# Airbus Crisa

## Commercial GaN FETs. Radiation destructive events: Lot-to-lot and intra-lot variability

CRISA

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# AGENDA

1 ELECTRONIC STRUCTURE OF GaN

2 WHY GaN?

3 RADIATION SEE VALIDATION

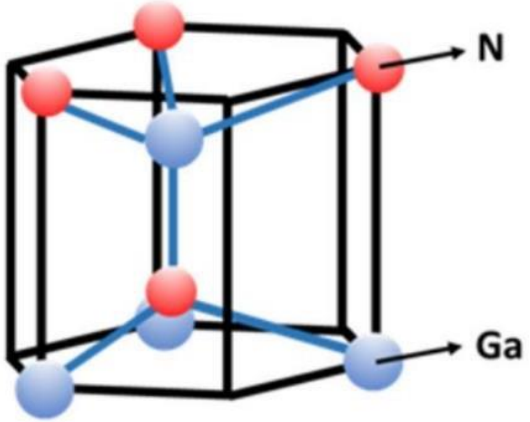
4 DEVICES UNDER TEST & TEST CONDITIONS

5 RESULTS

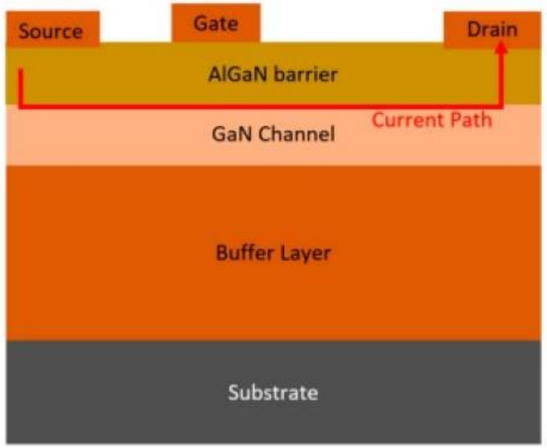
6 CONCLUSIONS

7 REFERENCES

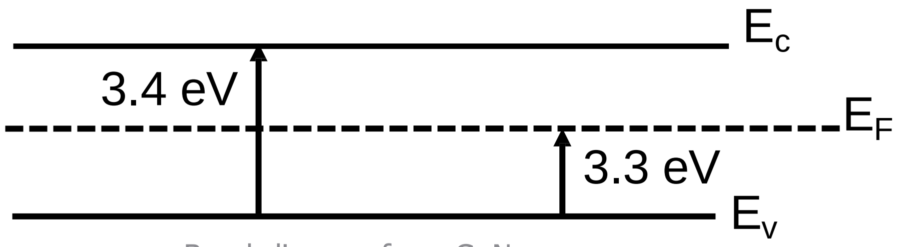
# ELECTRONIC STRUCTURE OF GaN



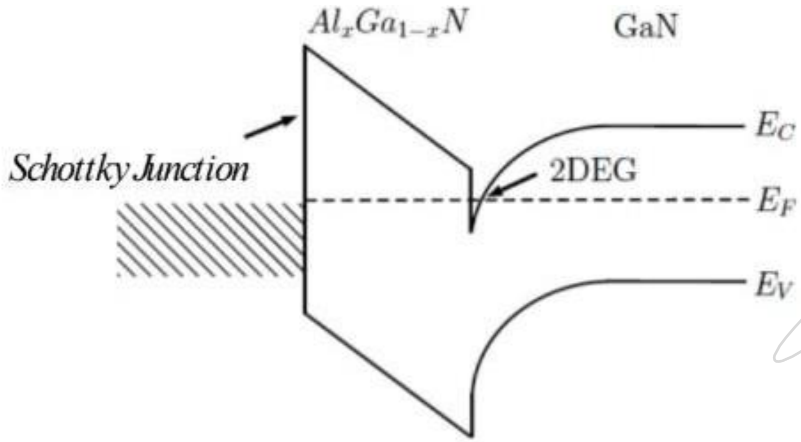

Crystal Lattice for GaN: Wurtzite [1]




Lateral GaN FET device structure [2]




