[Airbus Amber]

Final Presentation Days 2023 – ESA ESTEC – 30.06.2023

Status on OSIP Studies on COTS Power GaN Heavy Ion Effects evaluation for Space.

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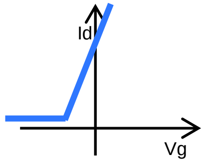
Summary

- Context – Adoption of Power GaN technologies for Space Applications.
- Summary of observed effects in Heavy Ions irradiations
- Study Results
  - OSIP Homogeneity
  - OSIP Sensitivity
  - OSIP Synergy
- Conclusion & Outlook of the study

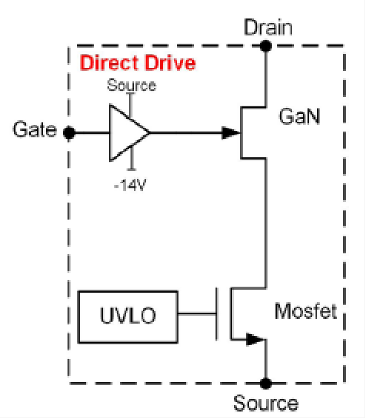
COTS Power GaN FET solutions

Normally-On HEMT



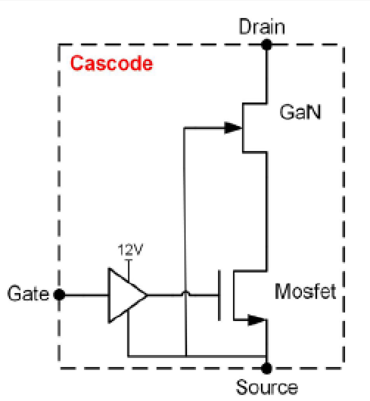
Direct Drive structure

Neg. Embedded Drive solution
+ Embedded Current monitor
Serial LVMOS (Mixed Signal Process)

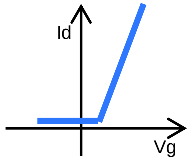


Cascode structure

LV MOS Gate Drive solution
On a Serial Vertical COTS NMOS

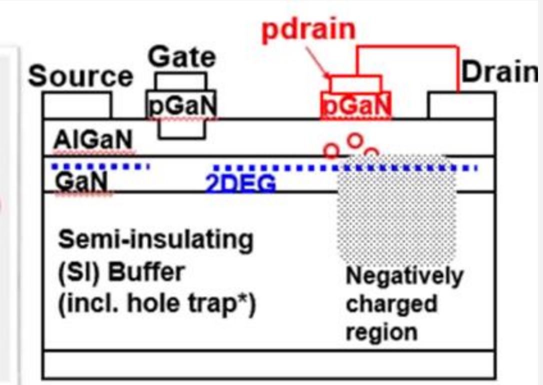


Normally-Off HEMT



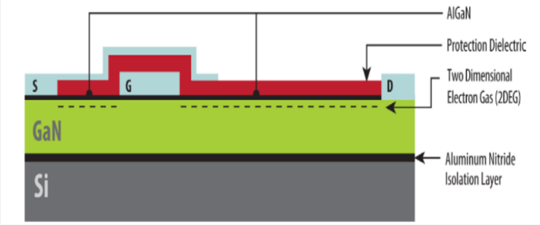
Hybrid Drain Gate Injection Transistor

Current control Gate drive solution
(Gate Diode Clamp Voltage)



pGaN Gate technology

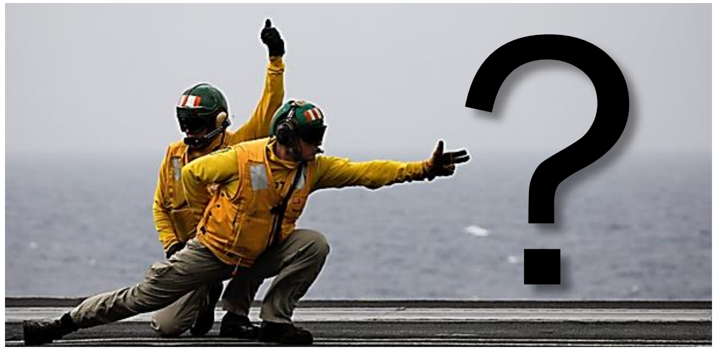
Voltage Control Gate up to 6 V.



Power GaN a key technology for Space ?

Better figure of merit

	FOM/3			
RdsON	**RdsON** ↘	Conduction losses ↘	**Efficiency** ↗	**Power density** ↗
Parasitics	**Cgs & Cgd** ↘	Switching losses ↘	**Volume & weight** ↘	
No reverse recovery time	**Qrr → 0**	Frequency ↗		

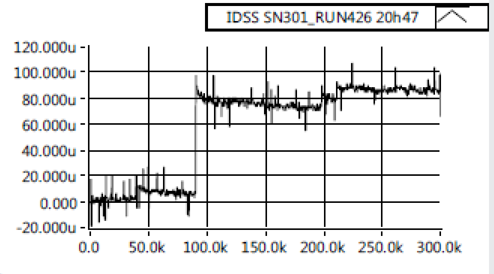


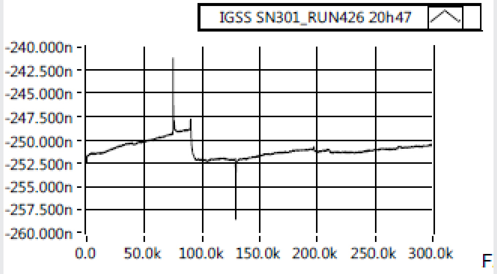
Power Function failure is not an option for Space, we maintain continuous survey

- **Reliability** : Early Life, Wear Out modelling
- **Integration**, Assembly for Space Electronics
- **Traceability**, Supply Chain
- **Radiation Hardness**

Radiation - Single Event Effects in Power GaN

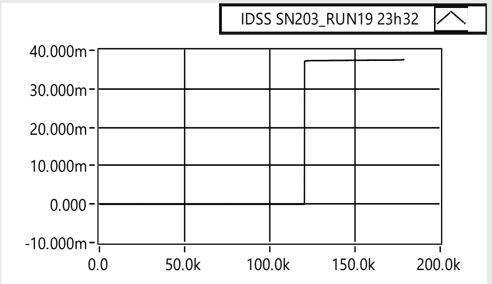
Heavy Ion Induced Current

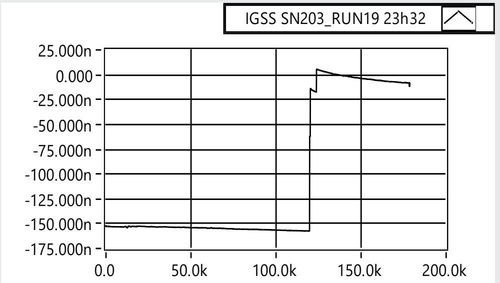




Under beam degradation observed on Drain to source path

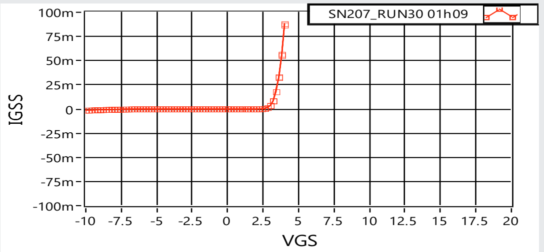
Single Event Burnout Under beam failure





Under beam failure observed on Drain to source path.. **Unconditional SOA** can be defined.
Gate overblocking to be explored.

Latent Defects Post beam failure



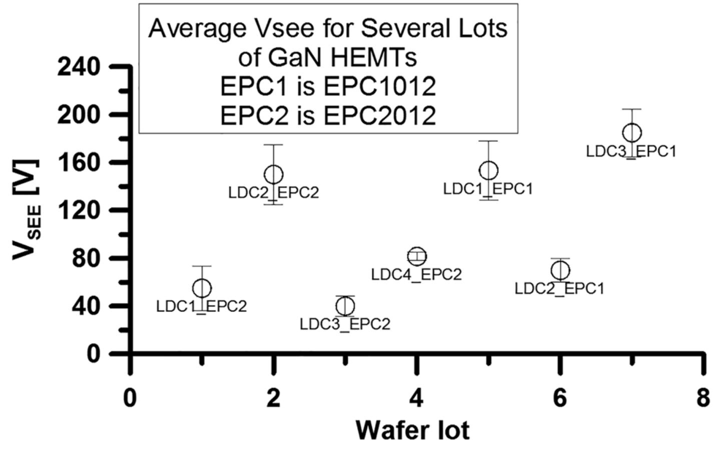
Latent Defect generated by heavy ions / protons can be detected through Post irradiation Gate and Drain sweep.

Not directly observed during irradiation but observed after irradiation during Gate or Drain voltage sweep.

