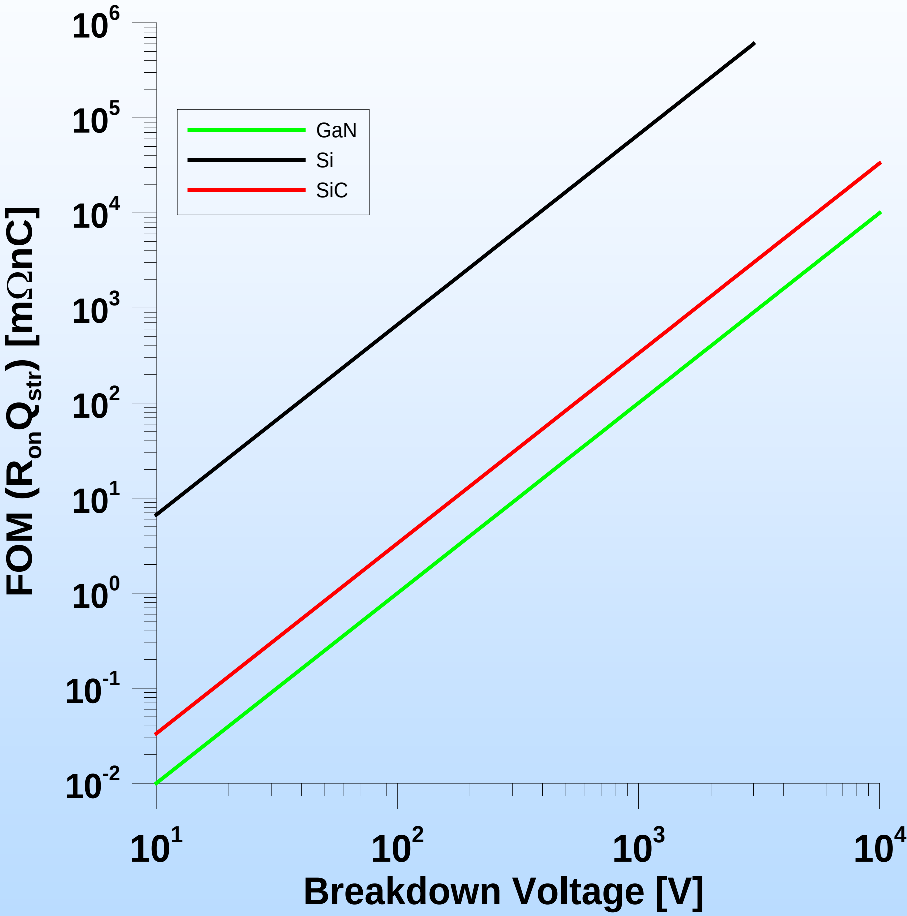


Comparing power switching materials

Property	Si	GaN	3C-SiC	6H-SiC	4H-SiC
Bandgap, Eg (eV at 300K)	1.12	3.4	2.4	3	3.2
Critical electric field, Ec (V/cm)	2.5 10^5	3 10^6	2 10^6	2.5 10^6	2.2 10^6
Thermal conductivity, (W/cmK at 300K)	1.5	1.3	3-4	3-4	3-4
Saturated electron drift velocity, vsat (cm/s)	1 10^7	2.5 10^7	2.5 10^7	2 10^7	2 10^7
Electron Mobility, ìn (cm2/Vs)	1350	1000-2000	1000	500	950
Hole Mobility, ìp (cm2/Vs)	480	30	40	80	120
Dielectric constant	11.9	9.5	9.7	10	10

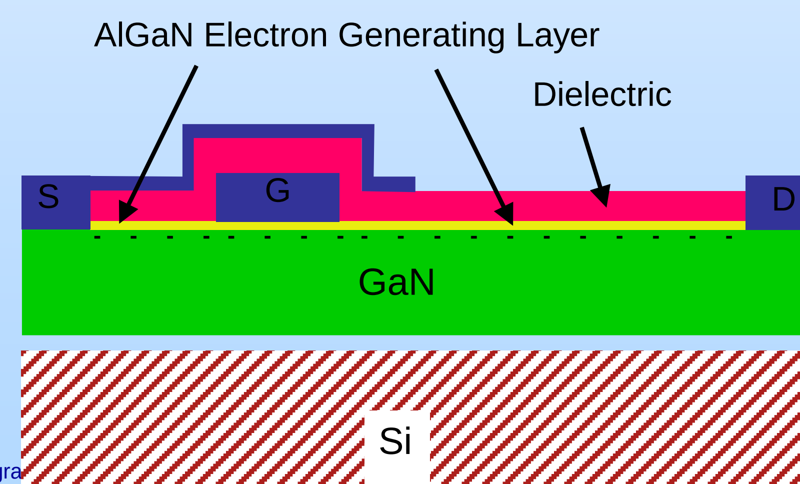
Putting these technologies practice

- Silicon power delivery is a decade below GaN and SiC at material limits
- Processing and manufacture, radiation effects, reliability effects and cost, however, weigh on what device will be used in NASA missions
- Both GaN and SiC have these challenges to meet
- But GaN and SiC players have well traveled path to meet



Gallium Nitride

- **Device are becoming available**
  - **Efficient Power Conversion 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 limited (abs max of Vgs +6, -5 V)**
  - **Thermal effects and aging are under study at GRC**

