GaN Power Motivations and Challenges

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DEFENCE AND SPACE

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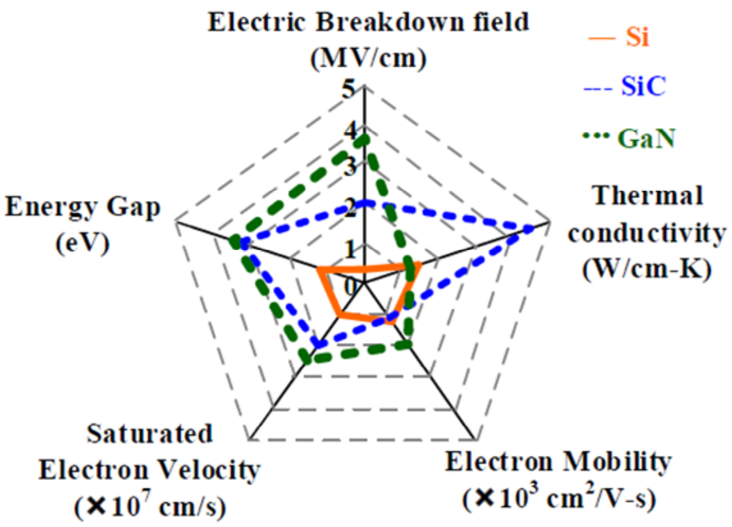
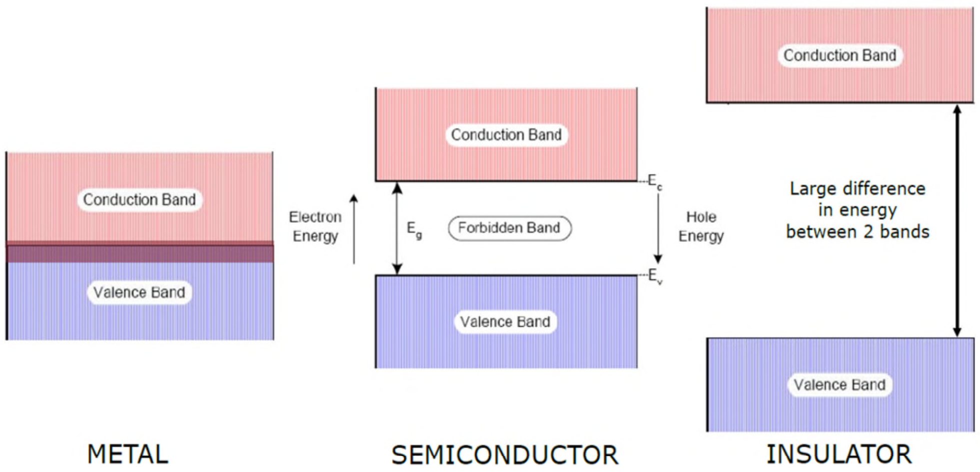
Contents

Why GaN?





Material properties ⇨ Device performance ➡ Applications

Material properties

- High electron saturation velocity ≈2.5 x10^7 cm/s
- High carrier density ≈10^{13}/cm^2
- Large bandgap
  - High breakdown field
  - High temperature operation
  - Radiation robustness
- Heterostructure design (GaN)

Device performance

- High output power density, small size, easy impedance match
- High voltage operation, simplified voltage conversion
- Operation under extreme environmental conditions

Applications

- Telecommunications
- Radars
- Novel sensors, detectors
- Power switching
- Solar cells, blocking diodes

Narrow band gap Eg<<1eV → Intermediate band gap Eg≈1eV → Wide band gap Eg>3eV

	InSb	InAs	$In_{0.53}Ga_{0.47}As$	Si	GaAs	SiC	GaN
Electron Mobility x10^3 (cm^{2}V^{-1}s^{-1})	30	16	8	0.6	4.5	0.8	1.6
Electron Velocity (10^7 cm/s)	5.0 (peak)	4.0 (peak)	2.7 (peak)	1.0 (sat.)	2.0 (sat.)	2.0 (sat.)	2.7 (sat.)
Band-gap (eV)	0.18	0.36	0.72	1.1	1.43	3.2	3.4
Breakdown field (MV/cm)	0.01	0.1	0.4	0.6	0.6	3.5	3.5
Thermal conductivity (W/cmK)	0.18	0.27	≈0.3	1.5	0.46	3.55	1.7
Heterojunctions	Yes	Yes	Yes	Yes	Yes	No	Yes

GaN-FET players (Power Conversion)

This list is not exhaustive

North America

- EPC/EPC Space (AEC)
- GaN Power
- GaN Systems (CAN) (AEC)
- Renesas
- SSDI
- Nexgen
- Vishay
- IR
- Power Integrations
- Texas Instruments (AEC)
- Transphorm (AEC)
- ...