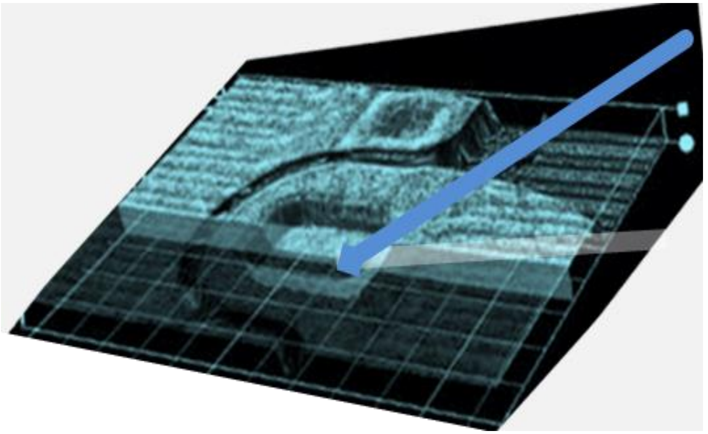
In application, this leads to a destructive event.
Sensitivity to latent defect is used for **Unconditional SOA** determination.

Lot to Lot Variability & Intra-Lot Variability : To be investigated.

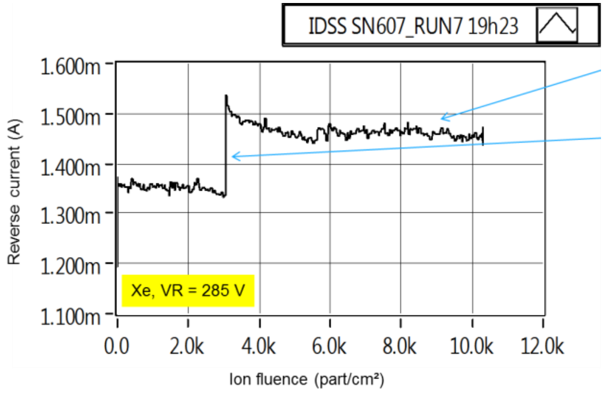
/ OSIP HOMOGENEITY



/ OSIP SENSITIVITY



/ OSIP SYNERGY



ESA ITT OSIP Call – One Pager

/ OSIP HOMOGENEITY

Study title :

SYSTEMATIC ASSESSMENT OF SINGLE EVENT EFFECT HOMOGENEITY IN WIDE BAND GAP COTS TECHNOLOGY

ESA Contract No. **4000135685/21/NL/GLC/ov**

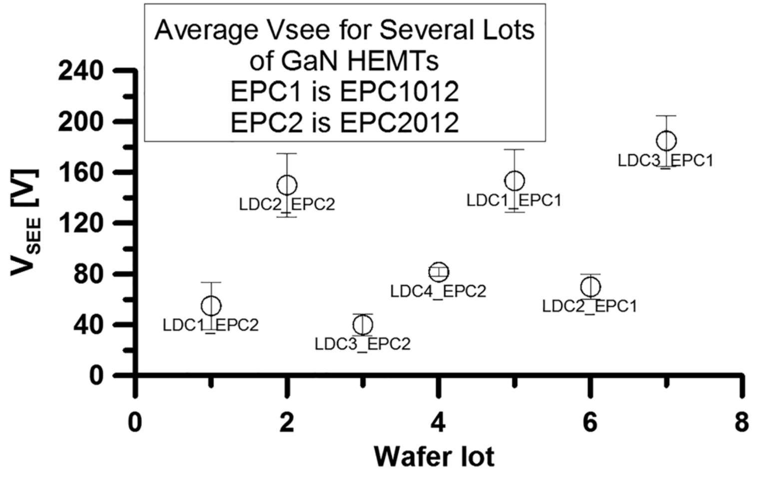
Contract Officer : ***Gian Lorenzo Casini***

Technical Officer : **Christian Poivey**

Project Duration : 12 months

Key Objectives

- evaluate the **lot-to-lot and intra-lot variabilities** against SEE effects for high voltage normally off GaN devices based on the radiation safe operating area of a large number of parts.
- develop of an **optimized test methodology**, in order to reduce test cost.



L. Scheick, "Determination of Single-Event Effect Application Requirements for Enhancement Mode Gallium Nitride HEMTs for Use in Power Distribution Circuits," in IEEE Transactions on Nuclear Science, vol. 61, no. 6, pp. 2881-2888, Dec. 2014, doi: 10.1109/TNS.2014.2365545.

Test methodology

- Isofluence sweep from V_D 0 V to max usable V_D 520 V
  - V_{GS} at 0 V

– **Destructive Failure Criteria**
  – Unability to operate (switching capability loss)
    – Test after irradiation (Sweep A / Switch test / Sweep B / Switch test B …)
  – Self-Heating conditions (> 0.5 W dissipation)
    – Ex. at V_{DS} of 400 V, 1,25 mA leakage would be considered as a destructive event.

– **Soft Failure Criteria**
  – Drain current leakage above device specification
  – On-State Resistance degradation

Methodology is to define cumulative distribution plot & determine a distribution law.

20 samples per LET conditions would be the baseline (pending opening success ratio)
3 LETs conditions can be used :
- Low LET conditions (typically 3 MeV.cm²/mg)
- Intermediate LET (Encompassing worst case Recoil Ions >= 24 MeV.cm²/mg Si)
- High LET (Typically 60 MeV.cm²/mg)

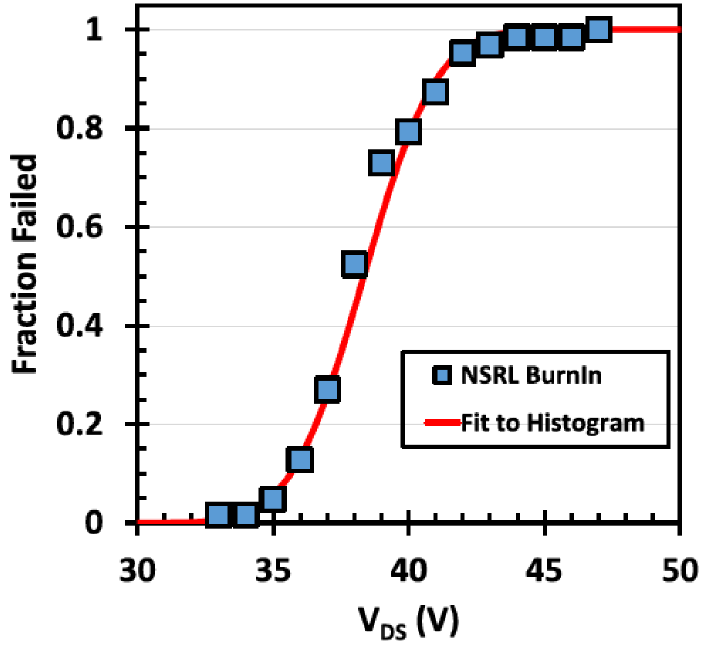
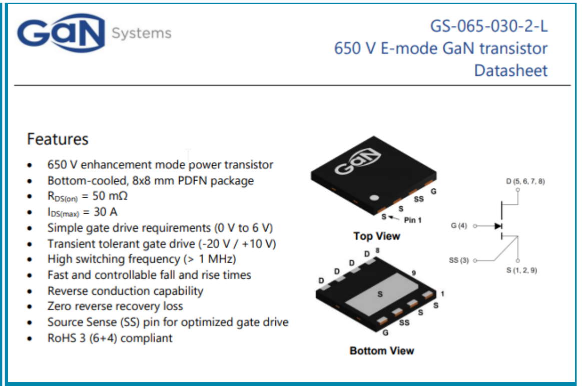


Fig. 4. Cumulative distribution function (CDF) for the IRF6646 (80 V) devices. The solid line is the CDF for the normal fit to the histogram data.

“ In general terms, increasing the test sample population will reduce sampling error and lessen the K_{TL} factor that accounts for it. It is recognized that many efforts will lack a reasonable means to obtain a 50+ sample result, but even an expansion from 3-6 samples to 10-20 allows for a significantly improved assessment of sample variation. ”

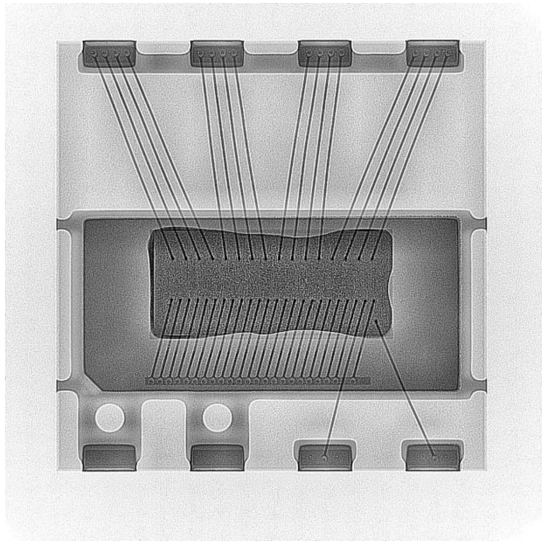
After, Lauerstein on COTS MOSFETs

COTS Test Candidate Status for Homogeneity Axis

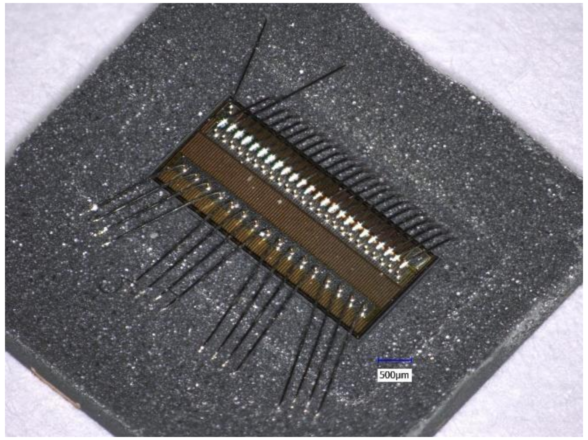

GaN Systems
GS-065-030-2-L
650 V E-mode GaN transistor
Datasheet

Features
- 650 V enhancement mode power transistor
- Bottom-cooled, 8x8 mm PDFN package
- $R_{DS(on)}$ = 50 mΩ
- $I_{DS(max)}$ = 30 A
- Simple gate drive requirements (0 V to 6 V)
- Transient tolerant gate drive (-20 V / +10 V)
- High switching frequency (> 1 MHz)
- Fast and controllable fall and rise times
- Reverse conduction capability
- Zero reverse recovery loss
- Source Sense (SS) pin for optimized gate drive
- RoHS 3 (6+4) compliant