Band diagram for a GaN



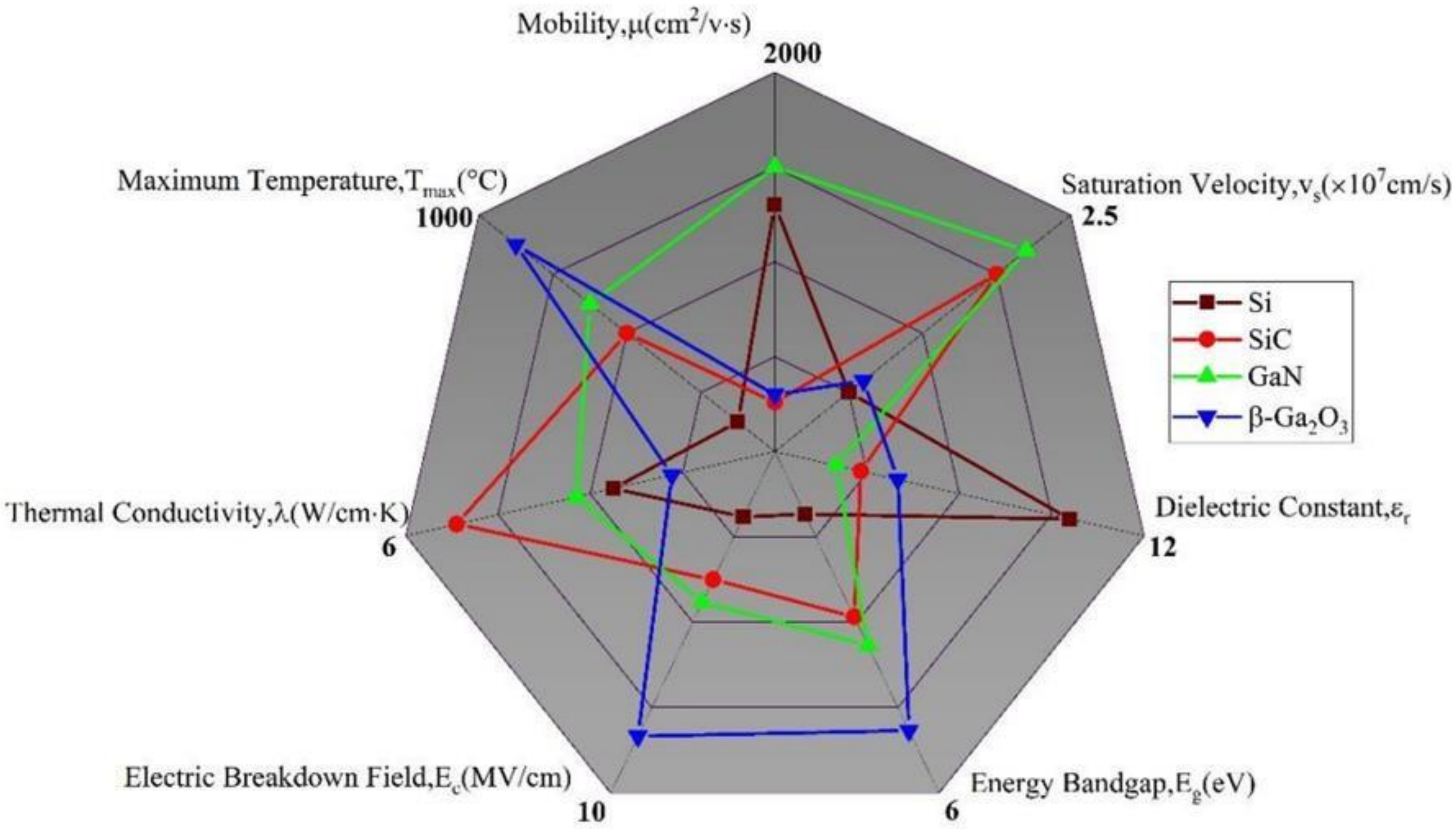

Band diagram for a GaN FET devices [3]





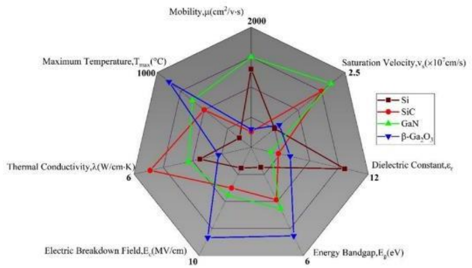
 

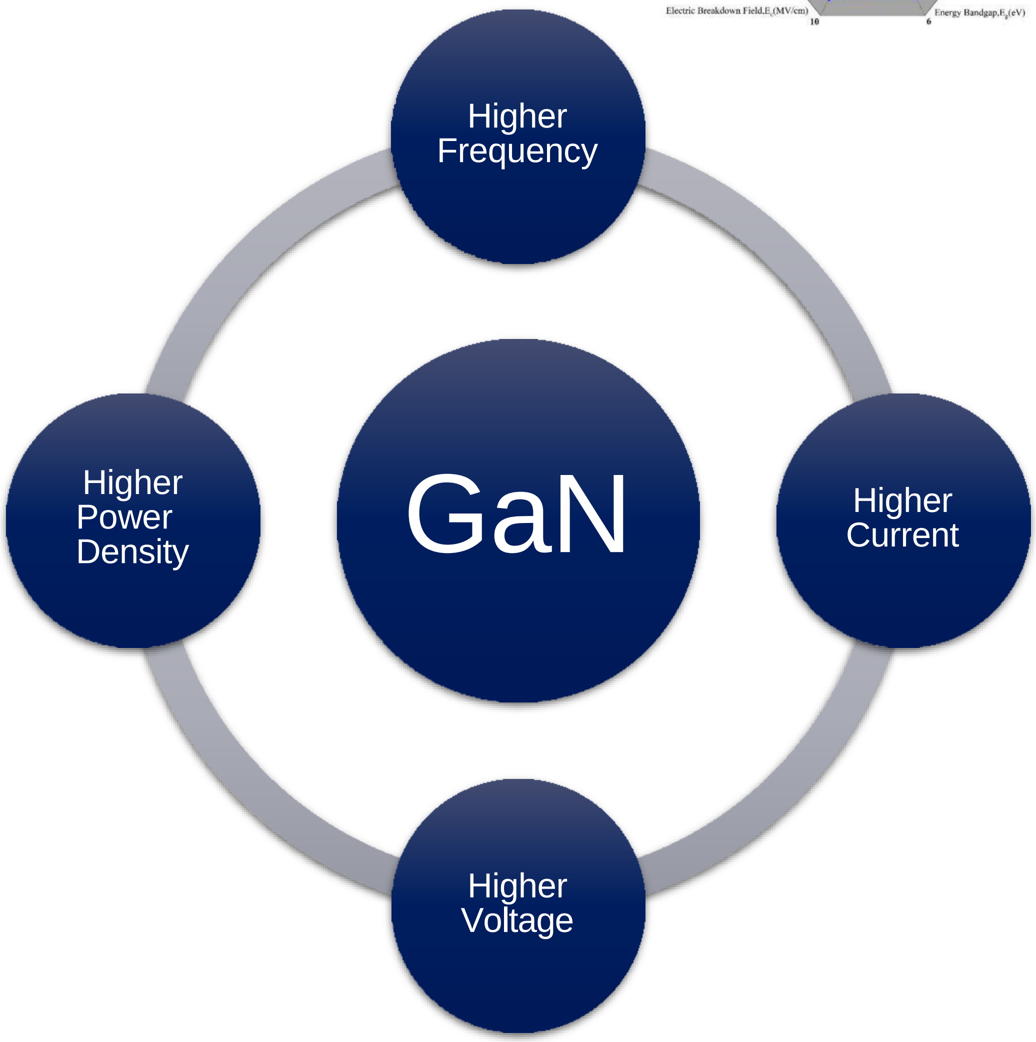
# WHY GaN?