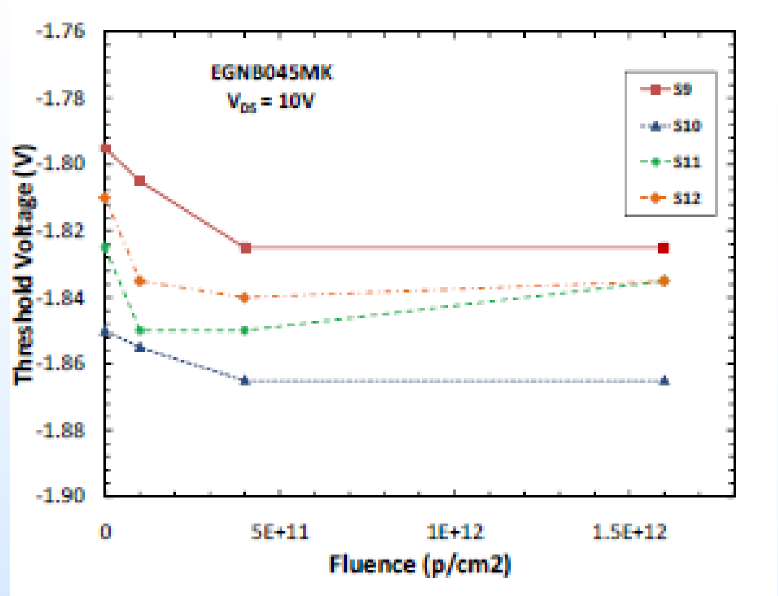


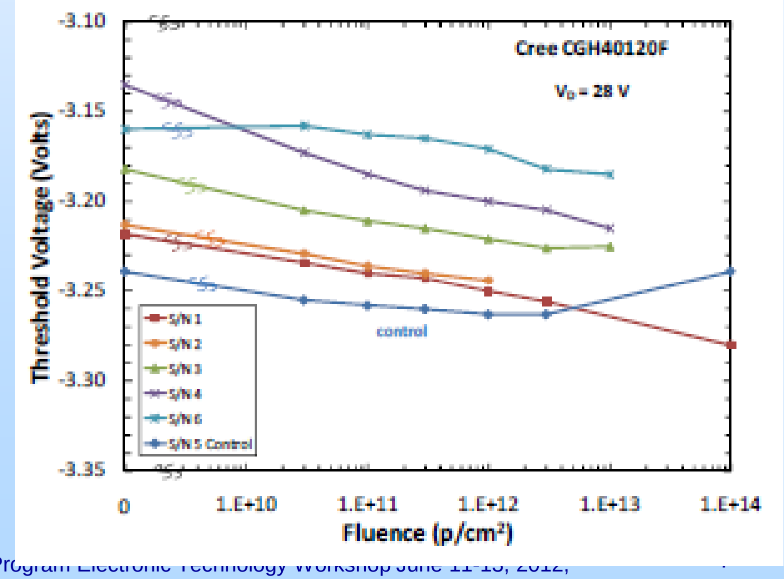
GaN FETs are HEMT only so far

Rating (V)	Device	Man.	Availability
40-200	EPC10XX	EPC	Q1FY09
40-200	EPC20XX	EPC	Q2FY11
40-200	MGN29XX	EPC/Microsemi	Q4FY12
84	CGH40025	Cree	Q1FY10
84	CGH40120F	Cree	Q2FY10
84	CGH40180PP	Cree	Q2FY10
120	EGNB010MK	Sumitomo	Q3FY10
120	EGNB045MK	Sumitomo	Q3FY10
50	RF3934	RFMD	Q3FY10

TID/DDD in RF GaN

- **GaN HEMTs have been shown to be robust to DDD and TID**
- **GaN MOSFETs are not expected to be as hard**
- **SEE tests on GaN HEMTs have shown no SEE**
  - **As expected since HEMTs are similar to JFETs**

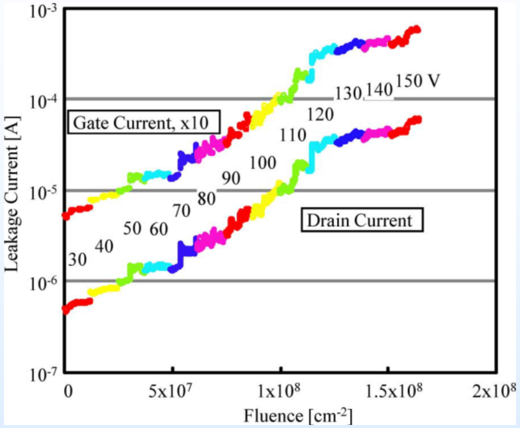


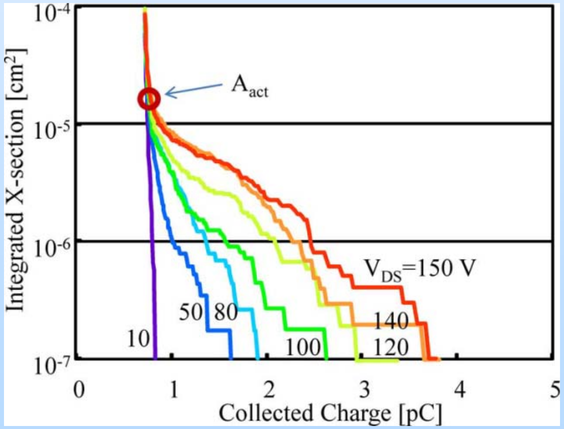


Radiation Characterization of Commercial GaN Devices Richard D. Harris IEEE Radiation DWS, 2011

SEE in RF GaN

- **Kuboyama et al saw HI damage in GaN HEMTs devices, but had parts with much lower leakage than NASA tested. This will have to be revisited.**
  - **Single-Event Damages Caused by Heavy Ions Observed in AlGaN/GaN HEMTs, Satoshi Kuboyama, Akifumi Maru, Hiroyuki Shindou, Naomi Ikeda, Toshio Hirao, Hiroshi Abe, and Takashi Tamura**





eGaN® FET SEE testing

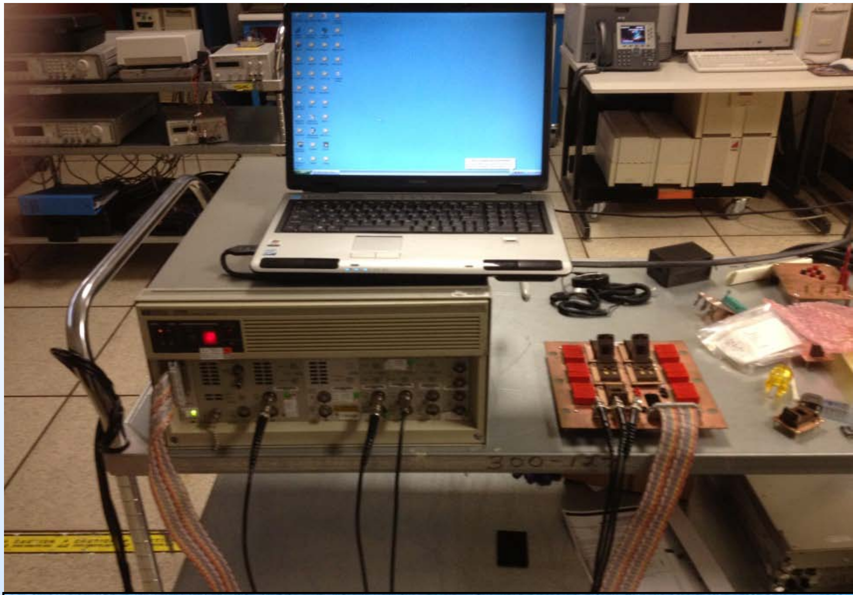
- **EPC/Microsemi has HEMT GaN FET that transists similarly to enhancement mode FET**
  - **Designed for PMAD applications**
  - **Similar specification to silicon power**
  - eGaN ® is a registered trademark of Efficient Power Conversion Corp.
- **SEE testing start with DPA that indicate that dead-bug irradiation through the solder bumps would be adequate for testing**
- **Lateral devices would need angle studies**
- **Initial SEE testing was promising on the first generation (Gen1), so Gen2 was re-spun with a thicker epitaxial and the source and substrate connected to reduce SEE effects**