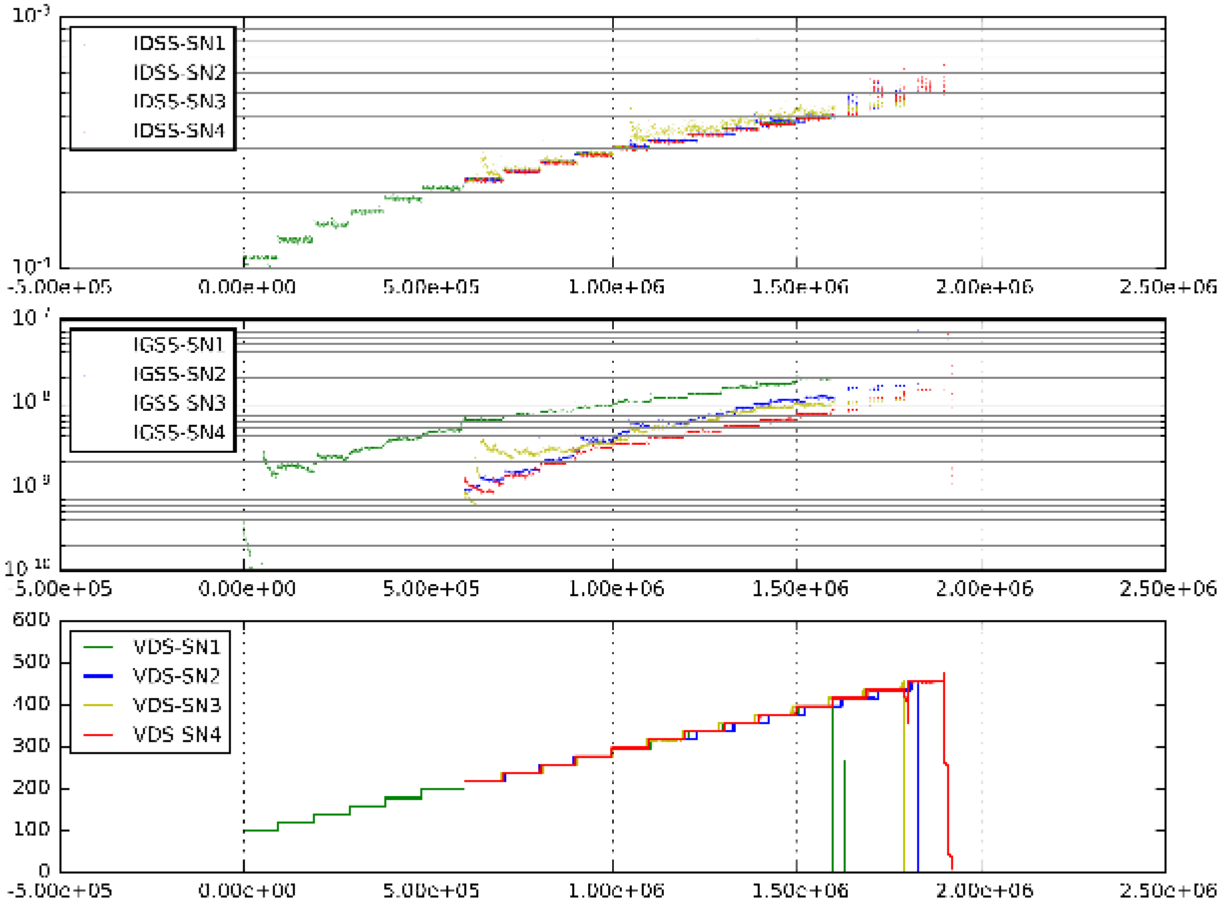
Reference	GS-065-030-2-L
Technology	pGaN Gate GaN/AlGaN HEMTs on Silicon
Manufacturer	GaN Systems
Procurement Status	☑ Stock ☑ UP 10 - 20 €
Known sensitivity	☑ Internal Data
Expected Sample preparation	[?] Top Opening

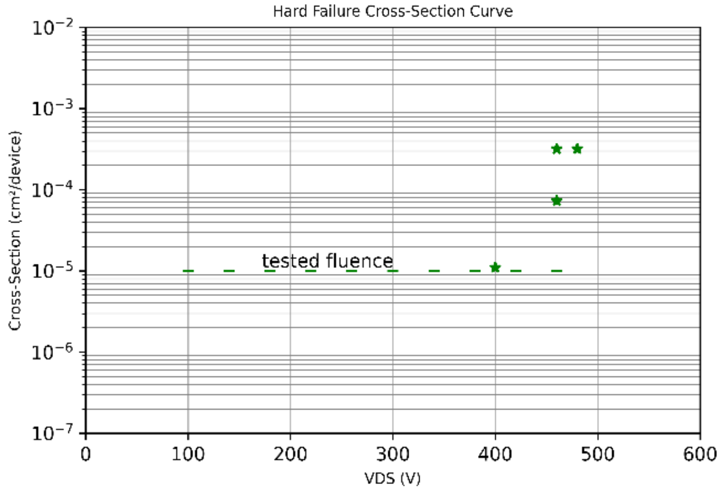


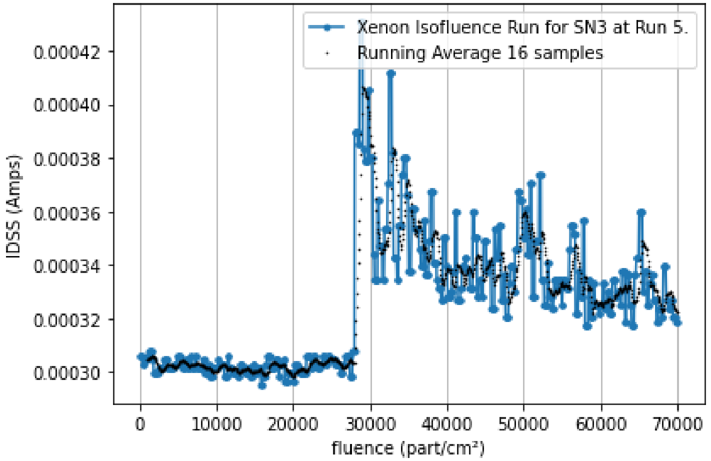
Plasma – Test OSIP Synergy



Preliminary Results







- ✓ Desrtuctive Failure detected at 400 V (Xe, UCL, 0°, 0°)
- ✓ Partial leakage detected at 320 V

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/ OSIP SENSITIVITY

Study title :

Heavy ion failure rate computation based on sensitive volume characterization in GaN/AlGaN FETs

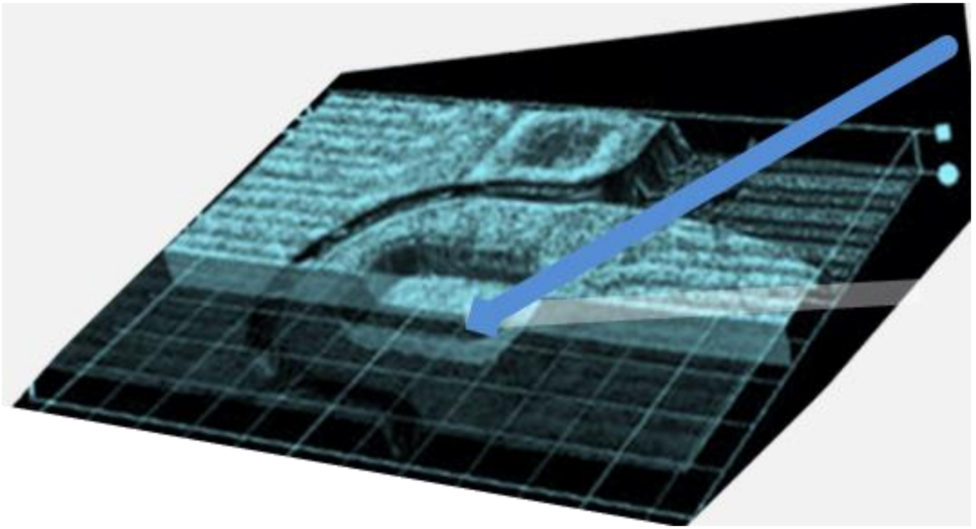
ESA Contract No. **4000135683/21/GL/ov**

Contract Officer : ***Gian Lorenzo Casini***

Technical Officer : **Christian Poivey**
Project Duration : 12 months

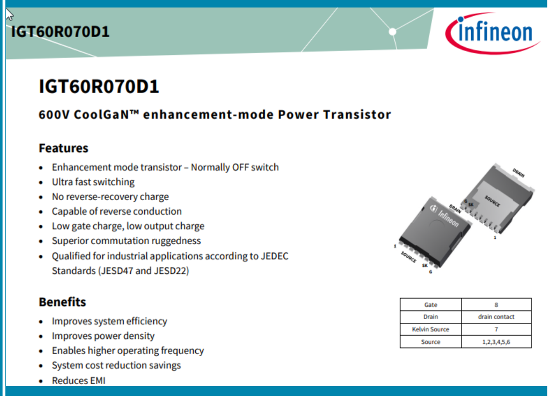
Key Objectives

- Determine the extension of sensitive volume in Power GaN/AlGaN pGaN technology.
- Propose **recommendations toward radiation risk assessment of Power** GaN/AlGaN pGaN technology.