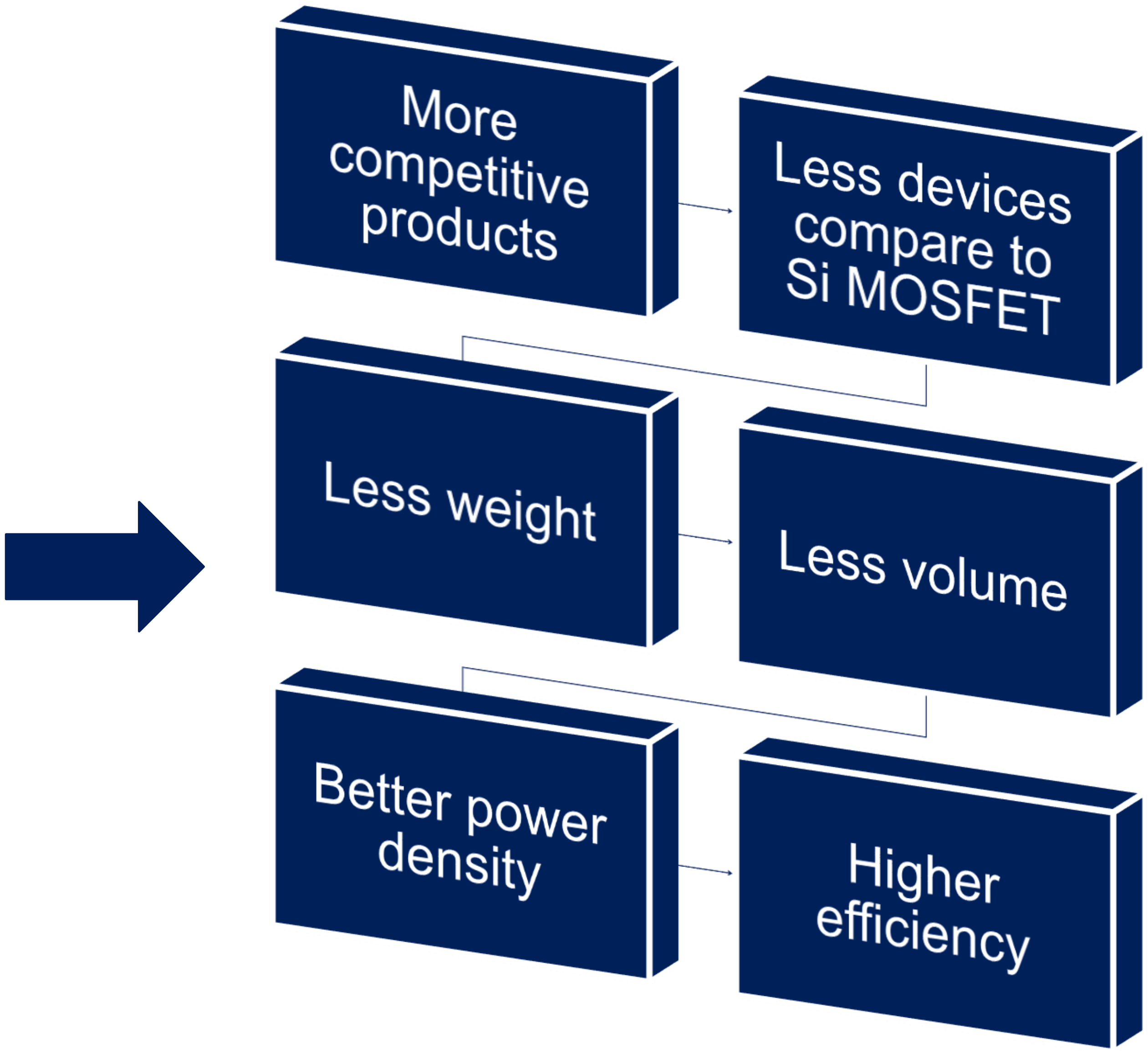



Material properties for Si, SiC, GaN & β-$Ga_2O_3$ [4]

# WHY GaN?


Mobility,μ(cm²/v·s)
2000
Saturation Velocity,vs(×10⁷cm/s)
2.5
Dielectric Constant,εr
12
Energy Bandgap,Eg(eV)
6
Electric Breakdown Field,Ec(MV/cm)
10
Thermal Conductivity,λ(W/cm·K)
6
Maximum Temperature,Tmax(°C)
1000
Si
SiC
GaN
β-Ga2O3


Higher Frequency
Higher Power Density
GaN
Higher Current
Higher Voltage


More competitive products
Less devices compare to Si MOSFET
Less weight
Less volume
Better power density
Higher efficiency

# RADIATION SEE VALIDATION

ESCC
European Space Components Coordination

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SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES

ESCC Basic Specification No. 25100

**4 PLANNING AND PROCEDURES**
Further information on test planning is given in the guidelines (Appendix A).

4.1 SAMPLE SIZE, SELECTION AND PREPARATION
For the characterisation of non-destructive events (SEU, SEFI, SET, …), a sample size of 3 pieces is recommended, 2 pieces are required as a minimum. For the characterisation of destructive events (SEGR, SEB, …), a sample size of 3 pieces shall be used as a minimum to check the pass compliance for each test condition unless specific agreement has been made with the Customer. A larger number of pieces might be used for a better statistical determination of failure events. In all cases, the selected samples shall be of identical technology, i.e. same process and same diffusion mask set.

