Fonctionnement collaboratif entre l'IRT St Exupéry et la plateforme PROOF

COS – PROOF 05.10.2022

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12 competences

High voltage energy
High Reliability Energy
High density energy
Metallic materials and processes
Surfaces / assemblies
Composite materials
Advanced Learning
AI for critical systems
Autonomous Connectivity & Detection
Systems Engineering
Multi Discipline Optimization
Critical Embedded Systems

4 Technological Axes

Greener Technologies
Advanced Manufacturing Technologies
Smart Technologies
Methods and tools for the development of complex systems

Electrification of (embedded) systems and functions!

- Improve products life cycle
- Enable increased electrification of systems
- Reduce products weight and volume
Technological & Methodological Levers

The big picture

- Optimized Control
  - WBG Power Module Integration
  - WBG PCB embedded
- Cooling Systems
- Magnetics and bobins
- Converter Topology
- Cosmic radiation Immunity
- Failure Risk Assessment Methodology
  - TTF vs. Mission Profile
- Failure Risk Assessment Methodology

High Integration & Efficiency

High Dependability (harsh Envir / High constrain)

Multidisciplinary Design Optimization

EMC, EMI from component to system
  - (active filter, Near field Scanning, …)

In-System-Validation
Testing and Optimizing the converter in the entire EM chain
Dependable Electronics for Embedded Systems: Projects supporting roadmap

INTEGRATION (2014 – 2018)

EPOWERDRIVE (2017 – 2021)

ROBUSTESSE (2015 – 2018)

FELINE (2017 – 2020)

SICRET (2020 – 2023)

IPCEI /KDT

SOLER (2022 – 2025)

GANRET (2022 – 2026)

DRIVER (2021 – 2023)

OCEANE (2021 – 2025)

DOUBLE & BUMP (2014 – 2018)

APSITHERM (2016 – 2020)

CASCADE (2016 – 2018)

SISIC (2021 – 2023)

PGIP ( 2019)

HYPNOTIC (2020 – 2023)

HYPNOTIC (2020 – 2023)

CVS ARCJET (2023 – 2026)

IMPERIAL (2021 – 2024)

IMPERIAL (2021 – 2024)

SOCCOL (2016 – 2019)

SOCCOL (2016 – 2019)

2018

2021

2025

Comprehensive multi-sector program

>40M € Budget since 2014

Integration
Power density increase

Reliability / Robustness (HiREL)
**OBJECTIVES**

- Develop and apply the Failure Risk Assessment Methodology (FRAME) to COTS components (DSM and WBG) in real operational environments (Mission Profile).
- Address component obsolescence from an EMC perspective through the use of digital simulations.
- Durability of electronic component assemblies in small signal applications.

### Lot 1

**Reliability of COTS (DSM and WBG)**

- PoF modeling of DSM and WBG technologies: TDDB, BTI, HCI, EM...
- Deployment of the FRAME approach.
- Reliability platform (tool): agile and easy to use.

### Lot 2

**Radiation**

- Behavior of recent semiconductor technologies with respect to cosmic and atmospheric radiations: Heavy ions, Neutron, Proton and TID.

### Lot 3

**CEM**

- Validate the non-regression of the EMC performance of an equipment to cope with the change of a component using measurement on a component / electronic board:
  - Near field emission measurement (NFSe).
  - Near field immunity measurement (NFSi).

### Lot 4

**Electronic assemblies**

- Durability of low power electronic boards: mechanical fatigue of microelectronic assemblies.
- Multi-scale modeling: from the solder joint to the equipped board.

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**ACTIA, AIRBUS, AIRBUS DS, CONTINENTAL, ELEMCA, NEXIO, LIEBHERR, SAFRAN TECH, TECHFORM, THALES AV, THALES AS, TRAD, ZODIAC AEROSPACE, LAAS-CNRS, INSA Toulouse, IMS Bordeaux, IETR-CNRS, IES-CNRS**

**6,9 M€**

**48 Mois (2017–2021)**
GaN (Power Transistor) Reliability Evaluation for Transport

Main Challenges:

- PoF not-well understood / established
- Panoply of (not mature) technologies (e/d mode)
- Design rules and test protocol for advanced (embedded) packaging

Application domain:

GaN (Low/Medium Voltage)
- Low Voltage
  - PFC / Power supply
  - Space Power Supply
  - Audio Amplifier
- Medium Voltage
  - PV inverter
  - UPS
  - EV/HEV
- High Voltage
  - Motor control
  - Ships
  - Power Grid
  - Wind energy
  - Train transportation