COTS Test Candidate Status at Project KO

/ OSIP SENSITIVITY


IGT60R070D1

IGT60R070D1

600V CoolGaN™ enhancement-mode Power Transistor

Features

- Enhancement mode transistor – Normally OFF switch
- Ultra fast switching
- No reverse-recovery charge
- Capable of reverse conduction
- Low gate charge, low output charge
- Superior commutation ruggedness
- Qualified for industrial applications according to JEDEC Standards (JESD47 and JESD22)

Benefits

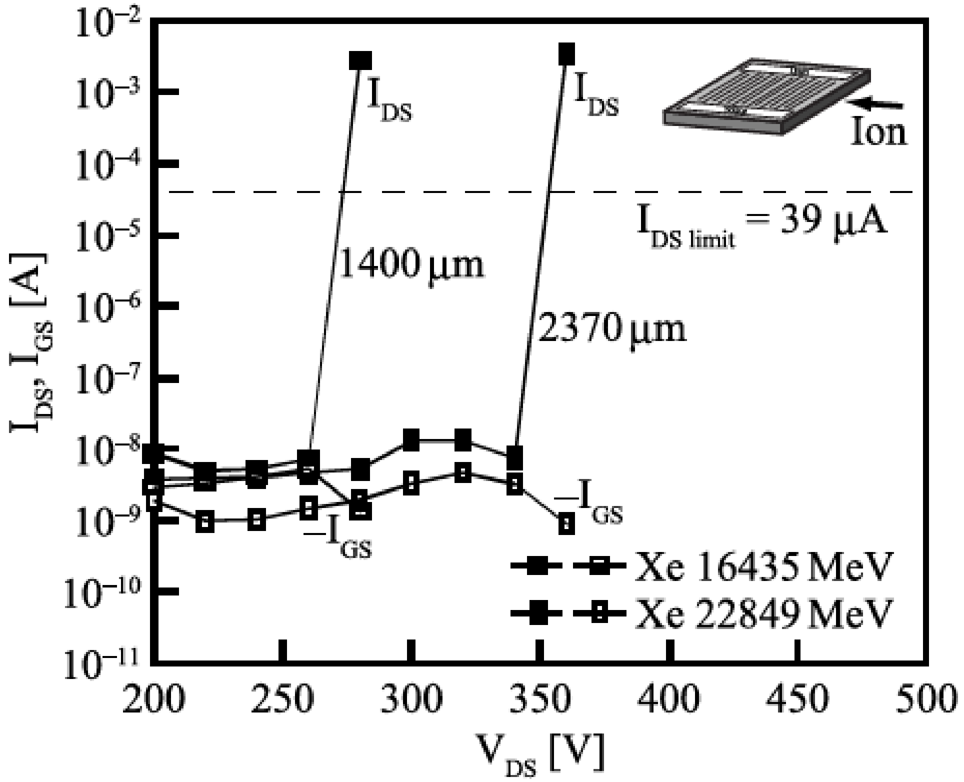
- Improves system efficiency
- Improves power density
- Enables higher operating frequency
- System cost reduction savings
- Reduces EMI

Gate	8
Drain	drain contact
Kelvin Source	7
Source	1,2,3,4,5,6

Reference	IGT60R070D1
Technology	HD-GIT GaN/AlGaN HEMTs on Silicon
Manufacturer	Infineon
Procurement Status	☑ Stock ☑ UP 20 - 30 €
Known sensitivity	☑ Panasonic Equivalent (JAXA, JPL, IRT)
Expected Sample preparation	☑ Top Opening

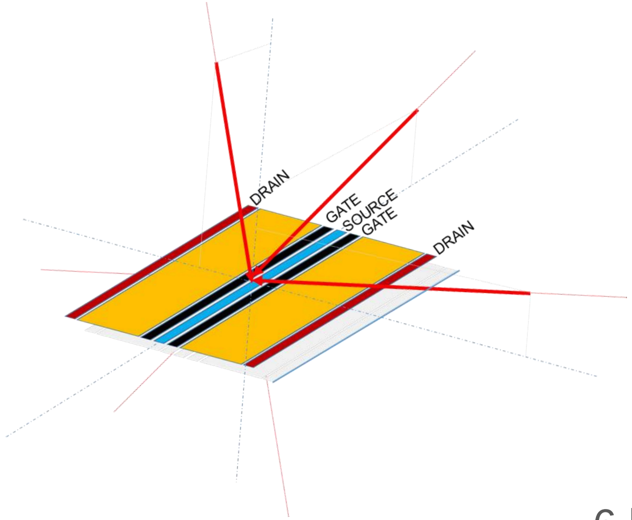
Expected results and current Hypothesis

- using high penetration beam parallel to one lateral face of the device (QST HIMAC).
- ion crossing a transverse electric field can generate destructive events below the SOA domain obtained with normal angle.
- In the tested vehicle, the observed SOA reduction is of 25 %.
- The other collinear direction, demonstrate quasi immunity to heavy ion beam.



E. Mizuta *et al*., "Single-Event Damage Observed in GaN-on-Si HEMTs for Power Control Applications," in *IEEE Transactions on Nuclear Science*, vol. 65, no. 8, pp. 1956-1963, Aug. 2018, doi: 10.1109/TNS.2018.2819990.

What are we looking at ?



Current Hypothesis :

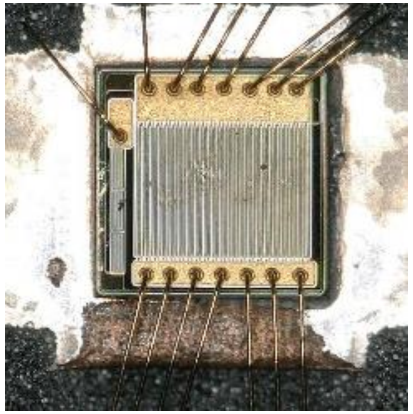
1. Charge collection and failure are mostly governed by LET at sensitive volume (< 30 µm)
2. Literature evidence angular effect on pGaN FET technology. [Mizuta and al.,Scheik and al.].

But how the sensitivity evolve with heavy ion angle ?
Then what amount of ions spectrum could contribute to such sensitivity ?

We propose to investigate the contribution of tilt and roll angle on COTS High Voltage pGaN FET.