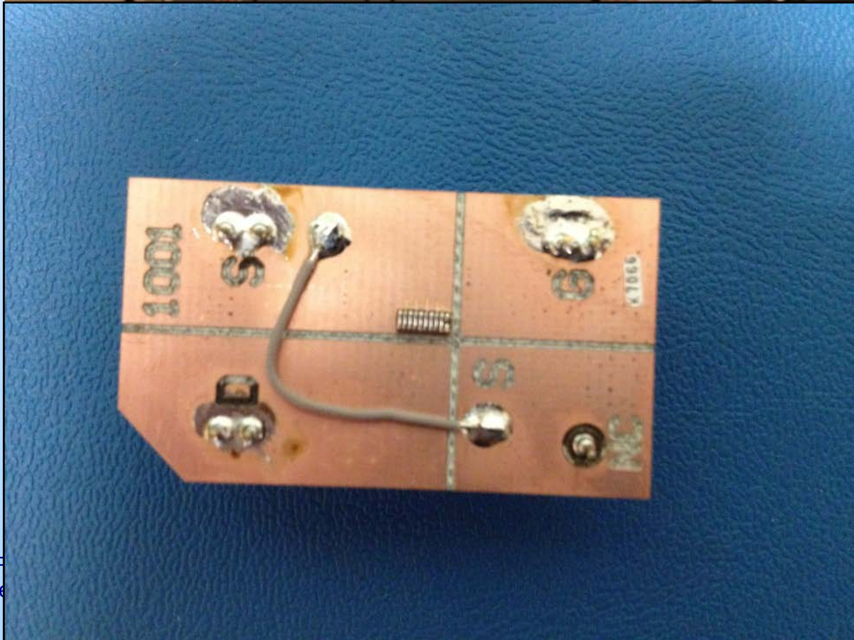
Test Methodology

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

Tilt

Roll

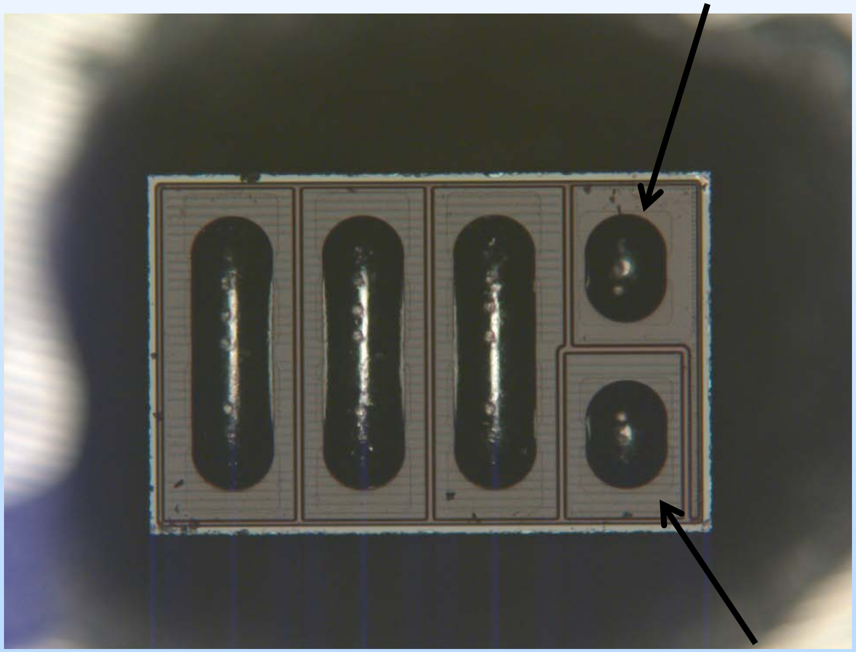




EPC 1014

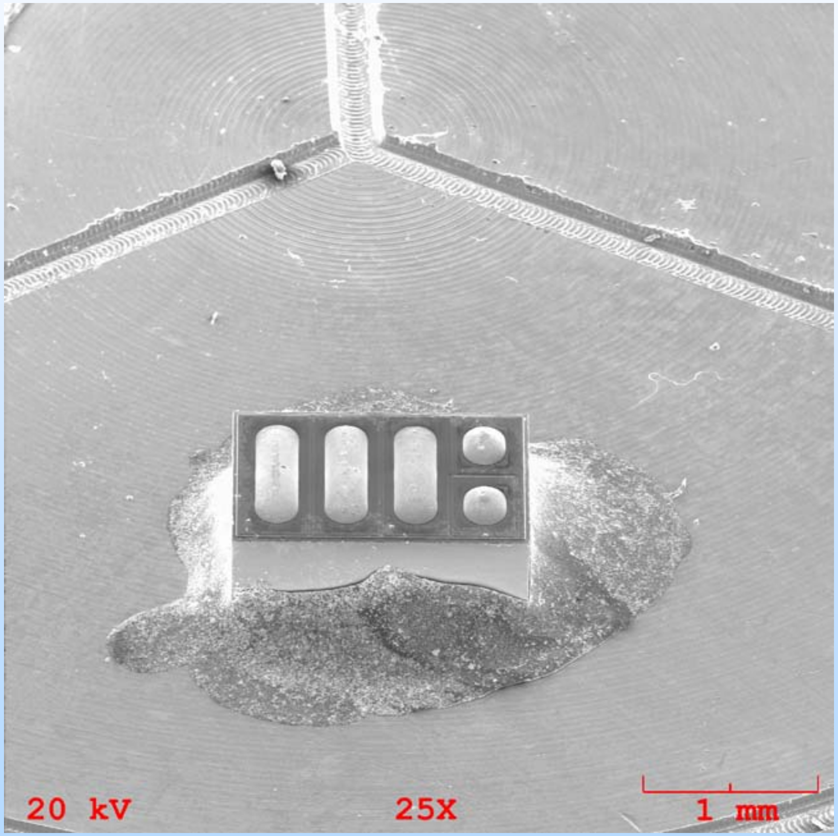
Optical Photo, 50X

Drain Source Drain Gate



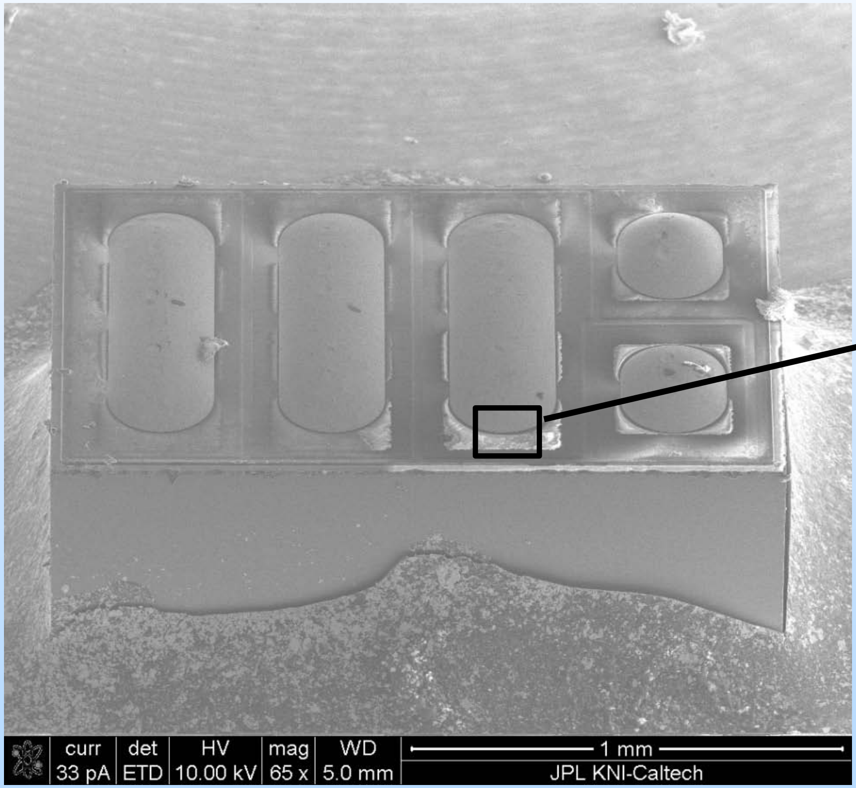
Source

SEM Micrograph, 25X