ECSS-Q-ST-60-15C Rev.1 DIR1
10 September 2024

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

**Space product assurance**

**Radiation hardness assurance - EEE components**

f. SEE test data shall meet the following criteria to be acceptable:

Test are performed in conformance to

(a) MIL-STD-750E method 1080 for power MOSFET,

(b) ESCC 25100 for all other parts.

NOTE Useful information about SEE testing is also provided in EIA/JESD 57.

Tested parts are manufactured with technology identical to the technology of flight parts: same process and same diffusion mask.

Test conditions are worse or equivalent to the application.

**What does this mean?** If there is no necessity a Product Change Notification (PCN) affecting manufacturing process there is no need to test again

GaN technology being not fully mature yet, sampling size recommended may need to be revised case by case until it has reached a better stability



# DEVICES UNDER TEST CONDITIONS

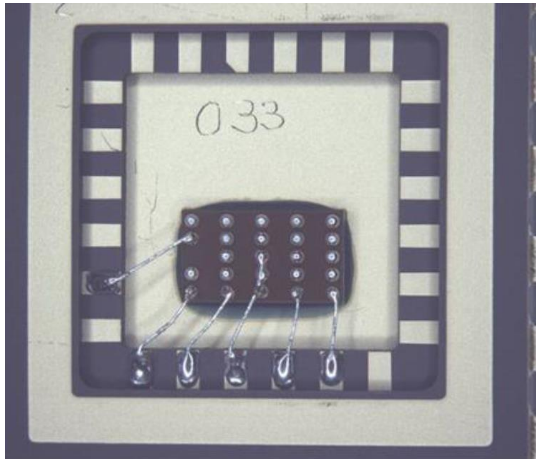



Image of how the samples were tested

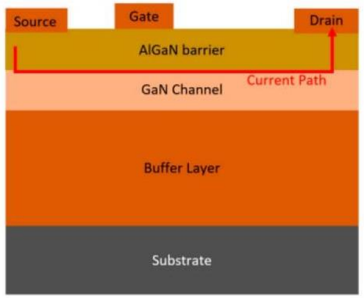
Normally-Off N-Channel devices

| Parameter | Symbol | Reference A | Reference B |
|---|---|---|---|
| Drain to source voltage | $V_{DS}$ | 200 V | 200 V |
| Drain to Source On Resistance | $R_{DS(ON)}$ | 8 mΩ | 10 mΩ |
| Drain to Source Leakage Current | $I_{DSS}$ | 0.15 mA | 0.1 mA |
| Gate Threshold Voltage | $V_{GS(th)}$ | 1.1 V | 1.4 V |
| Lots tested | - | 2 lots were tested: A-1: 7 pieces A-2: 5 pieces | 2 lots were also tested: B-1: 4 pieces B-2: 19 pieces |

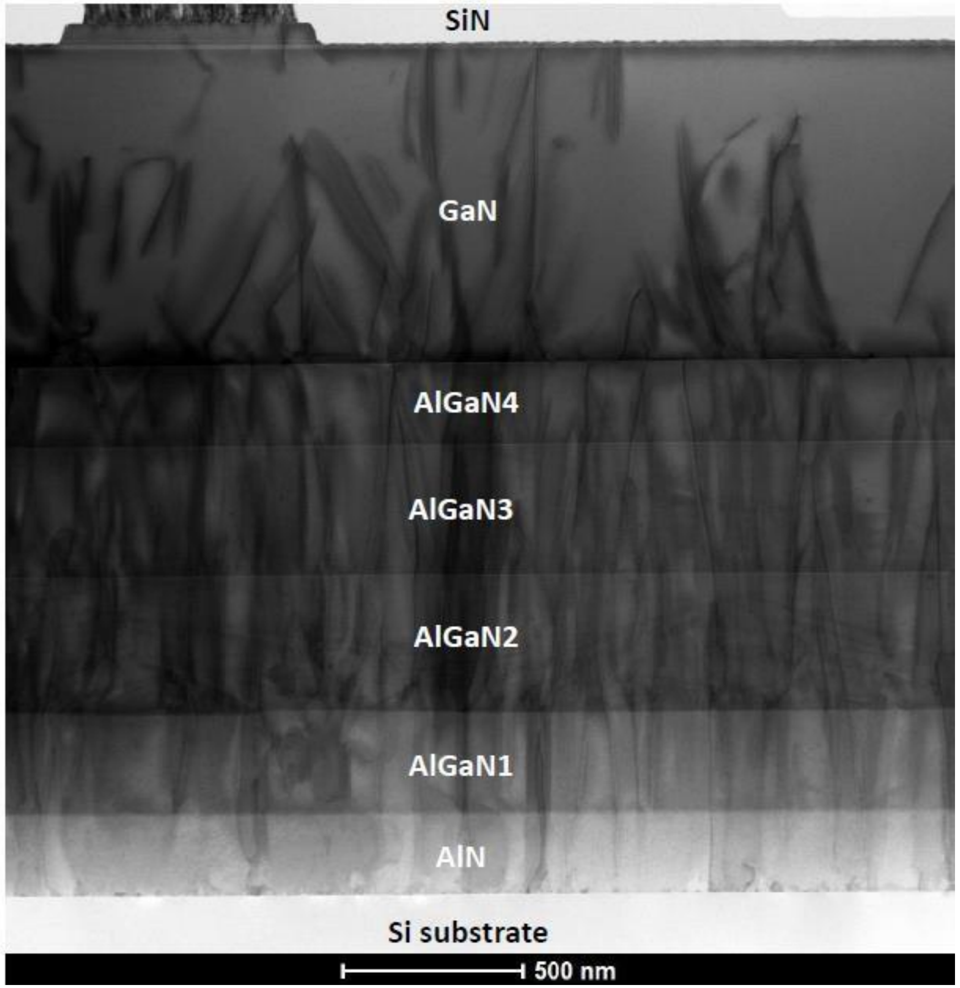
| Facility | Ion | DUT Energy [MeV] | Range [µm Si] | $LET_{Surface}$ [MeVcm²/mg] |
|---|---|---|---|---|
| UCL | $^{84}Kr^{25+}$ | 769 | 94.2 | 32.4 |
| | $^{103}Rh^{31+}$ | 957 | 87.3 | 46.1 |
| | $^{124}Xe^{35+}$ | 995 | 73.1 | 62.5 |
| RADEF | $^{126}Xe^{44+}$ | 2059 | 157 | 48.5* |