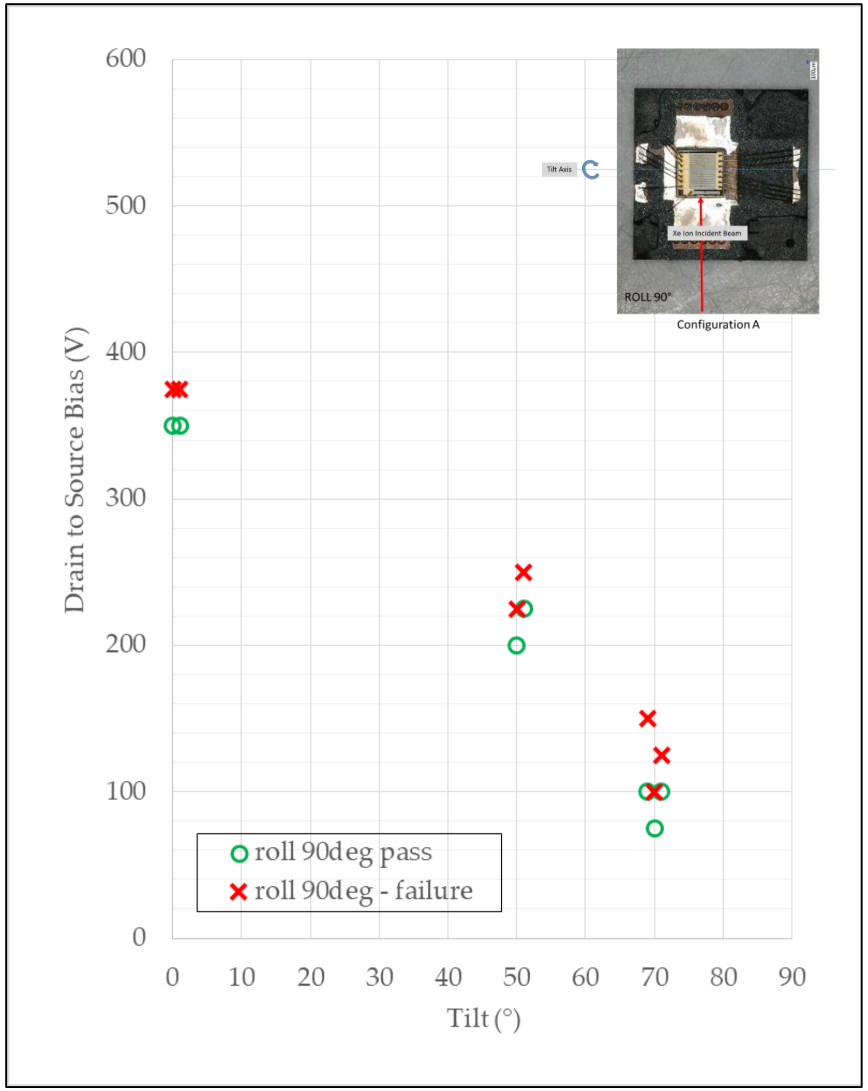
Test Candidate is

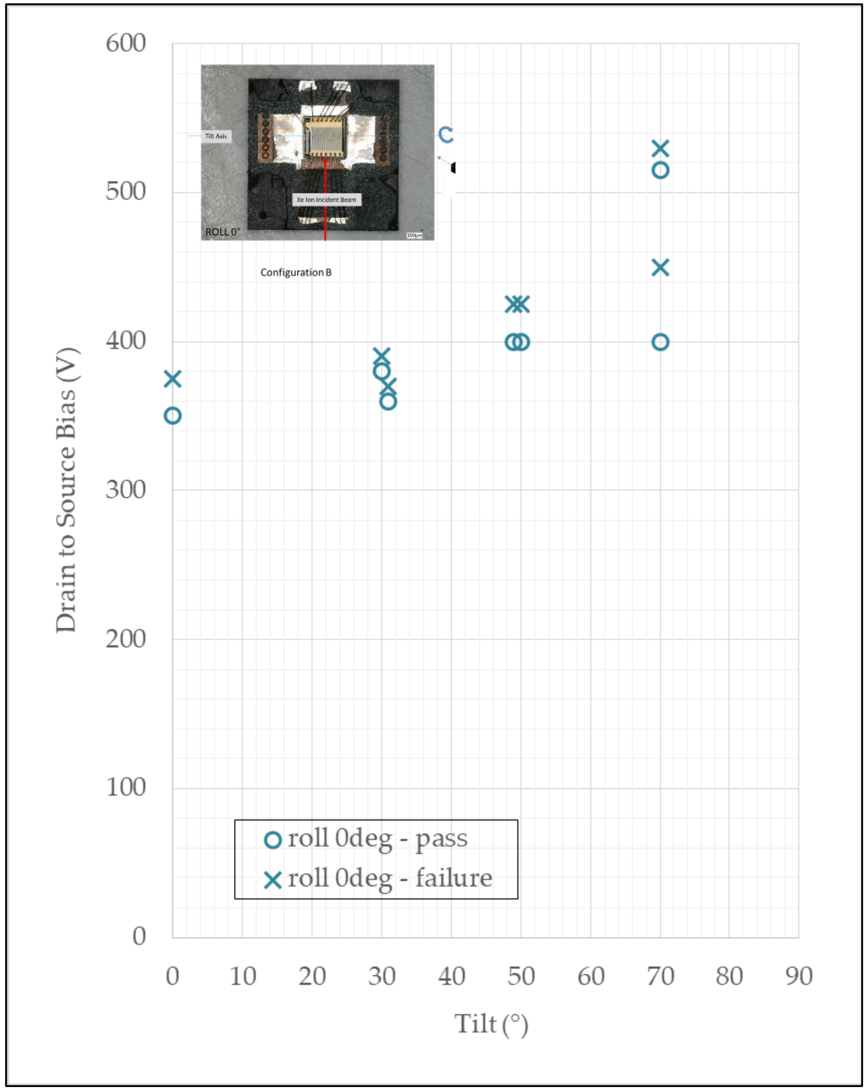
6 h from ESA beam slot.
20 samples

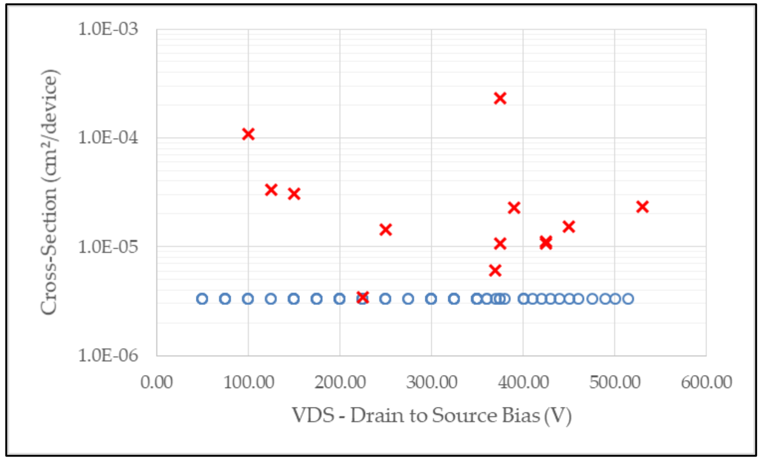


Main constraint is Package deprocessing.

Synthesis of Results for OSIP Sensitivity Test Campaign (from last PM)

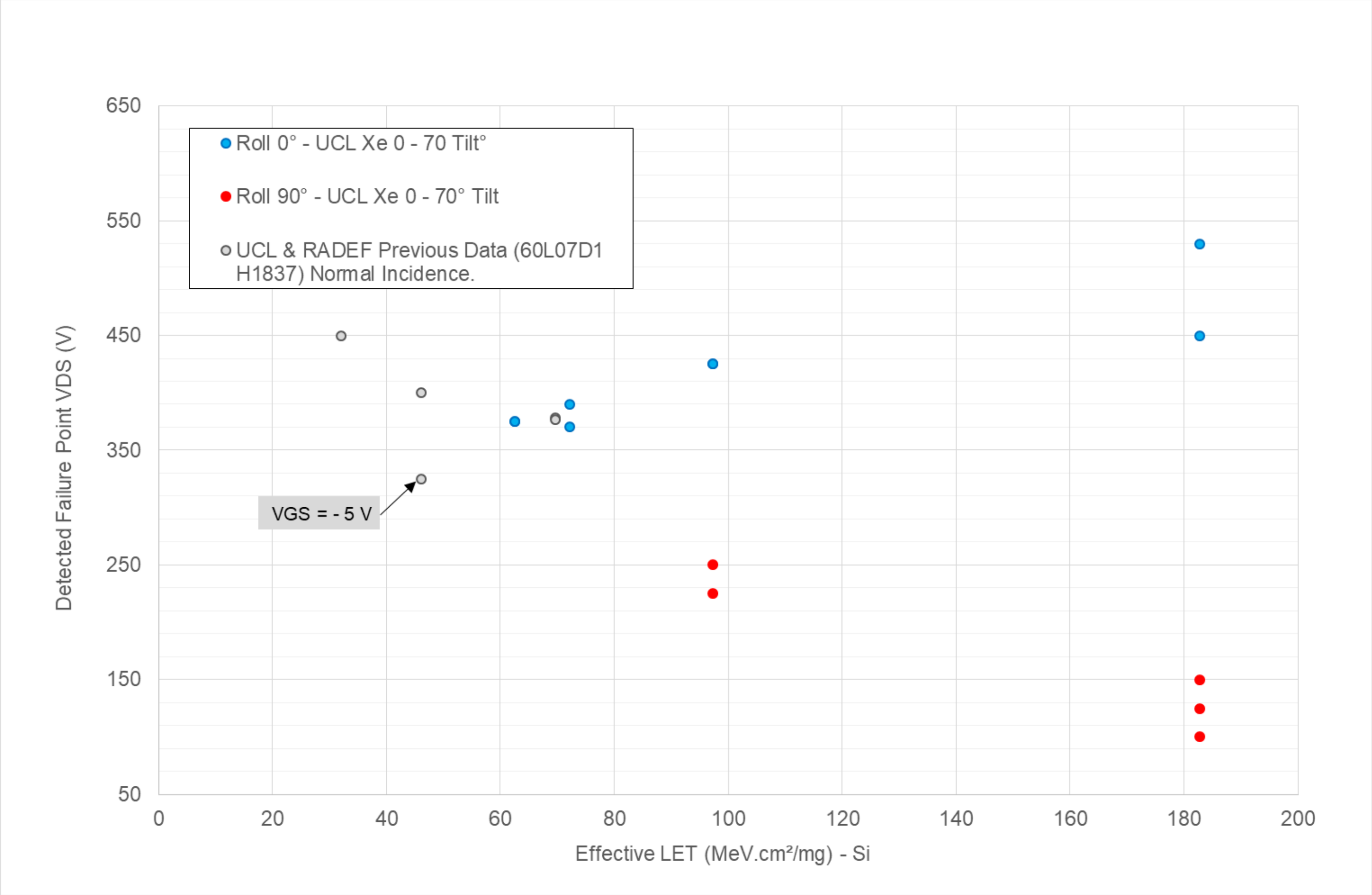






- Significant impact on the destructive SOA of surface **orientation versus devices drain & source fingers.**
- Beams parallel to fingers improve SOA immunity from Normal to Grazing angle. (+ 15 % min).
- Transverse beam lower SOA immunity from Normal to Grazing Angle. (- 70 % wc)
- Confirms previous observation on inhomogeneous behavior with beam orientation