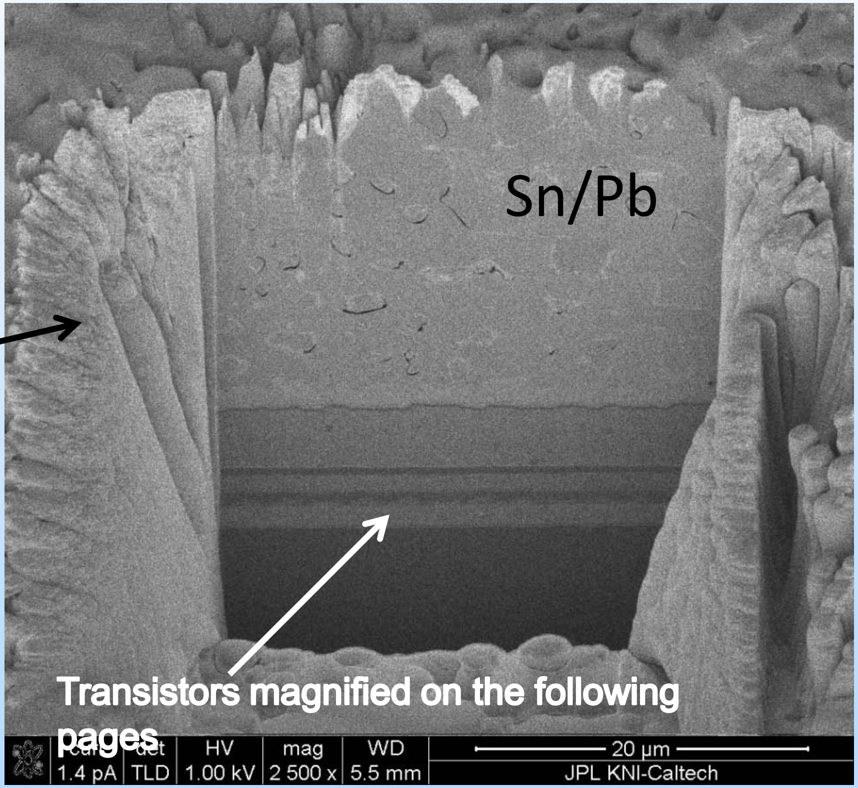


EPC 1014

SEM Micrograph, 65X , 52 deg. Tilt

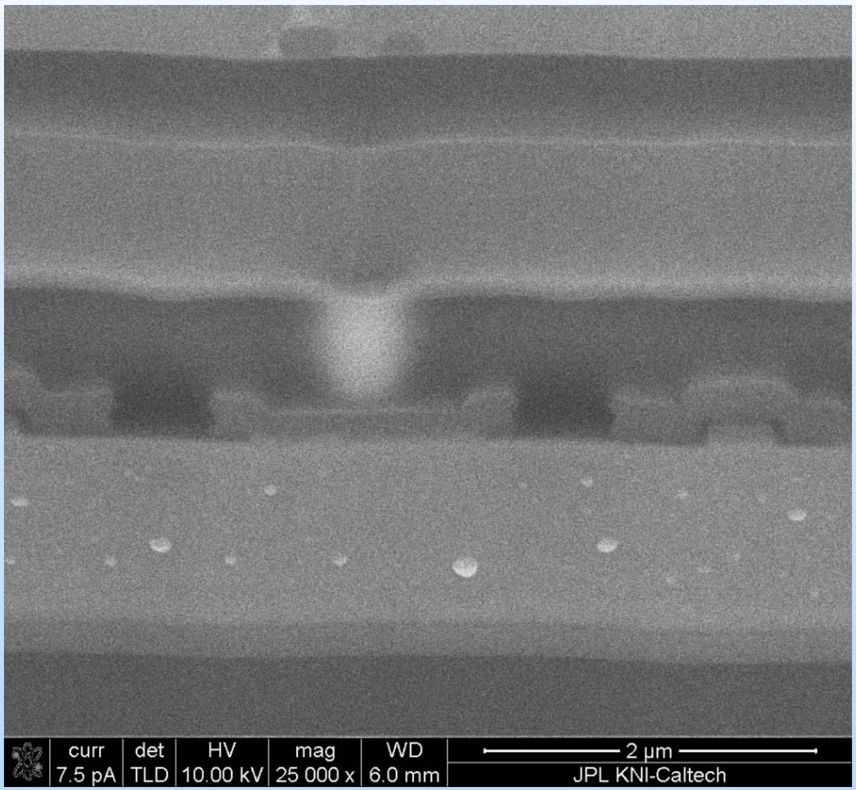


SEM Micrograph after FIB Cut, 2500X, 52 deg. Tilt

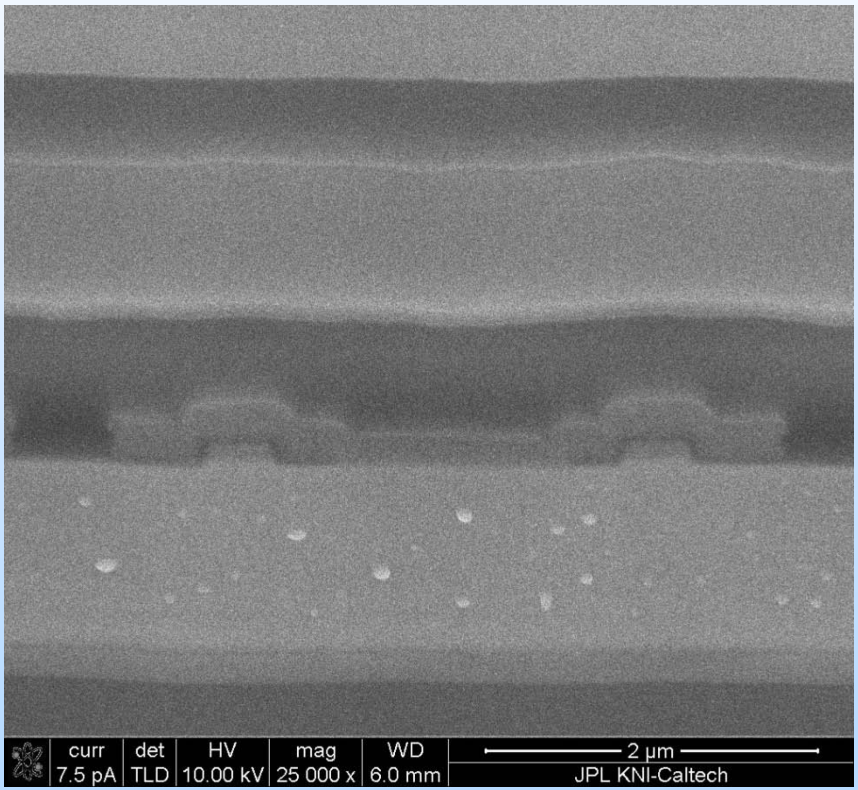


EPC 1014

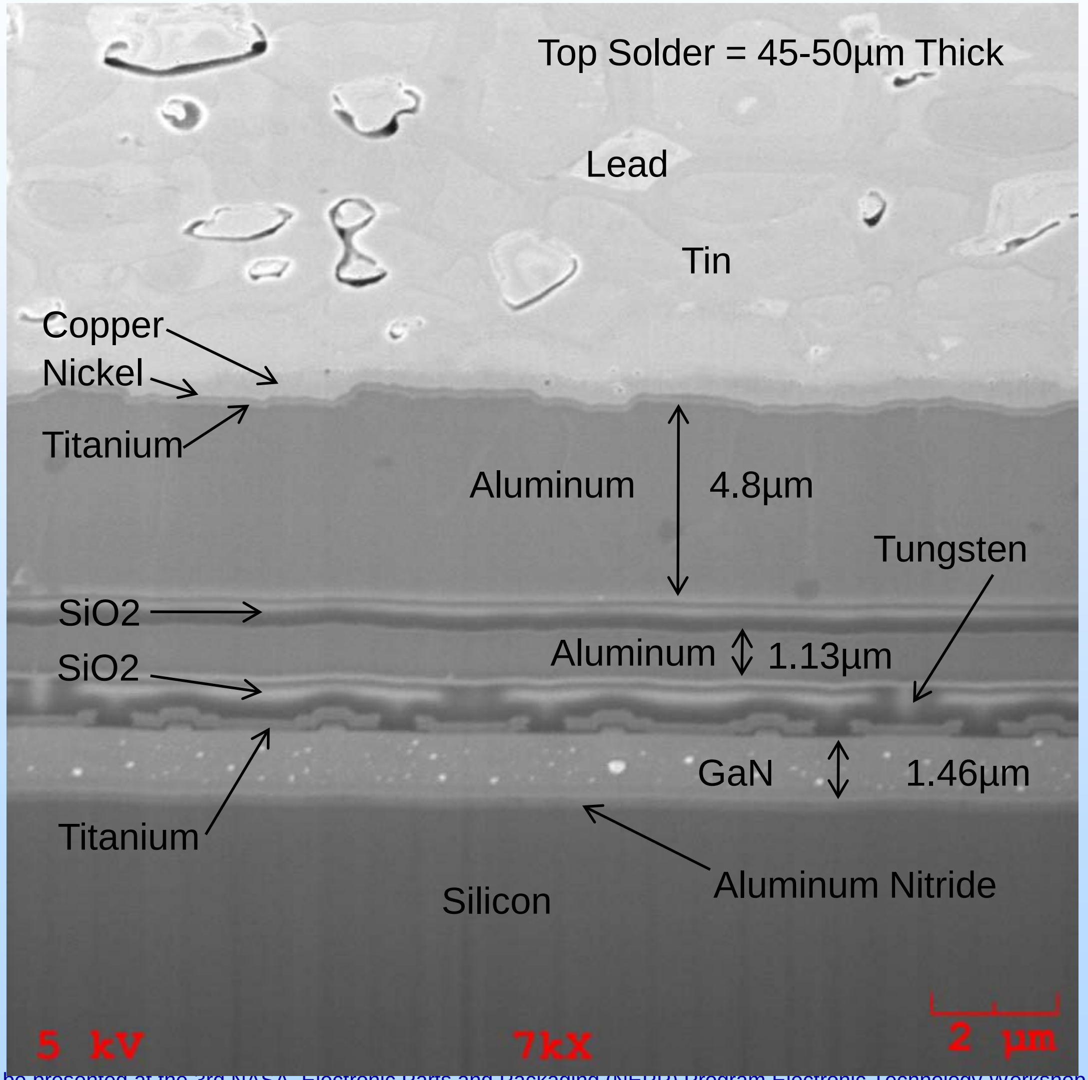
SEM Micrograph after FIB Cut, 25,000X , 52 deg. Tilt