Application domain:

GaNRET

Project Rational:

- BUDGET: ~ 10 M€
- DURATION: 48MM
- Start Date: 2022-Q1

END USER (Multi-sector) NEEDS

DUTs

STM (EXAGAN)

Collaboration Agreement

Reliability Set up / Laboratory

END USER (Multi-sector) NEEDS

Scientific / Technical Offer (Laboratories):

i) Reliability analysis (advancing in the understanding of underlying failure mechanisms)
ii) Definition of test procedures and methodologies adapted to the specific needs of the industry and towards dedicated GaN technology qualification
iii) Establishment of mitigation solutions such as design recommendations (e.g. ESD, derating rules for safety margins, ...)

Source: Schweizer and Infineon

Source: IRT- EPOWERDRIVE Project
Gallium Nitride Reliability for Transport

**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

**Main Objective:**
Enabling GaN based power electronics insertion into severe environmental constrains

**Objectives Implementation:**

1. **Understanding of underlying PoF:** Identification of the critical stressors and indicators specific to the given usage mission profile
2. **Test-for-GaN:** Definition of test methodologies adapted to GaN technology and support the definition of dedicated qualification protocols
3. **Design-for-GaN:** Definition of margin aware design rules and methodology for risk assessment and mitigation (design recommendation, safety margins, etc.)
4. **Manufacturing-for-GaN:** Support GaN ODM to improve manufacturing technology maturity

**Consortium:**
- End User (Multi-sector) NEEDs
- Others COTS providers
- Various scientific/technical offers (Laboratories)

**Work Packages:**

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

End-user oriented project focused on

- **Test for SiC**: Definition of test procedures and methodologies adapted to user mission profiles (dedicated SiC technology qualification)

- **Design for SiC**: Establishment of mitigation solution (with respect to end-user MP) such as design recommendation (e.g., derating rules for safety margins, etc.)

**Context**

- Future electrification technologies require drastic improvements of power electronics. SiC MOSFET are key enablers

- Reliability/lifetime are mandatory for SiC adoption

- Convergence of applications/high reliability requirements

- Strong investment of industry is necessary to adapt qualification approach and design rules

**Project members and partners**

~5.3 M€ (50% Public* - 50% Private)

*ANR: French National Research Agency

36 months (May 2020 to Apr 2023)
SICRET Program: What’s NEXT!
Discussion starting on 2022-Q2

At Power Module level including other studies/tests.
- Low pressure, humidity,
- Thermal management (power cycling, temperature cycling)
- EMC emission/immunity

Enhanced by the collaboration with STM (associate Partner of the project)

Qualification Test plan Definition (Proposal)
Guidelines definition (SOA, Design rules, …)

At discrete component level

SiC RET
Silicon-Carbide Reliability Evaluation for Transport

Source: ST Microelectronics

NEXT WS on 16.11.2022
Medium Voltage Reliability Test Plan

Optimization Methodological Approach (costs-effectiveness)

Investigation phase: Main Stressor definition

- TDDB-REL
- HTGB-REL
- ALT-HTRB-REL
- HTGS-REL

Reliability phase: Aging models
- End of life estimation

- Body Diode Conduction Test
  - ITASC*
- Surge Test

*Inverter Test with Accelerate Switching Condition

Jan. 2021 → Aug. 2022

Investigation Phase

Sept 2021 → Apr. 2023

Reliability Phase (4000h)

« REL » → above usual qualification time, up to EoL or degradation to derive ageing law
Investigation Test Plan: TDDB-REL Results

Investigation on TDDB for gate oxide lifetime prediction (STM-G2)

Lifetime projection obtained with E-model (most pessimistic model)
+ Prediction Error (50%) in Red dotted lines (because we are using very few components per test condition).

Max Negative $V_{GS}$ rating (-10V)

Max Positive $V_{GS}$ rating (22V)

- Very high life expectancy (> 40K years) @ Absolute Max $V_{GS}$ rating (-10V/22V) → Robust Gate oxide
- Negative bias were performed for the first time

- What about prediction accuracy and consistency ($V_{gs}$ too large with respect to FN threshold)?
- Only 1 sample per condition - No statistic yet
- Some phenomena yet to be studied (e.g. Bump on positive bias)
**Lifetime projections of gate oxide comparison**

**STM vs Infineon Trench and vs state of the art**

- Comparison between STM and Infineon; VGS POS

- Max rating temperature:
  - STM: 200 °C
  - Infineon: 175 °C

- Slope $T_{BD}$ STM > Slope $T_{BD}$ Infineon

- Very high life expectancy @ Absolute Max VGS rating

- Results consistent with other publications
Need of reliability insight
at semiconductor (die) level