Europe / Israel

- Teledyne-e2v (GaN Systems)
- Cambridge GaN Device
- Navitas
- Infineon
- ST (including Exagan)
- Belgan
- IMEC
- MindCET (imec)
- Nexperia (AEC)
- VisIC (ISL)
- Wise Integration
- …

Asia / Australia

- Panasonic
- Fuji / Furukawa
- Sanken
- Toyota
- Rohm
- Fujitsu / Transphorm
- Toshiba
- Skysilicon (CHN)
- IMCRC (AUS)
- Innoscience
- Cohenius
- DanXi
- GPOWER
- XINGUAN
- TSMC
- ……

Normally-off

Normally-on or Cascode

Discrete , SoC (System on Chip) and/or SiP (Systems in Package)

GaN on sapphire D-Mode

- **Co-existence of E-mode and D-mode**
- **p-GaN E-mode technique**
- **A large variety of device packaging**
- **GaN-on-Si**
- **Device voltage: push towards higher voltage (>650V) for lateral GaN. Vertical GaN**
- **Integration of gate driver and other functions with the switch (SiP or SiC)**
- **Few Manufacturer with Rad-Hard components space oriented**
- **New players from China are providing 650V products**
- **Several GaN companies are fabless and depend on TSMC (Taiwan) as foundry for their products**
- **Complexity of Supply Chain. Need of a Supply Chain with full control of Epitaxy growing and Chip Processing.**

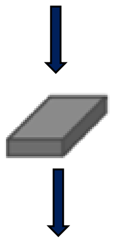
Wafer Supply → GaN Epitaxy → Chip Processing → Device Design → Device Packaging → Testing Qualification for Space Application

Derating and Package Focus

➢ DERATING RADIATIONS

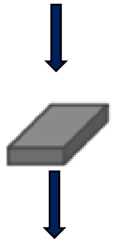
- GaN devices are **intrinsically** robust against accumulated radiation **dose**.
- However, the failures due to Single Event Effects (**SEE**) are still of high concerns for GaN device applications in space and can impact the range of the Voltage application.
- The Max Vds Voltage is really limited due to Single Event Effect, but the robustness to Heavy Ions getting better with Low Voltage Power GaN.