*The test was conducted in air with a 75µm Kapton foil to increase the LET to 62.5 $MeVcm^2/mg$

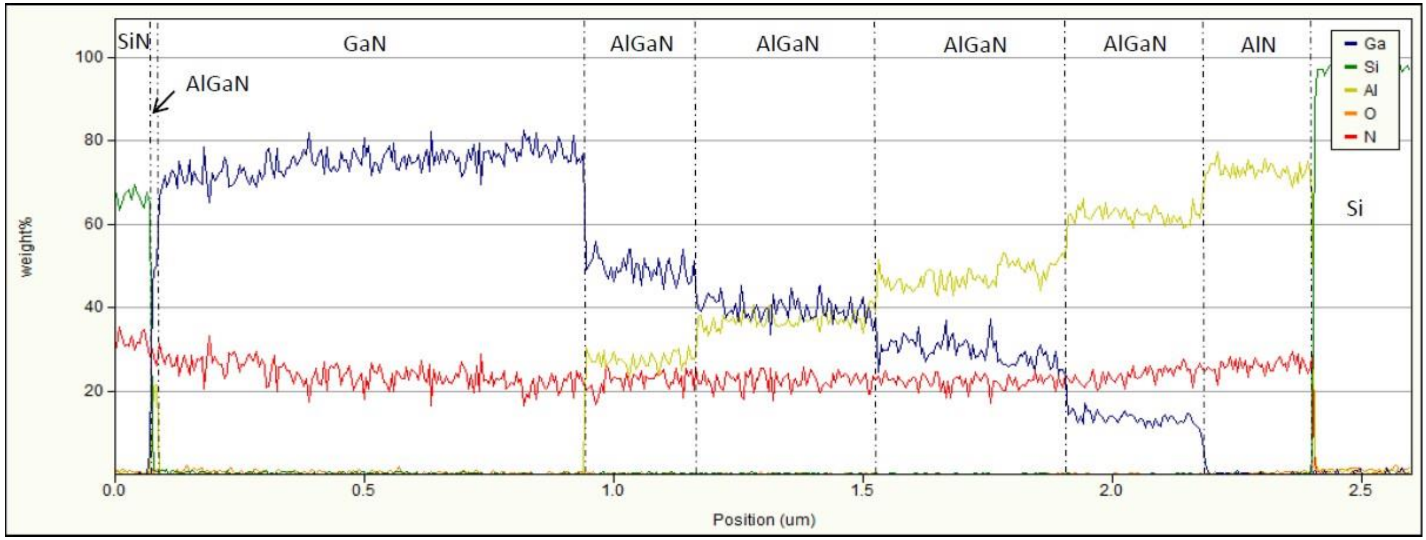
# DEVICES UNDER TEST CONDITIONS




TEM image for a sample from lot B



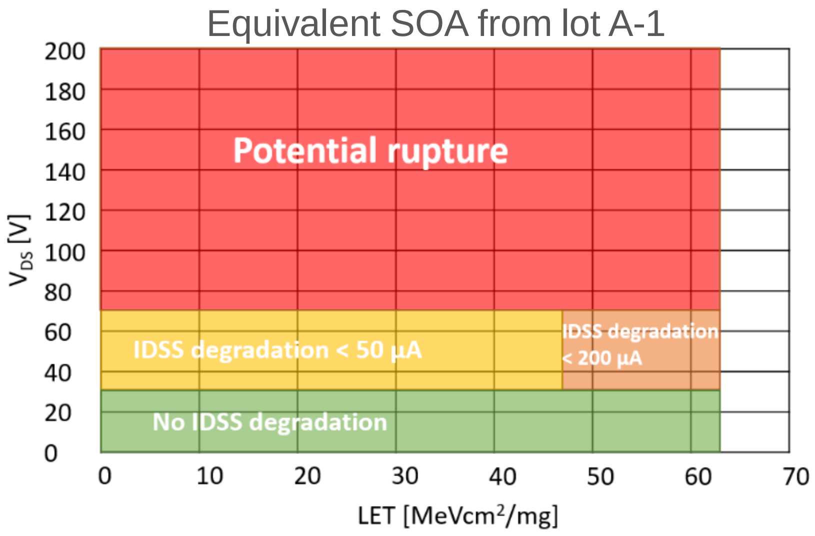

EDX pattern across the section

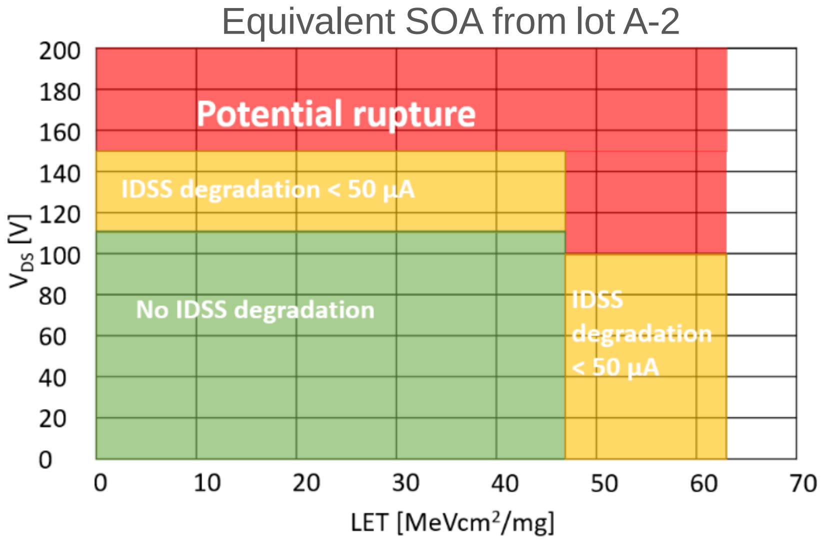