How to discriminate between reversible (recovery) and not reversible phenomena (aging)!!
Vth Characterization

VTH protocol definition

\[ V_{th} \text{ measurement } @ \quad I_d = 1 \text{ mA} \]

Unipolar

JeDEC

\[ V_{GS} \]

\[ V_{GS(+)}, \quad 1 \text{ ms} < t_+ < 100 \text{ ms} \]

\[ V_{th}, \quad t_{th} < 10 \text{ ms} \]

\[ t_{float} < 10 \text{ ms} \]

Bipolar

STM / ALTER

\[ V_{GS} \]

\[ V_{GS(+)}, \quad V_{GS(-)} \]

Academic Labs

\[ V_{GS} \]

\[ V_{GS(+)}, \quad V_{GS(-)} \]

SiC RET setup

Preconditioning

\[ V_{DS} = 0 \text{ V} \]

\[ I_d(V_{GS}), \quad V_{DS} = V_{GS} \]

Related to B1505A

Industrial Setup

Preconditioning

\[ I_d(V_{GS}) \]

SiC RET setup

Preconditioning

\[ V_{DS} = 0 \text{ V} \]

\[ I_d(V_{GS}), \quad V_{DS} = V_{GS} \]

Related to B1505A
Influence of pre-conditioning on Vth measurement and time for read-out

- Influence of \( t_{\text{float}} \)
  - Delay impact on the Vth value

- Influence of positive / negative stress
  - Pre-conditioning robustness against device “normal operation history”

<table>
<thead>
<tr>
<th>Pre-conditioning Method with ( t_{\text{float}}=0 )</th>
<th>( \Delta V_{\text{th-pos}} ) Positive Stress of 20s</th>
<th>( \Delta V_{\text{th-neg}} ) Negative Stress of 20s</th>
<th>( V_{\text{th}} ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive only</td>
<td>77 mV</td>
<td>144 mV</td>
<td>3.19</td>
</tr>
<tr>
<td>Negative + Positive</td>
<td>1 mV</td>
<td>14 mV</td>
<td>3.15</td>
</tr>
</tbody>
</table>
Vth Characterization

Example of stable Vth measurement

Without preconditioning

With SiCRET/JEP184 preconditioning

- Very stable and robust measurement of Vth (main aging indicator)
- True monitoring of Vth degradation
- SiCRET Vth method deployable on ALL environment (Research / Industry)

Random behaviors in the case of Vth measurements without preconditioning
Medium Voltage Reliability Test Plan
Optimization Methodological Approach (costs-effectiveness)

Investigation phase: Main Stressor definition

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- HTGB-REL
- ALT-HTRB-REL
- HTGS-REL

Reliability phase: Aging models
End of life estimation

- HTGB-REL
- ALT-HTRB-REL
- HTGS-REL

Investigation Phase
Jan. 2021
August 2022

Reliability Phase (4000h)
Sept 2021
Ap. 2023

Body Diode Conduction Test

ITASC*
Surge Test

*Inverter Test with Accelerate Switching Condition

« REL » → above usual qualification time, up to EoL or degradation to derive ageing law
HTRB : Vth (1mA) drift results - ST Gen 2
Comparison between Investigation / Reliability

Investigation phase Results

- No significant drift on any parameter
- 2 failures analyzed.
- No conclusion on these failures

Reliability phase Results @Vds = 1200V

- Vth drift < 8%
- Vth variation is mainly due to negative Vgs
- Very Robust to HTRB

- No Ageing law regarding static Vds voltage
HTGS investigation phase One Week
Same DoE for each Manufacturer (excepted Vgs values adapted per datasheet)

Glossary (from datasheet):
- Vgs,on: Recommended turn-on gate voltage
- Vgs,off: Recommended turn-off gate voltage
- VgMax: Max positive transient voltage
- VgMin: Min negative transient voltage
- VgsAv: Average value between VgsMin and Vgs,OFF