650V



200V-250V due to Radiation SOA

200 V

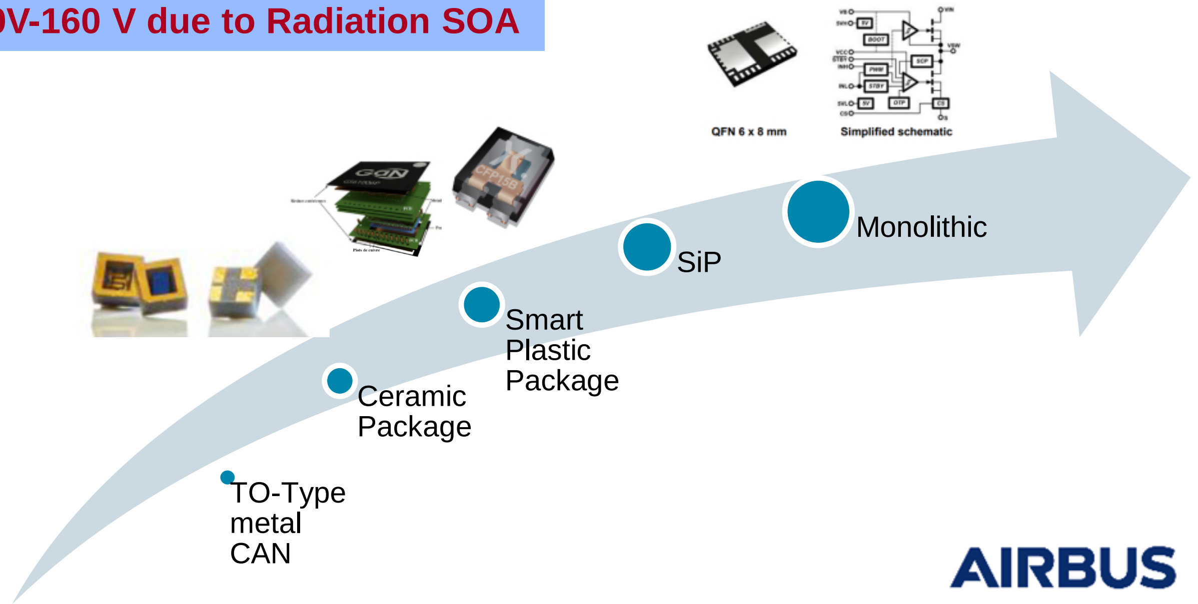


100V-160 V due to Radiation SOA

➢ PACKAGE

The selection of the assembly and package has a direct impact on the performance of the GaN device. The majors trends are:

- From Hermetic to Not Hermetic
- Smart Plastic Package (i.e. Embedded Technology, clip-bonded,….)
- From discrete to Monolithic
- SiP in Hermetic Box can be as an alternative way of packaging development.



GaN Needs and Challenges

Electrical Propulsion (> 200V)

Primary Conversion (> 100V)

Secondary Conversion (100 V < V < 50V)

Secondary Distribution (PoL) (< 50V)

Needs Electrical Performances GaN FET

- From 20V to 300V « derated»
- Up to 30A
- Rds < 2mΩ @ 25°C for Low Voltage and Rds < 25mΩ @25°C for high Voltage
- Hard and Soft Switching
- Discrete and IC (SiP and/or Monolithic)

Needs Quality GaN FET

- Robust reliability program (JEDEC Guideline on GaN and Airbus support and Automotive approach)
- Radiation program (SEE,…)
- Robustness evaluation (SOA, Vgs Max Ratings,…)
- Statistical Early « Infant Mortality » Failure characterization
- *Specially for IC, new idea's and standard for Reliability purposes*.

Needs Technological GaN FET

- Standard Package with innovative Die assembly technique and easy to assembly on the boards
- Process Homogeneity for same diffusion LOT
- Second Source availability (Form, Fit and Function equivalence)
- Rad Tolerant technology

Needs Space Standard GaN FET

- Lack of requirements for Space application for GaN Power device, <u>specially for IC device.</u>
- Part Stress with yet no derating requirements available
- WCA
- Thermal Analysis
- Specification and Testing Standardization (i.e. Vth test method,…)

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AIRBUS Qualification GaN Power – ESPC 2019 and Evolution

Airbus Amber

In 2019, AIRBUS showed during ESPC* (European Space Power Conference) the following GaN Qualification approach, which has been used in Next Space and traditional Airbus space project to qualify the use of GaN.

ESTABLISHED FRAME WORK FOR SI QUALIFICATION AND RELIABILITY → STATIC GaN FET

HARD SWITCHING, Characterization of Dynamic Rdson ….. → DYNAMIC GaN FET

Power Cell Qualification
"As we Fly" → DYNAMIC GaN FET in the Application

Airbus Power Cell "test as we fly" x Application

Jan. 2018

Hypothesis:
- No Standard
- No Mature Tech
- No Experience on GaN
- Large Margin with application (110V vs 650V)

Airbus Envelope Power Cell "test as we fly" with same Topology and Voltage Worst Case with different Project

2021

GaN use in Next Space and Traditional Space Program

July 2022

Power Cell Envelope successfully passed

Failure Mechanism Reliability and Radiation

Topology

Worst Case Voltage/Current

Hard Switching/Soft Switching

JEDEC
DHTOL**
SALT***
Manufacturer

+

TEST Vehicle (TCV) Power Cell

2023

***An overview of GaN FET Technology, Reliability, Radiation and Market for future Application**. M. Carbone et al. IEEE 2019 European Space Power Conference (ESPC)