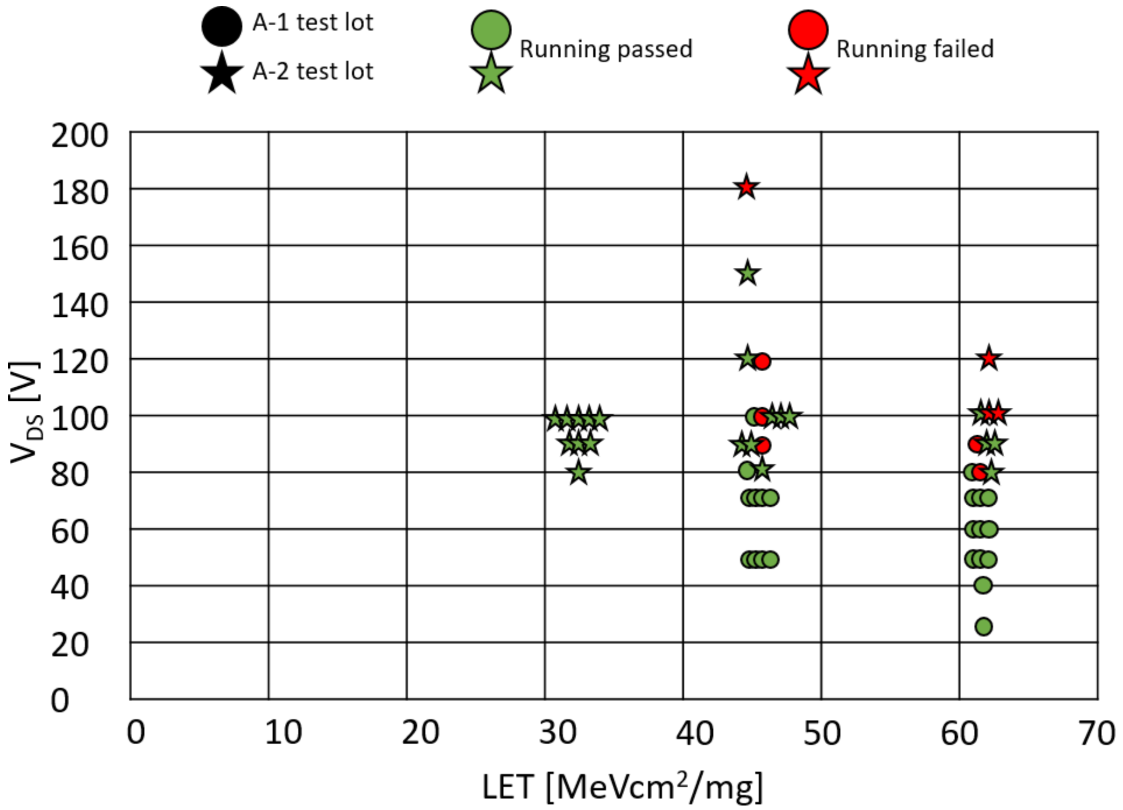

 

# RESULTS FOR REFERENCE A




Fluence = 1.1E+05 – 1.5E+06 [ions/cm²]




Runs for all tested Reference A parts at $V_{GS}$ = 0 V

# RESULTS FOR REFERENCE A

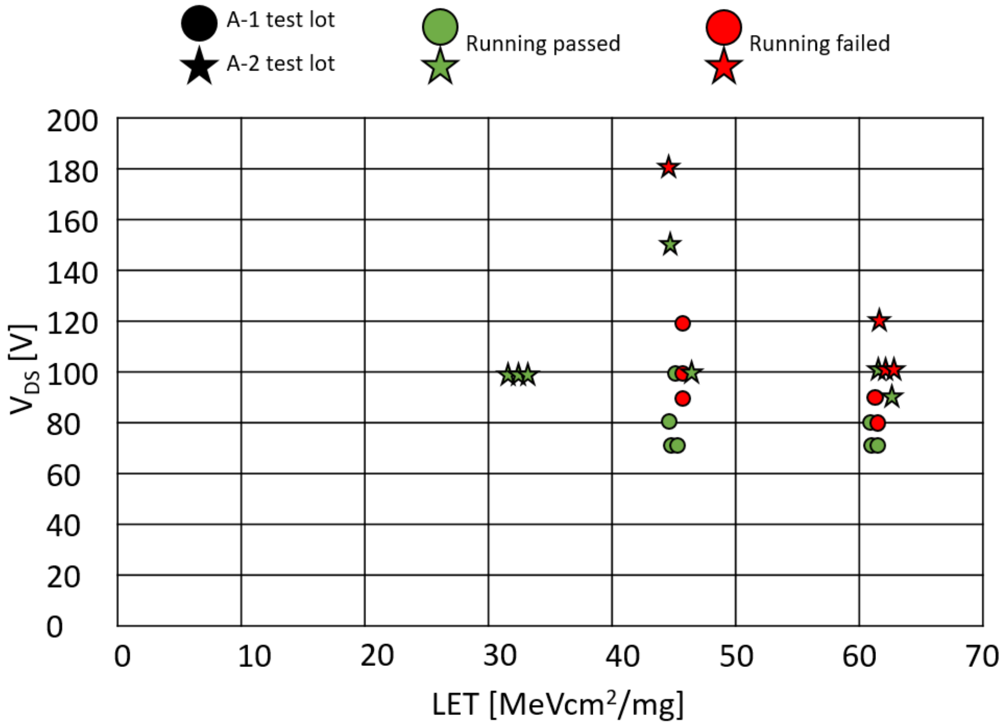
**SOA Intra-lot variability ($V_{DSmax}$):**