<table>
<thead>
<tr>
<th>HTGS DoE</th>
<th>Gate voltage</th>
<th>Temperature</th>
<th>Frequency</th>
<th>Duty cycle</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td>Vgs,off / Vgs,on</td>
<td>25°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 2</td>
<td>VgsMin / Vgs,on</td>
<td>25°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 3</td>
<td>VgsMin / VgsMax</td>
<td>25°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 4</td>
<td>Vgs,off / Vgs,on</td>
<td>25°C</td>
<td>500 kHz</td>
<td>80% (*)</td>
<td>3</td>
</tr>
<tr>
<td>Condition 5</td>
<td>VgsMin / Vgs,on</td>
<td>25°C</td>
<td>500 kHz</td>
<td>80% (*)</td>
<td>3</td>
</tr>
<tr>
<td>Condition 6</td>
<td>Vgs,off / Vgs,on</td>
<td>125°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 7</td>
<td>VgsMin / VgsMax</td>
<td>125°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 8</td>
<td>Vgs,off / Vgs,on</td>
<td>175°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 9</td>
<td>VgsMin / Vgs,on</td>
<td>175°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 10</td>
<td>VgsMin / VgsMax</td>
<td>175°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 11</td>
<td>Vgs,off / VgsMax</td>
<td>175°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
<tr>
<td>Condition 12</td>
<td>VgsAv / Vgs,on</td>
<td>175°C</td>
<td>500 kHz</td>
<td>20%</td>
<td>3</td>
</tr>
</tbody>
</table>

Note (*) : DC = 80% means 80% ON, 20% OFF
HTGS investigation phase One Week

Vth (1mA) drift evolution

DUT A – Trench

DUT B - Planar

DUT C - Trench

Main stressors:
VgsMin, VgsMax

Room temp, VgsMin

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STM Gen 2 – Investigation and Reliability Conclusions

HTRB

No significant drift with Drain Voltage
Vth variation is due to VGS (-10V)
→ very robust to HTRB
→ next studies : DRB “Dynamic Reverse Bias”

HTGB

The main stressors causing $V_{th}$ and $R_{DSon}$ drifts are related to:
• Temperature (200 °C).
• Gate voltages (specially if out of spec).
• $V_{th}$ drift less than 10% after 10 years with an Automotive MP (Inverter)

HTGS

On ST Gen 2, main stressors causing $V_{th}$ drift are:
• Temperature, VgsMin (and VgsMax?), commutation
  Note: Number of cycles during application operating life is in the range between $10^{12}$ and $10^{13}$

In order to know the main stressors governing the other DUTs HTGS
We decided to investigate a one week HTGS:
- Maximum available test bench frequency (500 KHz)
- Maximum and recommended Vgs values per datasheet
- Temperature influence (up to maximum rating value)

• $\Delta V_{th,HTGB}$ (static stress) < $\Delta V_{th,HTGS}$ (dynamic stress)
→ Dynamic stress is worse than the static one

Next step : find aging laws for HTGS
Synergy between collaborative Project
Toward dependable - “Trustfull” - WBG based power electronics

Main key elements for success:

- Converge on common needs across SC: converge on critical usage profile parameters (e.g. DT, dV/dt, …) - relevant for degradation

- Leveraging on existing knowledge: Sharing information and best practice on test-for-reliability / design-for-reliability (see AEQ324)

- Tackling functional safety for given SC case study: identify and focusing efforts on critical path on end-to-end value chain (e.g. impact of cosmic radiation or short circuit event on function availability
Lighthouse activities
Connecting with Specialized Networking

In order to engage and establish a high level scientific and technical discussion with the most pertinent stakeholders, this task will be organized in three main types of activities:

- To organize focused workshops with industrial and/or scientific entities.
- Identify and stimulate the discussion and exchange with specialized professional networks such as the European Center for Power Electronics (ECPE) in Europe or the Center for Power Electronic Systems (CPES) in USA or their counterparts in other regions.
- Exchange and support international normalization bodies currently dealing with standardization of emerging WBG technologies, such as JEDEC, AEC, AFNOR, IEC…
Conclusions and Perspectives

- PROOF is an important part of the Regional / National R&D asset and roadmap (toward electrification)
- IRT-SE consider PROOF as an essential partner to reach critical mass in WBG reliability projects

- Engage a discussion on evaluate how a more long term collaboration can be done (after PROOF PRRI)

- PROOF Scientific support (expertise and equipment) instrumental in running projects (e.g. SICRET, GANRET, …)

- Much more is ongoing and has to come yet:
  - Aging degradation monitoring by LFN (!?)
  - Dynamic behavior robustness (e.g. DRB, DBV, …) by ESD techniques (!?)
  - Interconnection degradation monitoring by RF detection (!?)
  - Device junction temperature for thermal monitoring and management (NRTW Rouen March 2023)
  - Use of NFS techniques to enhance EMC/I design (from device to board and back)
  - …
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