Cosine law verification

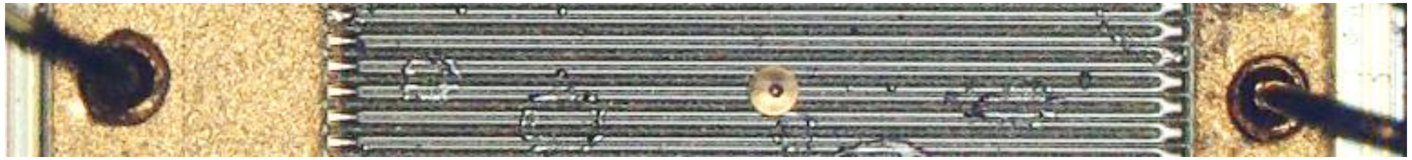


$$LET_{effective} = \frac{LET_{surface}}{\cos\theta}$$

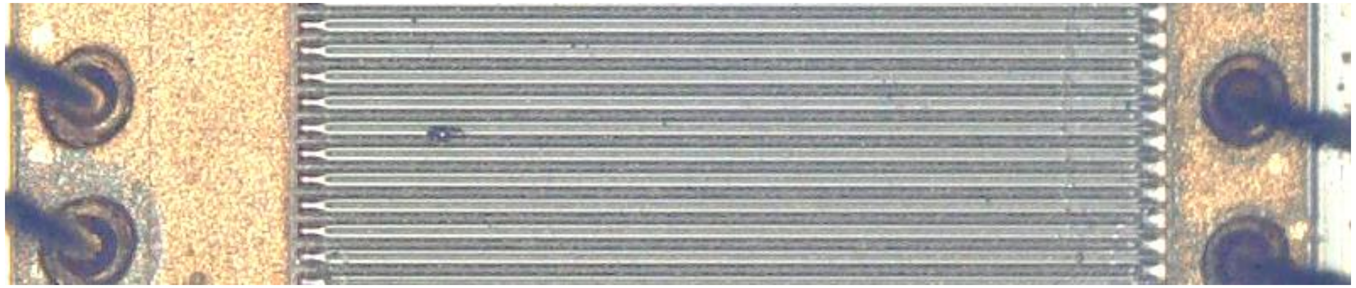
- Non-slowing assumption is considered
- Beam Crossing the DS fins – tends to follow a cosine law
- Beam Parallel to the DS fins are not following this trend
  - Sharing Collection
  - Range Effect

Die views - Post irradiation

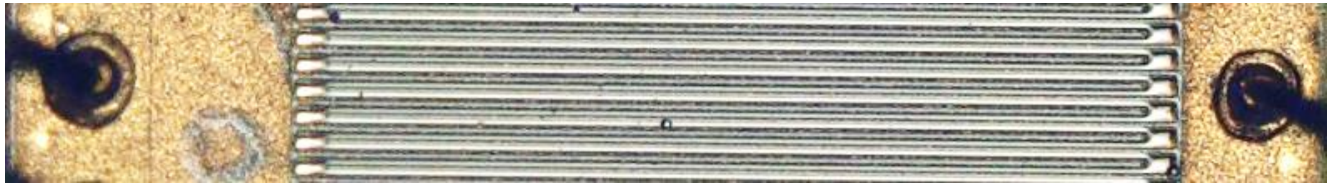
SN12 - Failure at 390 V / 30°Tilt / 0°Roll



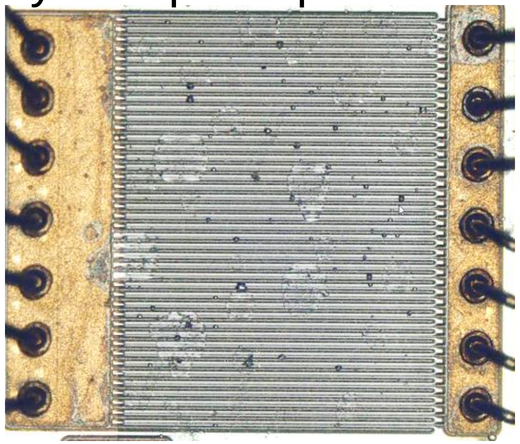
SN3 - Failure at 150 V / 70°Tilt / 90°Roll



SN7 - Failure at 125 V / 70° Tilt / 90°Roll



SN13 - Destructive Failure at 530 V / 70°Tilt / 0°R preceeded by multiple impact.



As fluence accumulated on DUTs, several defects spots are identified without leading to part failure.

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/ OSIP SYNERGY

Study title :

ESA Contract
EVALUATION OF COTS HEMT DESIGN DOMAIN EXTENSION TO HIGH VOLTAGE APPLICATIONS THROUGH MODELLING OF HEAVY ION EFFECTS ON LONG TERM RELIABILITY

ESA Contract No. **4000136037/21/NL/GLC/ov**

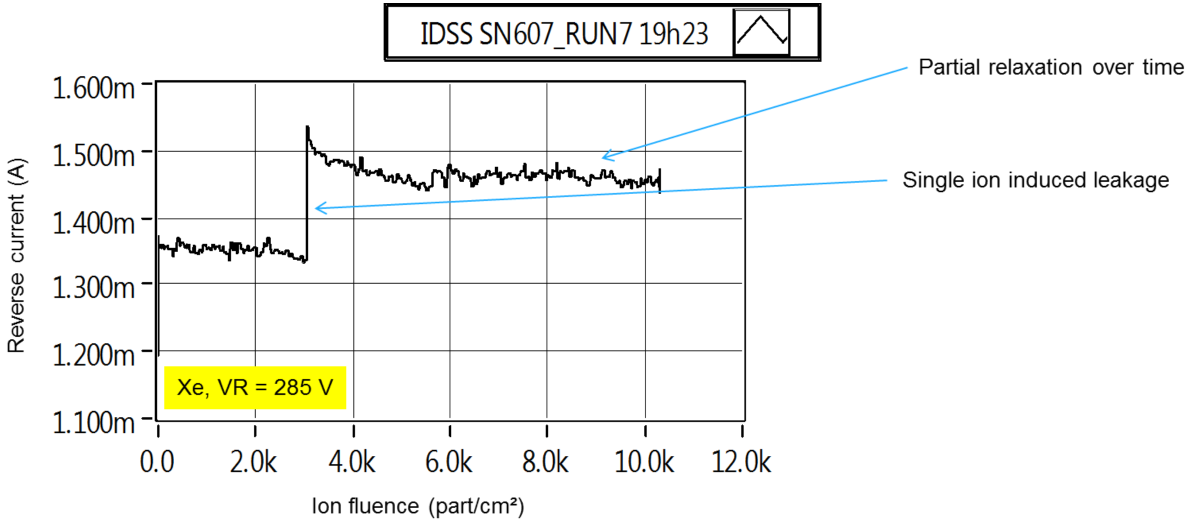
Contract Officer : ***Gian Lorenzo Casini***

Technical Officer : **Christian Poivey**

Project Duration : 12 Months

Key Objectives

- evaluate the impact on **performance and long term reliability of degradation generated by heavy ions during** space mission representative Single Event Effect testing.
- improve the radiation risk assessment by understanding the nature of the intermediate degradation regime area and its modelling