**DHTOL= Dynamic High Temperature Life Test
***SALT=Switching Accelerated Life Test

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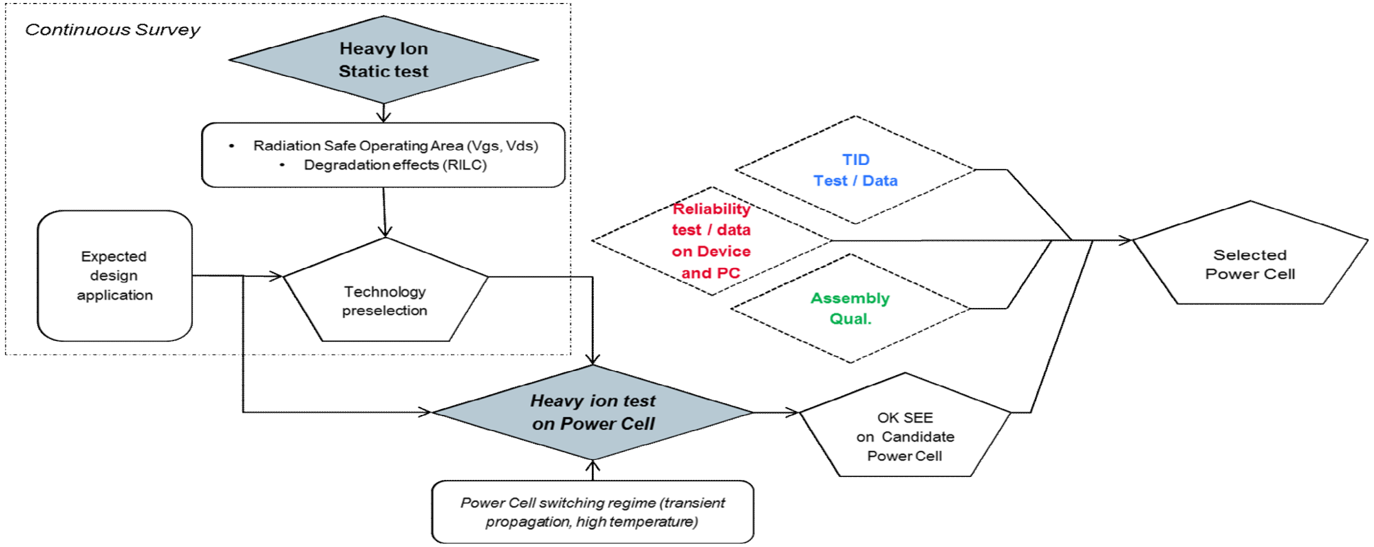
Accounting Radiation for Power GaN

- GaN material is inherently radiation hardened material, however the Power GaN FET technlogy is identified to be sensitive to Single Event Effect (refer to NASA JPL Survey, JAXA Studies).
  - High voltage commercial pGaN FETs presents failure to heavy ion already in the range of 50 % of their maximum rating.
  - Lower voltage GaN FETs showed a much better reliability due to the reduction of E-Field strength and specific pGaN Gate stack.
  - Radiation induced current leakage has been observed, risk can be assessed through degradation modelling.
  - Tolerance to short circuit of Power GaN FET is expected as limited. Then not only GaN tolerance to static irradiation, but power cell tolerance to SET propagation and FET activation is to be assessed. **Representative Power cell SEE test is considered as a key test for enabling GaN in Space.**

- Concerning Total Dose Test, being the GaN Technology sensitive to trapping effect, it needs to be well correlated with the expected mission profile (switching, static regime,…). Separate the reliability mechanisms induced by trapping from TID effects. **Risk related to TID is expected as low.**



methodology for PowerGaN selection for Space Power.