SEM Micrograph after FIB Cut, 25,000X , 52 deg. Tilt

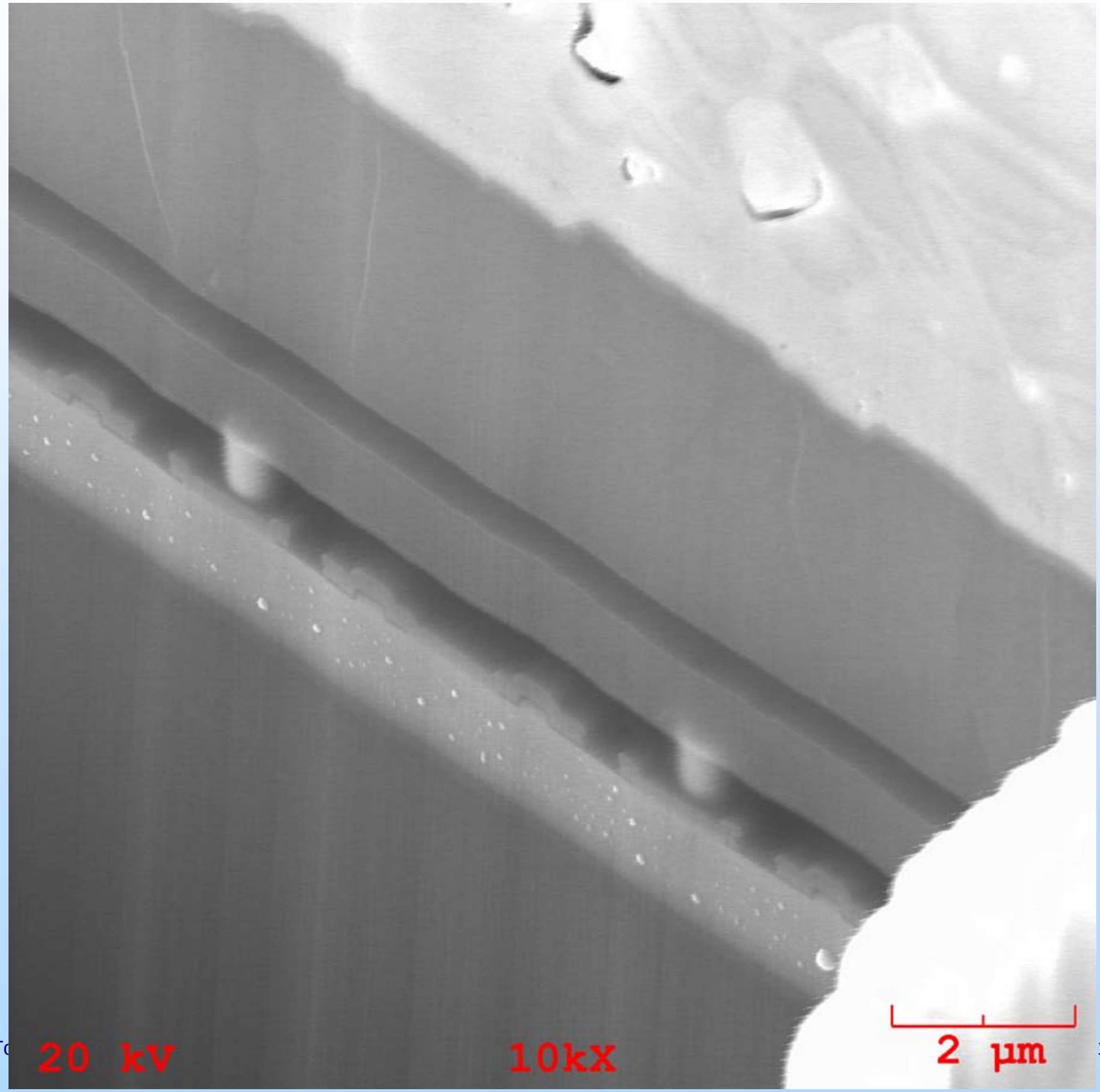


EPC 1014

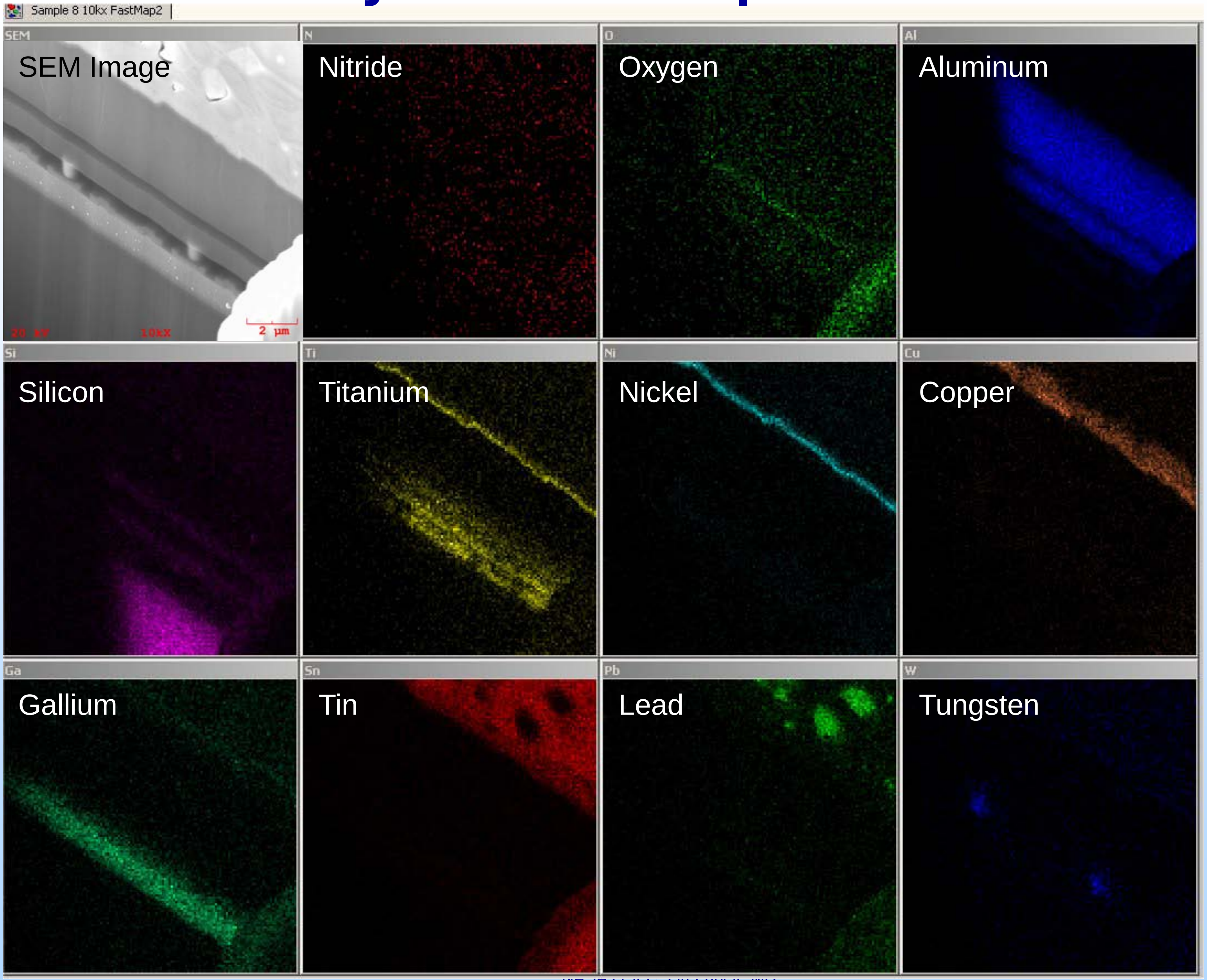


Top Solder = 45-50µm Thick
Lead
Tin
Copper
Nickel
Titanium
Aluminum
4.8µm
Tungsten
SiO2
SiO2
Aluminum
1.13µm
GaN
1.46µm
Titanium
Silicon
Aluminum Nitride
5 kV
7kX
2 µm

EPC 1014

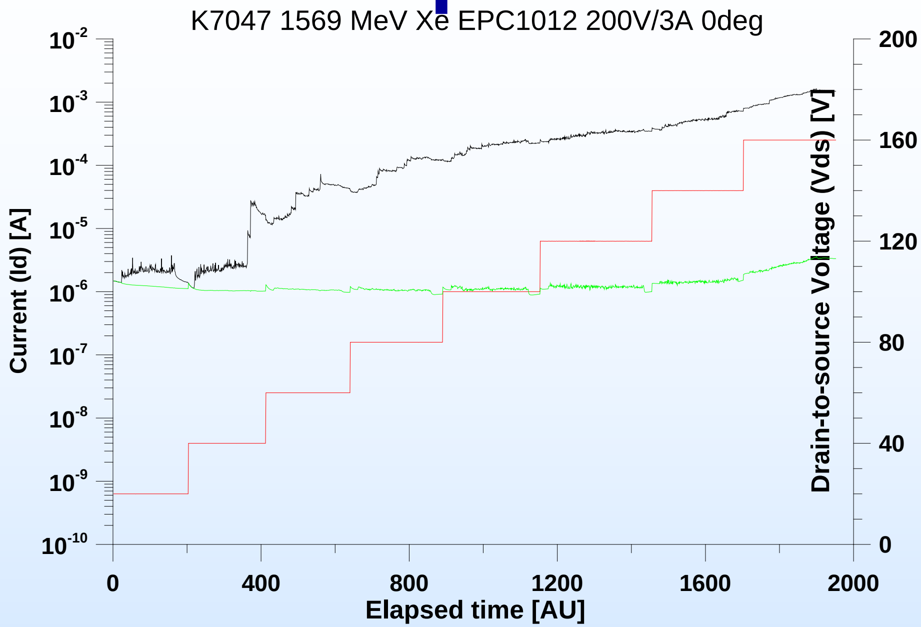


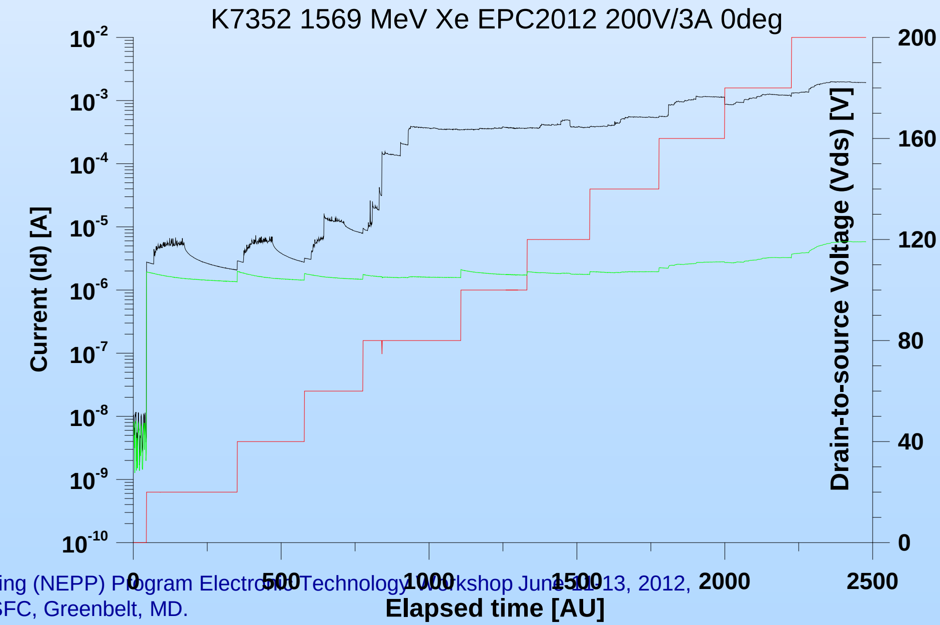