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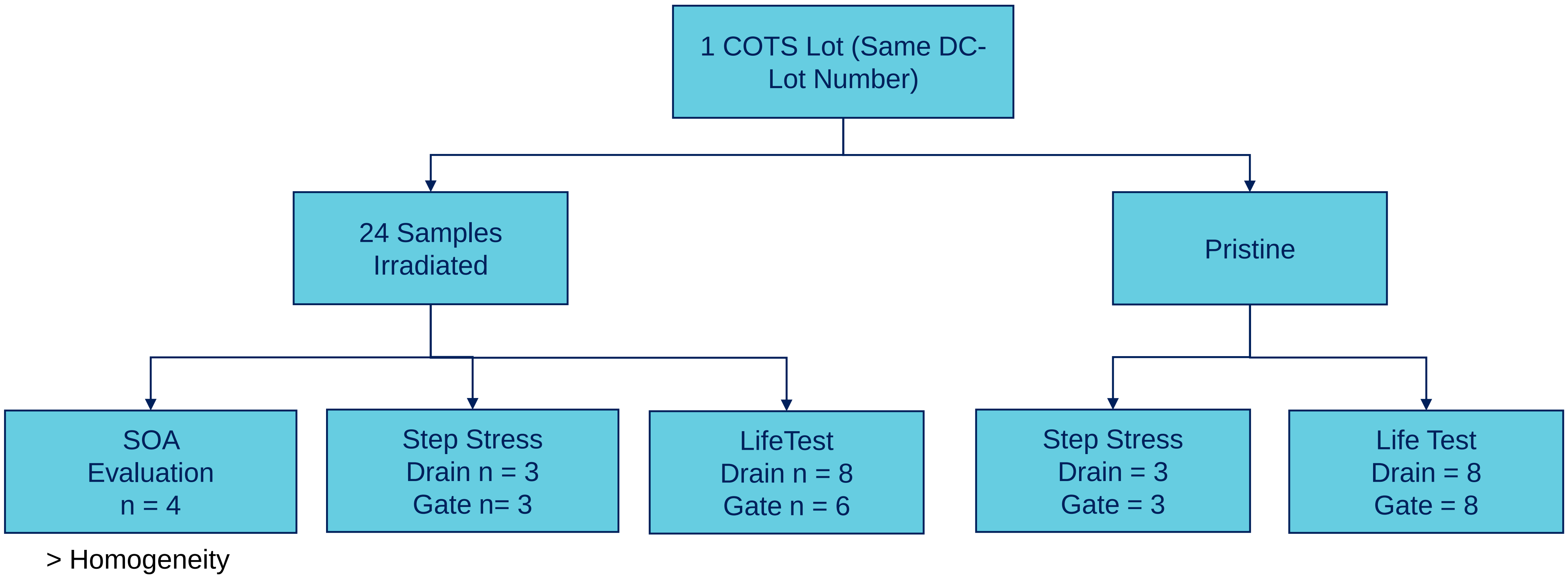
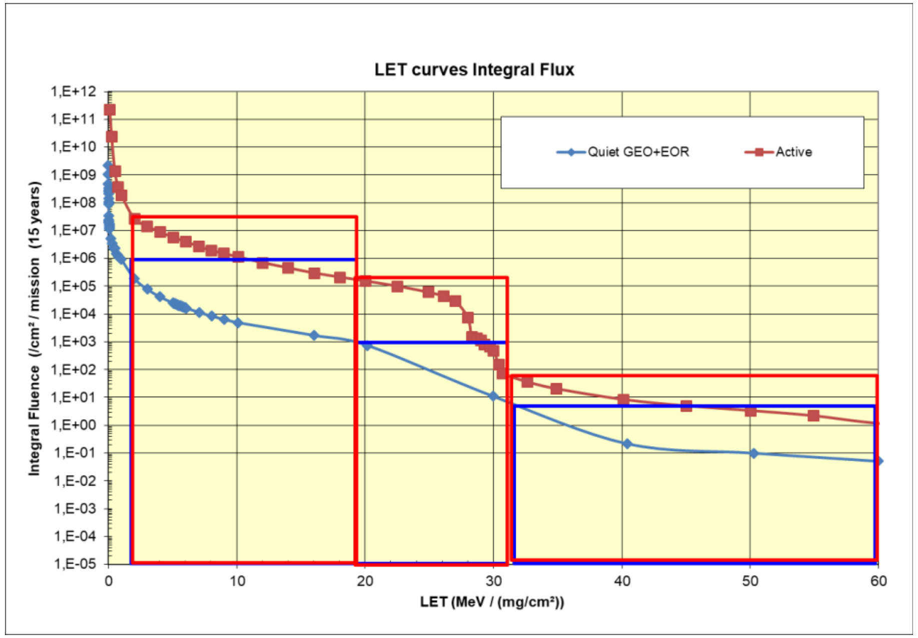
Test plan for OSIP Synergy



Cf. Heavy Ion test plan

Cf. Test plan considération
+
Test charts for beam time volume definition



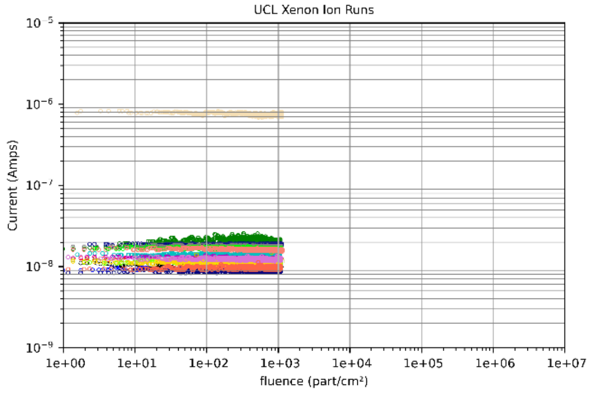
3 LETs evaluations

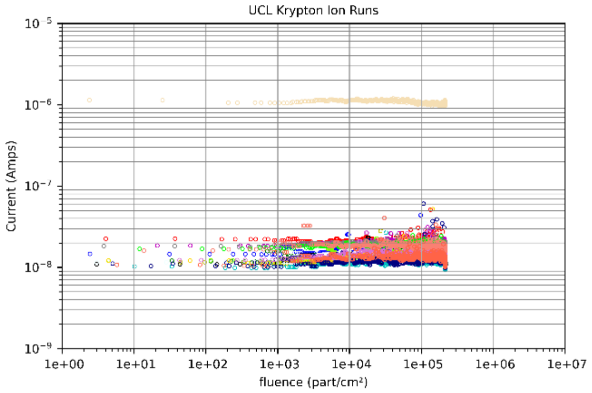
Ion	Energy [MeV]	Range [µm Si]	LET in Si [MeV.cm².mg⁻¹]
$^{124}Xe^{35+}$	995	73.1	62.5
$^{84}Kr^{25+}$	769	94.2	32.4
$^{40}Ar^{12+}$	379	120.5	10.0

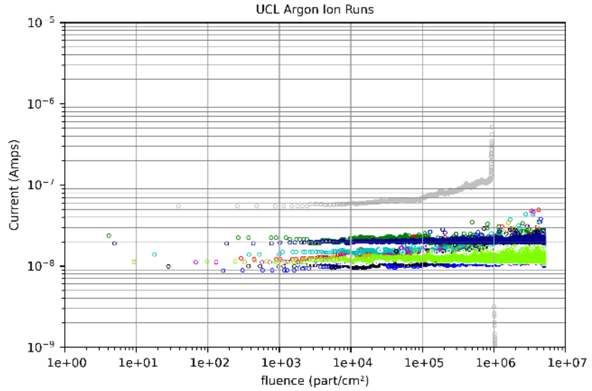
Evolution of current leakage during irradiation

Ion	Energy [MeV]	Range [µm Si]	LET in Si [MeV.cm².mg⁻¹]
$^{124}Xe^{35+}$	995	73.1	62.5
$^{84}Kr^{25+}$	769	94.2	32.4
$^{40}Ar^{12+}$	379	120.5	10.0

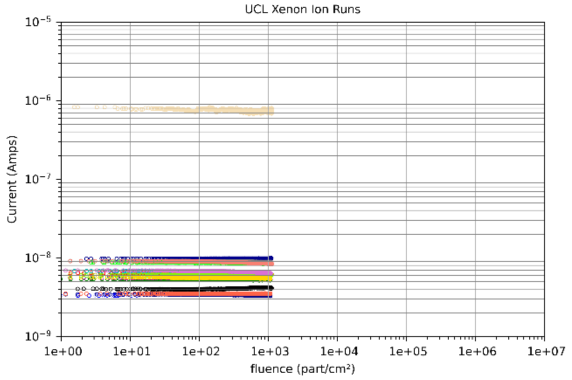
IDSS

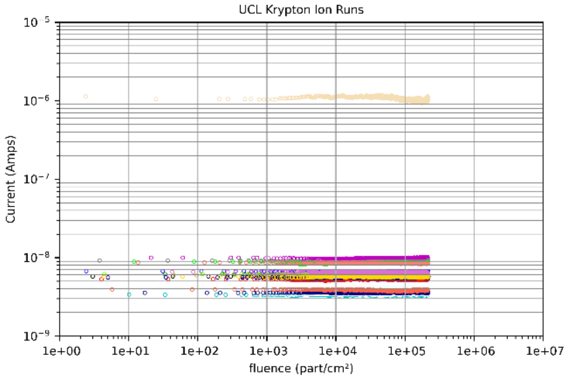


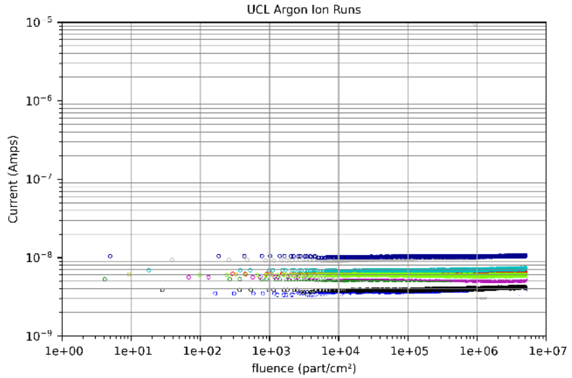




IGSS







- Reached Fluence under Xenon ions : 10^3 ions / cm² (active (worst week) period total fluence above ~ 30 MeV.cm²/mg in silicon)
- Reached Fluence under Krypton ions: 2. 10^5 ions/cm²(active (worst week, period total fluence above ~ 14 MeV.cm²/mg in silicon)
- Reached Fluence under Argon ions : 5.10^6 ions /cm² (active period total fluence above ~ 5 MeV.cm²/mg in Silicon)

