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Focus sur les activités fiabilité et Grand Gap

Présentation des projets en lien avec PROOF et perspectives pour une réflexion de structuration de l'écosystème électronique de puissance
dans la région et en France

COS – PROOF
04.02.2021 @ LAAS-CNRS

Fabio.Coccetti@irt-saintexupery.com

Responsible of the "High Reliability" Center of Competence

OUTLOOK

- Introduction: Context and Objective
- Overview of WBG activities for Power Electronics
- Focus SICRET:
  - From PoF to better test, better Design, (and better manufacturing)
  - Identification and deployment of the R&T program (beyond Q101, JEDEC)
  - Focus on collaboration with LAAS

- Conclusion and Perspectives

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IRT-Saint Exupery Model

*Le Programme d'investissements d'avenir

Catalyse → *Accélération* → *Transfert*

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High Reliability Center of Competence: Overview

Bridging (COTS[1] based on) emerging technologies to harsh environment operation

Reliability based on PoF analysis
(from component/cell to board/stack level)

- Comprehensive Risk (Lifetime & CFR) assessment methodology (FRAME)

Natural Radiation immunity

- Radiation induced failure mechanisms analysis and understanding

Electromagnetic Compatibility (EMC) from NFS to System

- Obsolescence management
- Fast Board prototyping and tool development for optimization / verification

(1) **Semiconductors** components (Deep Sub Micron (FDSOI, FinFET, 3D), WBG based transistor (GaN and SiC)…) and **Electrochemical** for energy sources/storage (Fuel cell, Li-X batteries, Supercapacitors); **Assembly and packaging solution** (High Power, High Density, High Frequency) SoC or SiP

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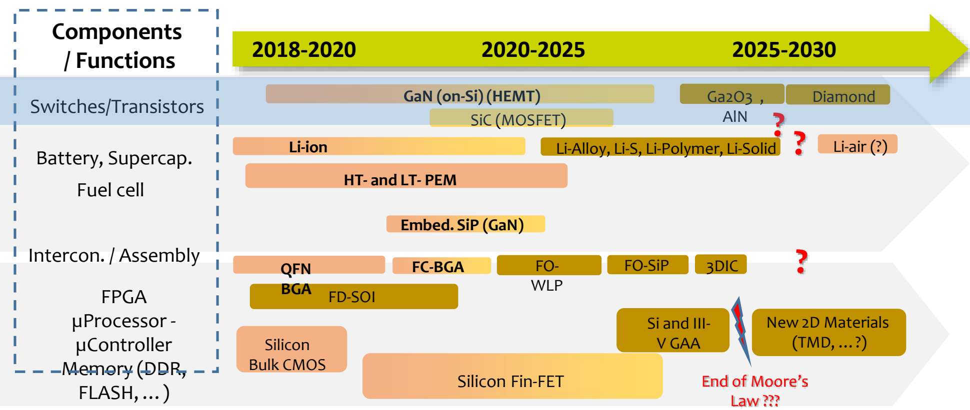
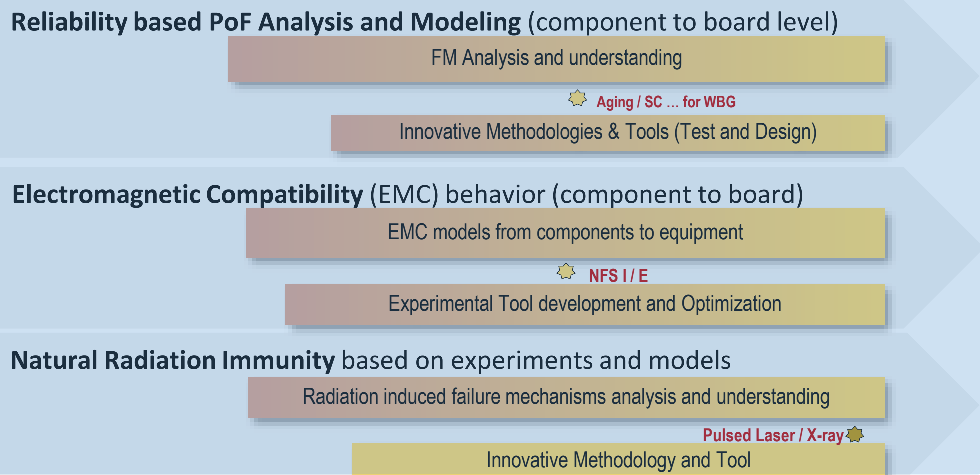
High Reliability Center of Competence: Roadmap





Objectives

Predictive / Diagnostic Reliability

Reliability (CFR / EOL) / Obsolescence Management

Fast / Virtual Prototyping (DfR, EMC compliance, Technology Eval.)