GaN RET Project Overview

GANRET **An end-user driven project**

Gallium Nitride Reliability for Transport

5.5M€ **48 months** **16 partners**

Context:

GaN HEMT are the ideal candidates for **high-power** & **high-frequency** applications

increased power density & improved efficiency

Challenge& Motivation:

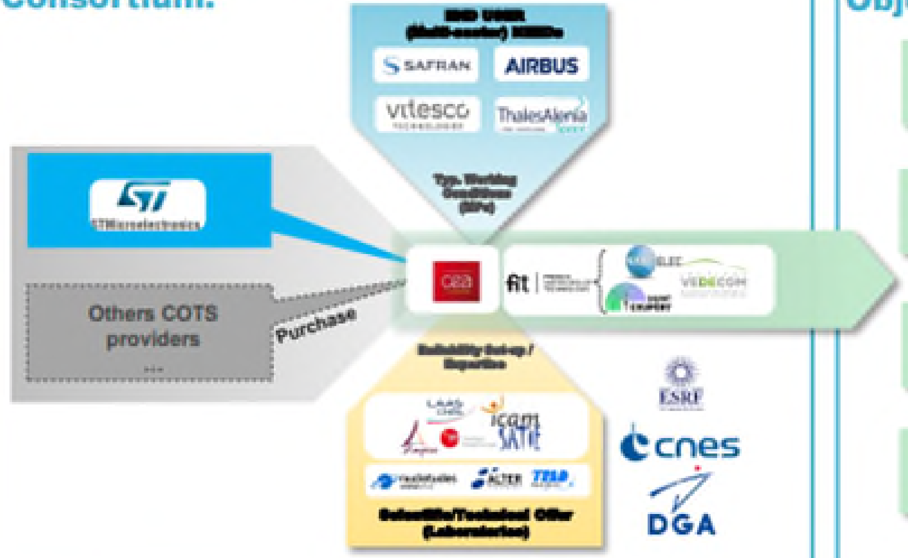
- ❑ GaN technology maturity shortcoming
- ❑ Panoply of technologies & providers
- ❑ Lack of suitable qualification standards

Reliability
- Qualification
- Robustness
- Durability

Main objective:

Enabling GaN based power electronics insertion into severe environmental constrains chain

Consortium:



Objectives Implementation:

Understanding of underlying PoF: Identification of the **critical stressors and indicators** specific to the given usage mission profile

Test-for-GaN: Definition of test **methodologies adapted to GaN** technology and support the definition of dedicated **qualification protocols**

Design-for-GaN: Definition of **margin aware design rules** and methodology for **risk assessment** and mitigation (design recommendation, safety margins, etc.)

Manufacturing-for-GaN: Support GaN ODM to **improve manufacturing** technology maturity ⇨ Technology improvement

AEC-Q
afnor
ECPE
IEC
JEDEC

WP1	WP2	WP3	WP4	WP5
DUT & Mission Profile Specification	**Electrical Characterization & Modelling**	**Reliability Investigation**	**Radiation Immunity Assessment**	**Exploitation & Capitalization**
Market analysis *DUTs selection* *Mission profile analysis*	*Measurement protocol* *Electrical characterization* *Thermal investigation*	*Static aging tests* *Dynamic aging test* *Short-circuit*	*Alternative test methodologies* *NDT methodology development* *Mutual effect reliability-radiation*	*Reliability tool for risk assessment* *Lighthouse initiatives* *Supporting standardization entities*

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Conclusion

- GaN technology has intrinsic advantages compared to silicon when used in power systems in space such as ability of higher switching frequency and lower switching losses, allowing for higher efficiency and downsizing of inductors and capacitors and thus improve the power density of power electronic systems.

- GaN devices cannot be considered as a simple “drop-in” alternative to silicon devices

- Reliability (Failure Mechanism Identification), Testing and Radiation (SEE) are the key investigation area for Power GaN FET HEMT device

- Push for a common package between manufacturers (double source & reduced mounting qualification)

- Need of a complementary European GaN supply chain for space applications (like GaN RF) . This Supply Chain should be composed of European companies covering each individual process step in the GaN device manufacturing, testing and qualification in order :

→ To avoid a “monopoly situation”
→ to maintain a “healthy” competition
→ to push for quality and performance
→ To push for cost reduction

- Make GaN as standard as Si MOSFETs and update the Space Standard to GaN technology (WCA, Part Stress, Thermal Analysis)

- Airbus is strongly interested to collaborate with Manufacturer, Agency, and Research group in order to continuously achieve the goals and needs for the use of this breakthrough technology in Space

Thank you

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