- A-1 lot →
  20% @ 46 MeVcm²/mg (80 – 100V)
  12.5% @ 62.5 MeVcm²/mg (70 – 80V)

- A-2 lot →
  0 % @ 46 MeVcm²/mg (180V)
  17% @ 62.5 MeVcm²/mg (100 – 120V)

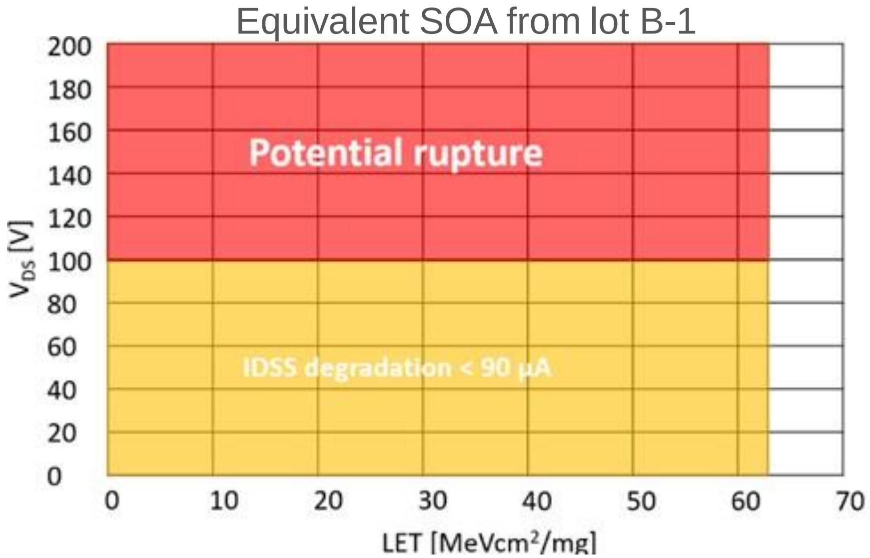
**SOA Lot-to-lot variability ($V_{DSmax}$):**

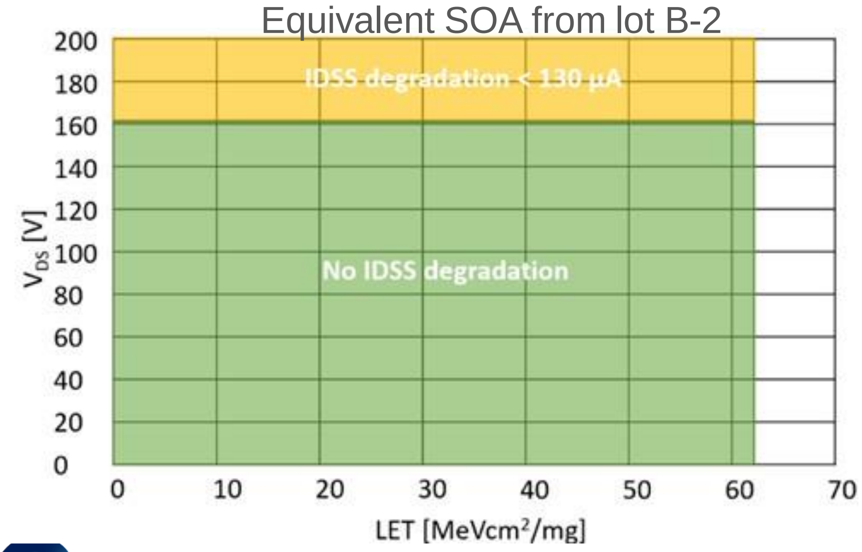
- A-1/A-2 lots →
  47% @ 46 MeVcm²/mg (80 – 150V)
  42% @ 62.5 MeVcm²/mg (70 – 120V)