X-Ray Element Map EPC 1014



EPC1012 / EPC 2012 Comp 0º

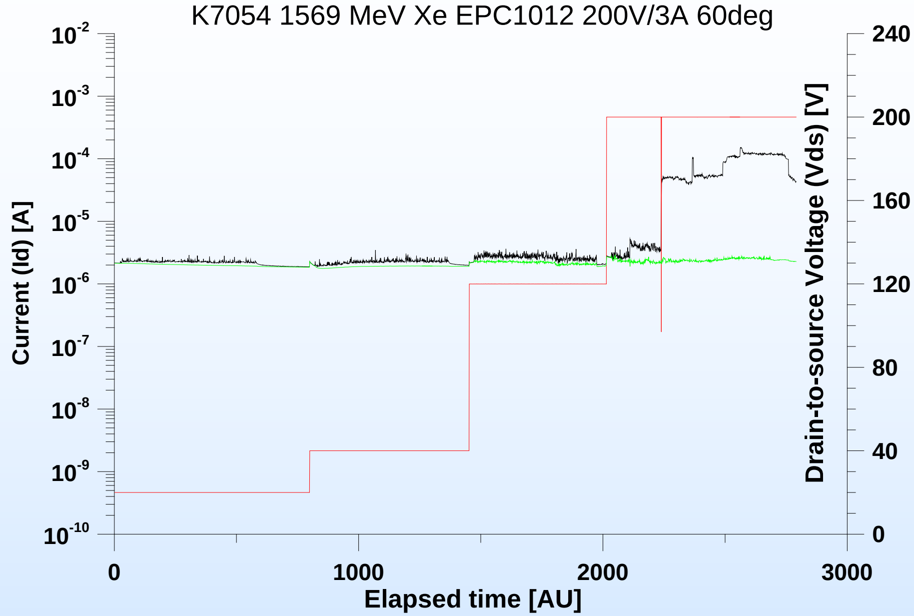
- **In all figures, green is Ig, red is Vds, black is Id**
- **The EPC1012 is a 200 V parts suspected to be worst case**
  - **Gen1 has SEE onset at 40 V (20%)**
  - **Gen 2 has SEE onset at 80 V (40%)**
- **Device rarely fails but drain leakage increases**
- **SEE mechanism is understudy**