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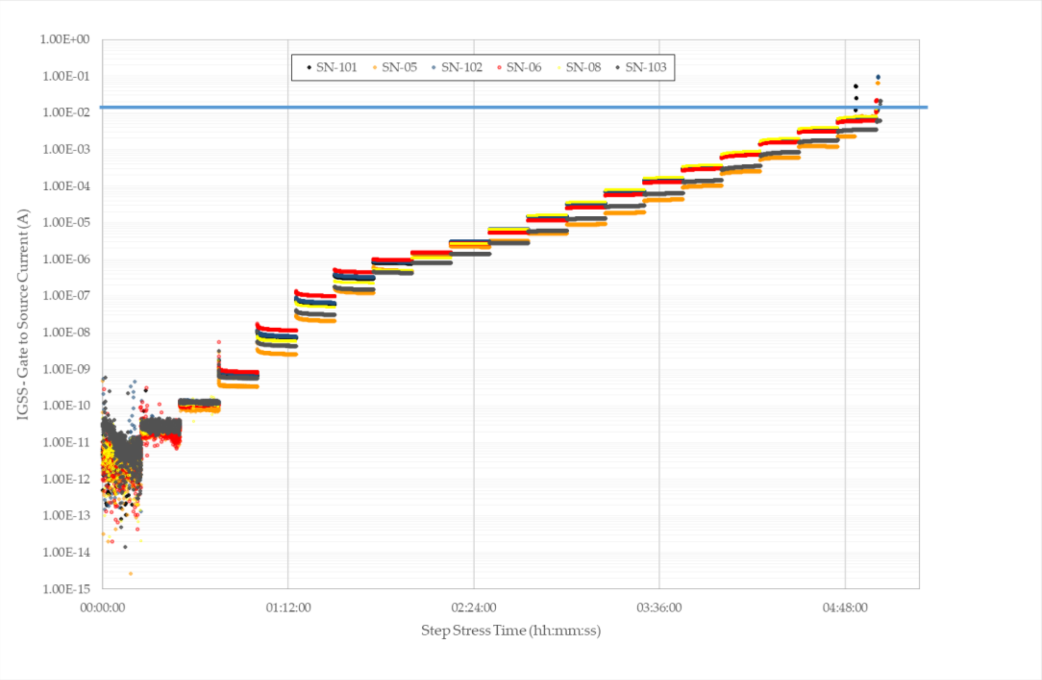
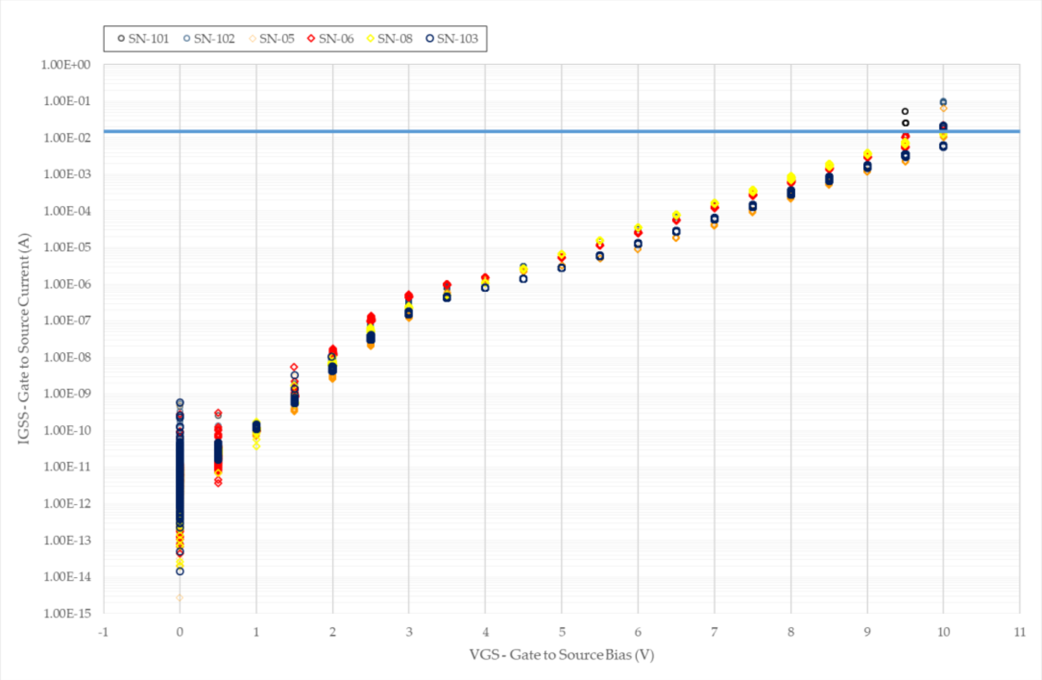
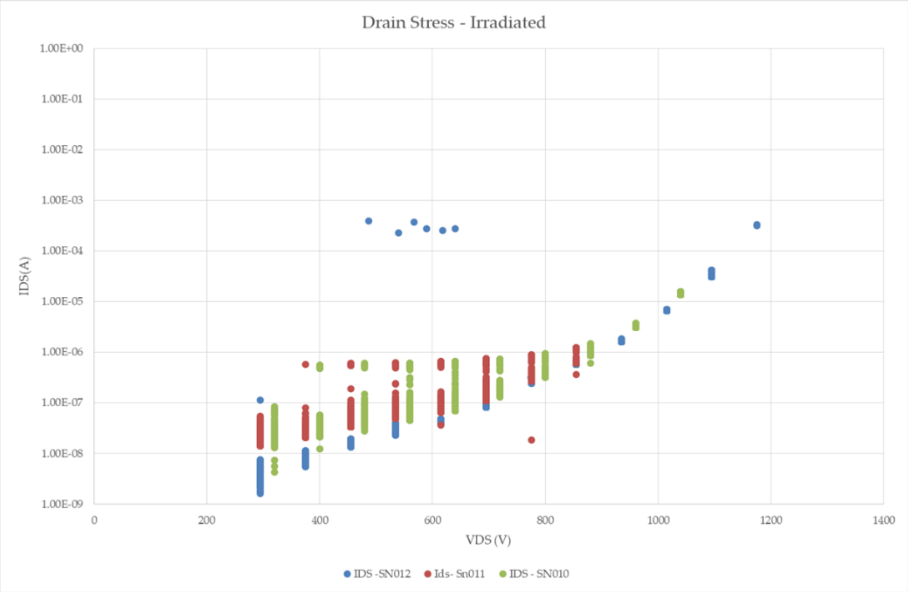
Synergy - Step Stress Results – Gate Stress Group (GS065030)

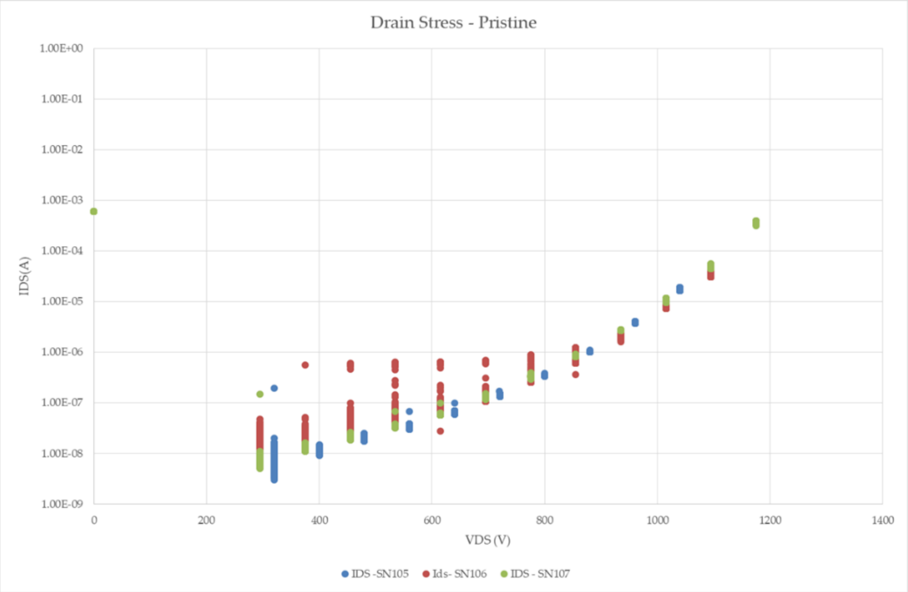




- Step stress of 15 minutes per bias point. Bias step of 500 mV from 0 V to 10 V.
  - SN 101-102-103 Pristine Parts
  - SN 05-06-08 Irradiated Parts.
  - Overall Consistent behavior.
  - No reduction of gate max voltage capabilities.

Drain Step Stress – Comparative Results





Room Temperature – Vstart ~ 300 V – Steps of 80 V – Typical Time at Step is 8 hours. Stop at I_{DSS} > 600 µA.
No identified failure up to maximum rated voltage. No instataneous failure even at 1 000 V.

Post Stress Test (Vth, Ileak) to be performed and we could consider to add those samples in Life Step Stress.

Next Activities

Synergy Life Test Conclusion

Homogeneity :

- Sample Preparations
- Test for Homogeneity campaign at RADEF in 2023

Conclusion

Power GaN is a candidate for space design

- Most commercially available PowerGaN technologies have been evaluated under heavy-ion, neutron, Co60 environment
- **Normally-off pGaN** demonstrate capabilities under radiation environment

OSIP R&T activities are underway to contribute in understanding of the failure mechanisms and quantify the margins notably against radiation risks.

- **Sensitive volume and effect of angle on device sensitivity is to be well characterized in both surface axis.**
- **Latent defects generation is under understanding. Preliminary positive results from step stress.**
- **Homogeneity of COTS lots behavior against radiation effects**. Outliers identification. Statiscally relevant data shall be seek.

Potential development is to continue understanding of failure mechanisms (failure site, materials, identify parameters of sensitivity to track for non-regression test).

Airbus is **maintaining** survey is key as new players and new technology are expected in the coming years.

Standardisation of test methods and Risk Assurance shall be seek.

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Thank you.