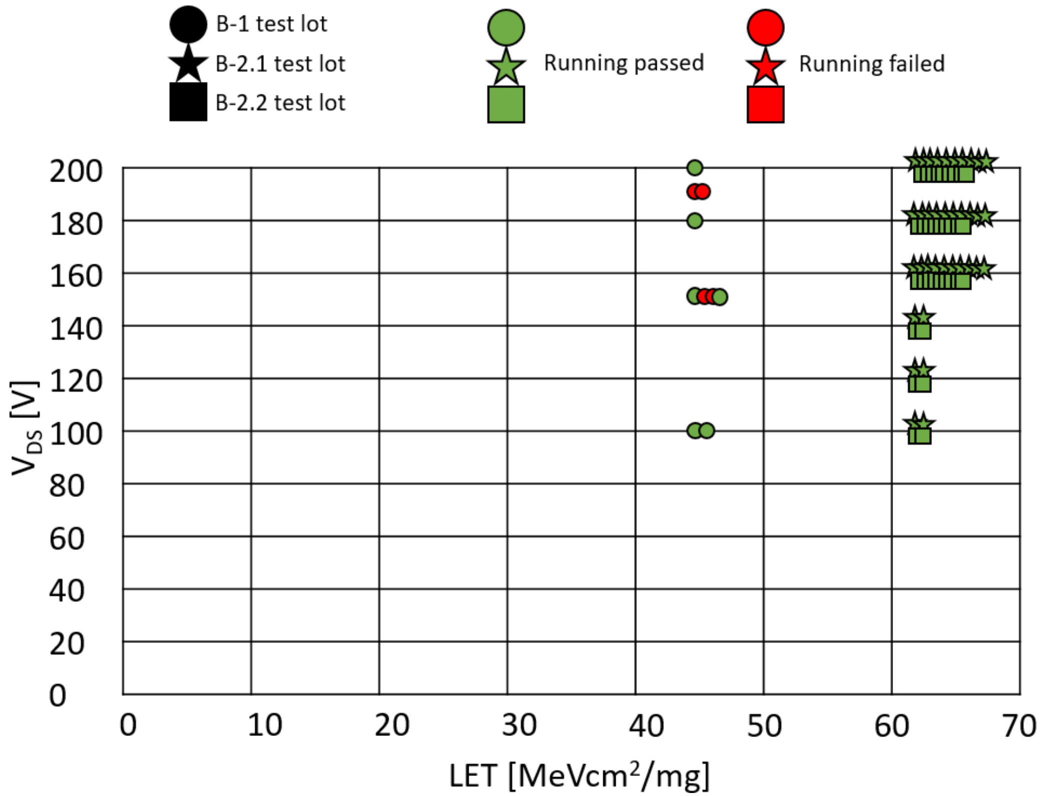

Runs for all tested Reference A parts at $V_{GS}$ = 0 V

# RESULTS FOR REFERENCE B




Fluence = 1.1E+05 – 1.5E+06 [ions/cm2]




Runs for all tested Reference B parts at $V_{GS}$ = 0 V

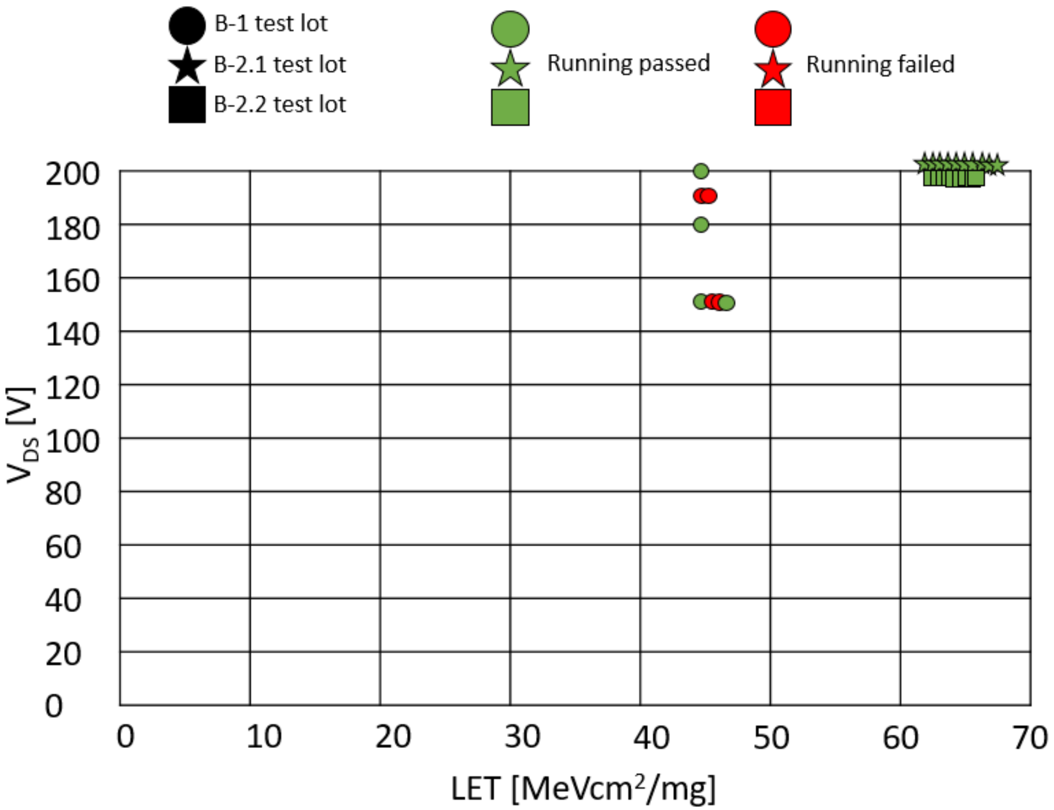
# RESULTS FOR REFERENCE B

**SOA Intra-lot variability ($V_{DSmax}$):**

- B-1 lot →
  25% @ 46 MeVcm²/mg (150 – 200V)
  No data @ 62.5 MeVcm²/mg
- B-2 lot →
  0% @ 62.5 MeVcm²/mg (240V)

**SOA Lot-to-lot variability ($V_{DSmax}$):**

- B-1/B-2 lots →
  38% @ Different energy (150 – 240V)




Runs for all tested Reference B parts at $V_{GS}$ = 0 V

# CONCLUSIONS

1. GaN properties are key to develop the power solutions demanded by the market.

2. Our SEE tests results show both lot-lot variability (up to 47%) and intra-lot-variabilty (up to 25%) in $V_{DSmax}$ which cannot be fully explained by the device traceability.

3. If GaN technology is to become baseline in industry for power solution applications, we would like to suggest further consideration to be given to the following:
   - Achieving better understanding of the built characteristics differences between “bad” and “good” lots leading to the observed variability => establish non-destructive screening methods (work in progress at Aribus Crisa).
   - Case by case adaptation if needed of existing test standards until the technology has acquired a maturity comparable to "older" technologies.

# REFERENCES

1. S.J. Pearton et al.: "***Radiation Effects in GaN-Based High Electron Mobility Transistors***" 2015.

2. Langpoklakpam, C. et al.: "***Vertical GaN MOSFET Power Devices***". Micromachines 2023, 14, 1937.

3. Pedro Javier Martínez Mecinas Thesis: "***Estudio de la fiabilidad de los dispositivos HEMT de GaN***".

4. Milligan, J. et al.: "***SiC and GaN wide bandgap device technology overview***". In Proceedings of the 2007 IEEE Radar Conference, Waltham, MA, USA, 17–20 April 2007; pp. 960–964.

5. European Space Agency – ***Space Product Assurance. Radiation Harness Assurance – EEE Components*** (ECSS-Q-ST-60-15C Rev1 – 2024).

6. European Space Agency – ***ESCC Basic Specification No. 25100*** – issue 02.

# Thank you



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