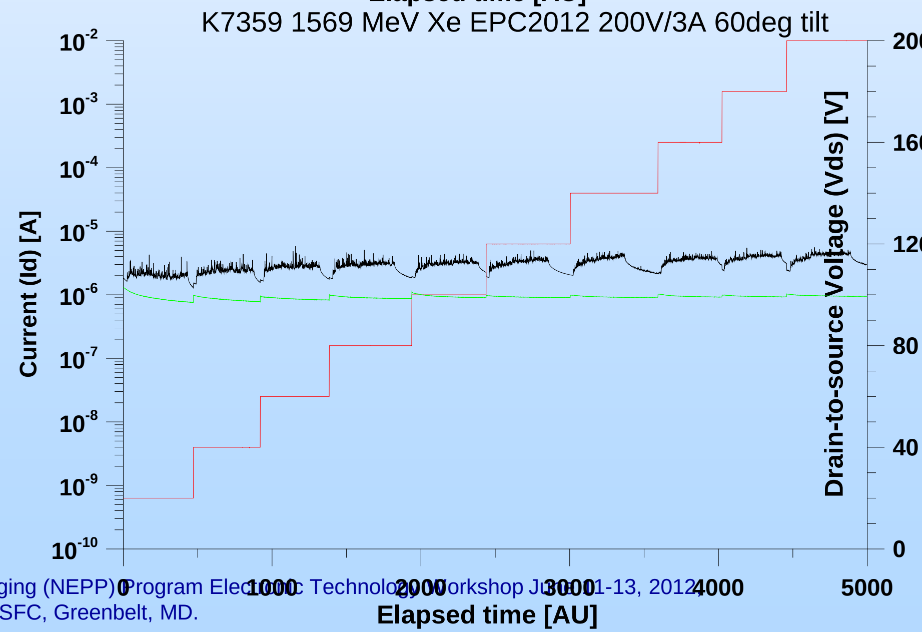




EPC1012 / EPC 2012 Comp 60º Tilt

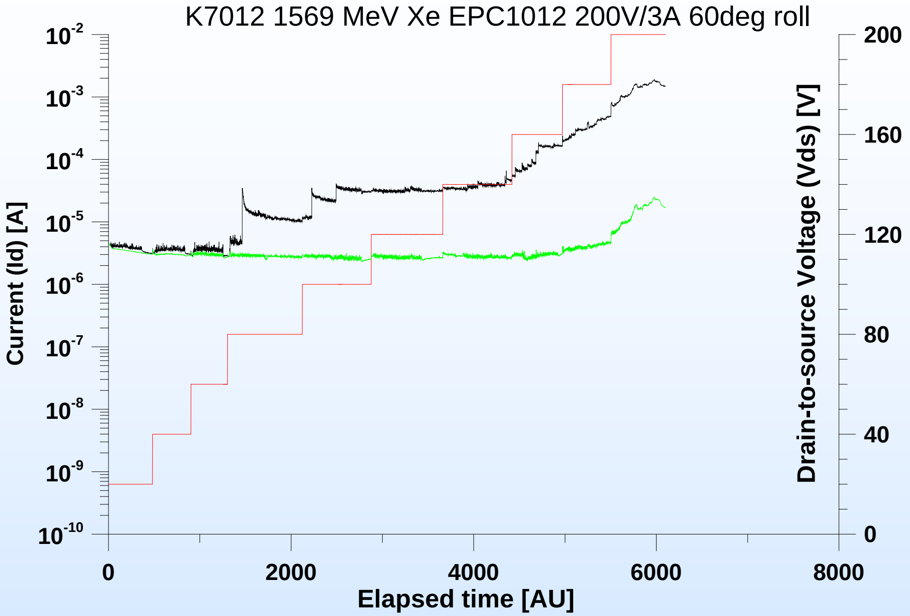
- **60 degree tilt angle irradiation shown less sensitivity to small break**
  - **Large SEE – SEDR and SET – seen at higher voltages**
- **TRIM calculation showed ion Bragg peak at or beyond the active region**

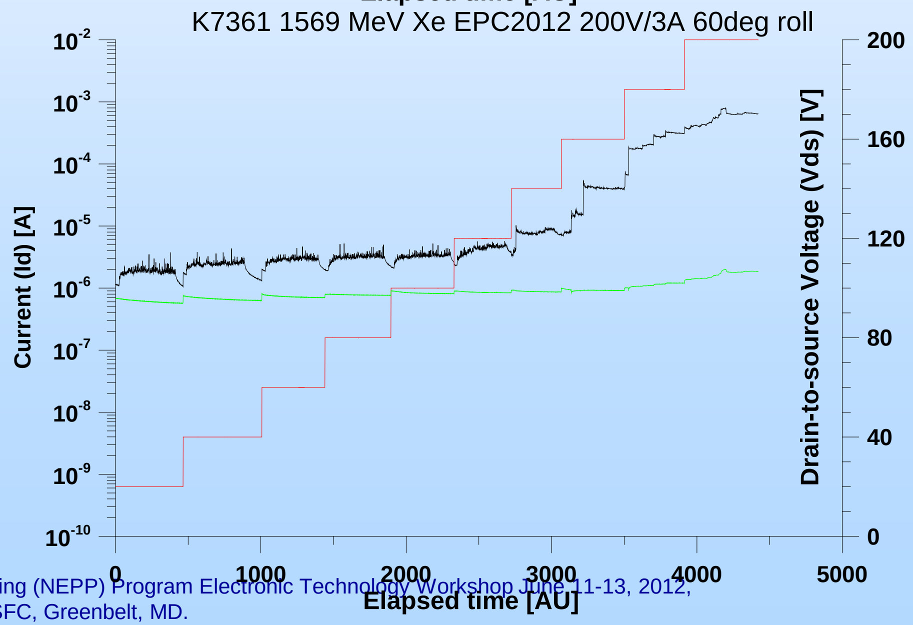




EPC1012 / EPC 2012 Comp 60º Roll

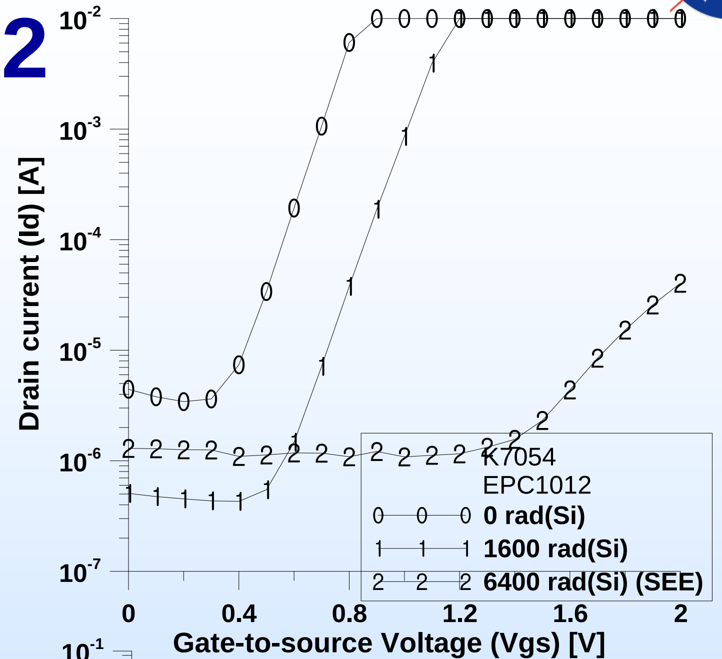
- 60 degree roll angle
  - Device is less susceptible than normal
  - But more susceptible than tilt
- Gen2 gate leakage also reduced compared to Gen1

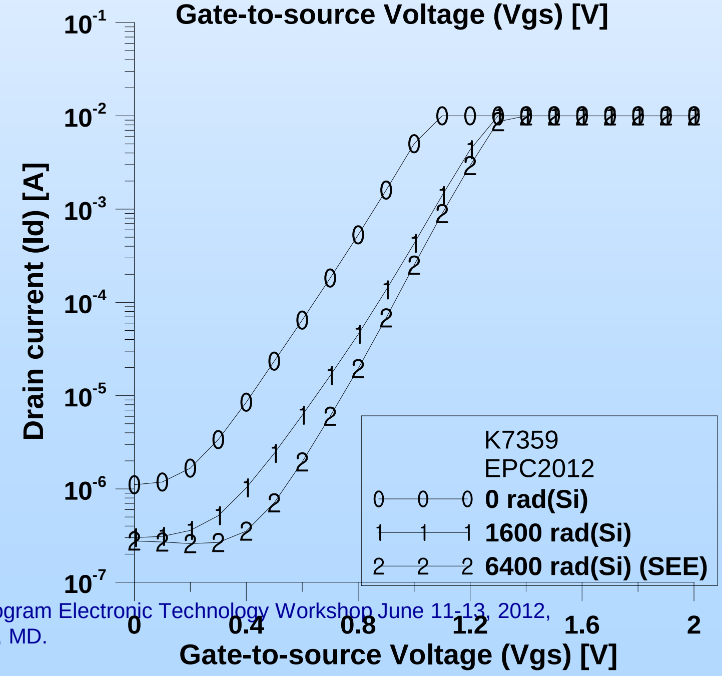




Transfer Curve Delta – EPC1012 and EPC2012

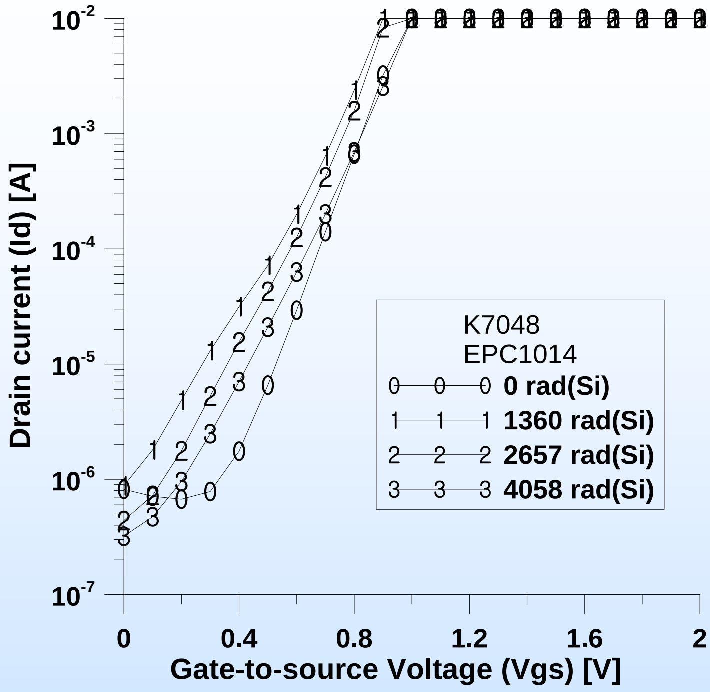
- **The threshold voltage and transconductance with ion damage**
  - **Xenon at 60º tilt shows effect event though no SEE are seen**
  - **All devices show this effect**
  - **Reportedly not seen in TID measurements**
- **Proton testing to be done**

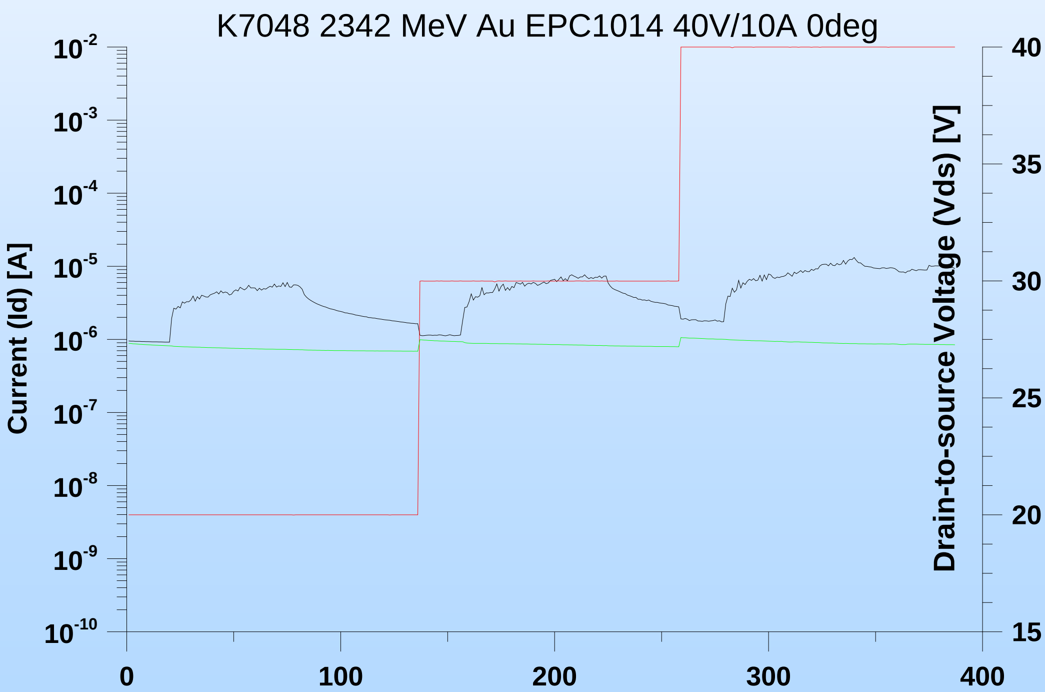




EPC1014

- **40 V EPC devices are the most robust**
  - **EPC2014 have similar response**





Trends for eGaN devices

- At normal incidence, the higher LET ion does more damage
  - This was expected
- Devices with lower voltage rating were less susceptible to dose damage
  - This was also expected
  - 40 V nearly immune
- Devices irradiated at 60º tilt showed little degradation
  - Devices irradiated at 60º showed catastrophic SEE with no dose damage precursors
- Devices irradiated at 60º roll showed some degradation
  - SEDR occurred at lower voltages than tilt
- Gen2 parts were more robust than Gen1
  - Substrate shorted to source in all
  - EPC2012 have thicker Epitaxial layer

Conclusion

- **Silicon is still primary power management and delivery component for NASA**
  - **But its limits are becoming NASA's limits**
- **Gallium Nitride**
  - **Pros: High speed and high efficiency prospects open up high-power/low-voltage delivery**
  - **Cons: Reliability and manufacturing questions are now being addressed**
  - **EPC eGaN FET showing increasing promise as next generation solution (Gen2 superior to Gen1)**
- **Future work**
  - **Proton (SEE and DDD) and TID testing**
  - **Identification of the SEE mechanism with follow on modeling**
    - **Include angle, ion-energy, and bias effects**