Certification Support

- **Done**
- **Planned**
- **Opportunities**

Platforms

? → Breakthrough needed to enable actual disruptive evolution (high risk / fundamental research)

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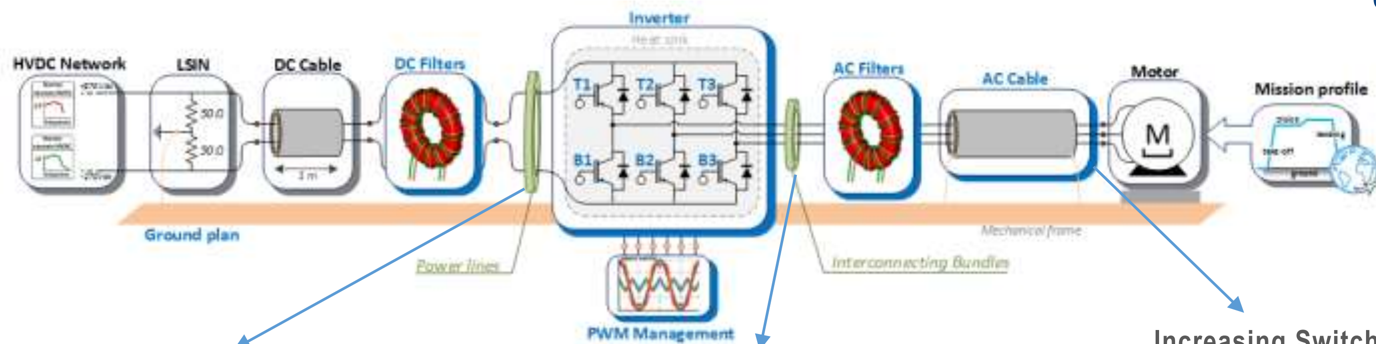
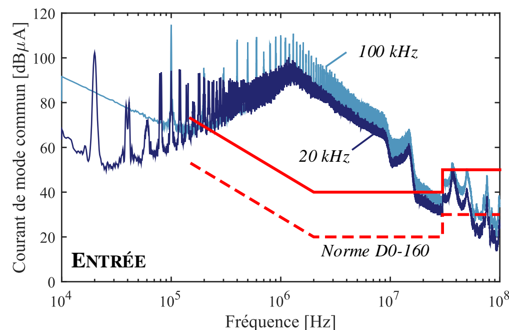
Power Drive Systems

Use of SiC and GaN

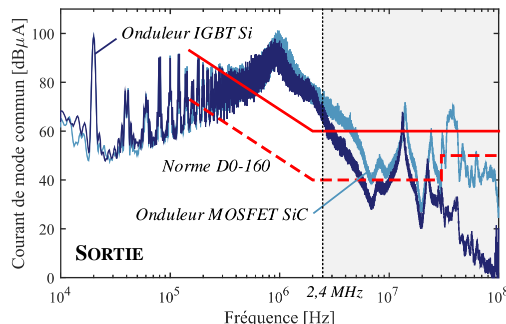


Increasing Switching Frequency



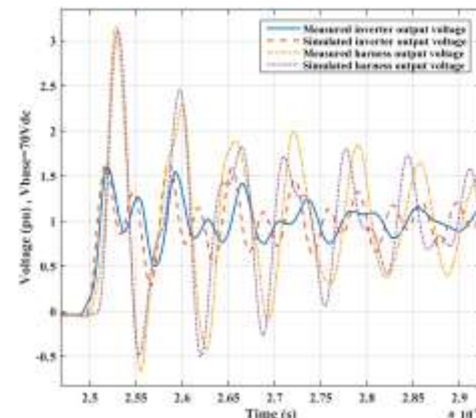
- High CM Current
- Heavy/bulky CM Filters

Increasing Switching Speed



- High CM Currents
- Heavy/bulky CM Filters

Increasing Switching Speed



- High overvoltage on motors
- Heavy/bulky DM Filters

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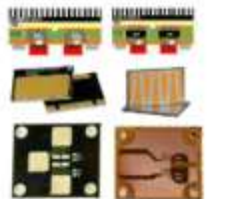
Project WBG: Overview

Multidisciplinary design optimization of electrical system

Control card & algorithm, optimized PWM, active gate driver

Cooling system optimization

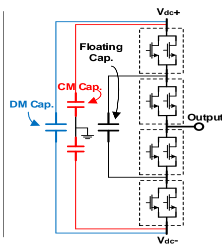

GaN PCB embedded

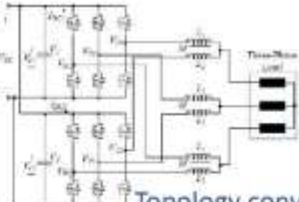
Innovative SiC power module

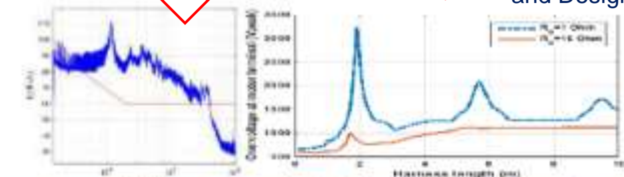
High Efficiencey & Integrated SiC & GaN Power Converters*

Component, power module & magnetics loss characterization

RF Modeling and Design



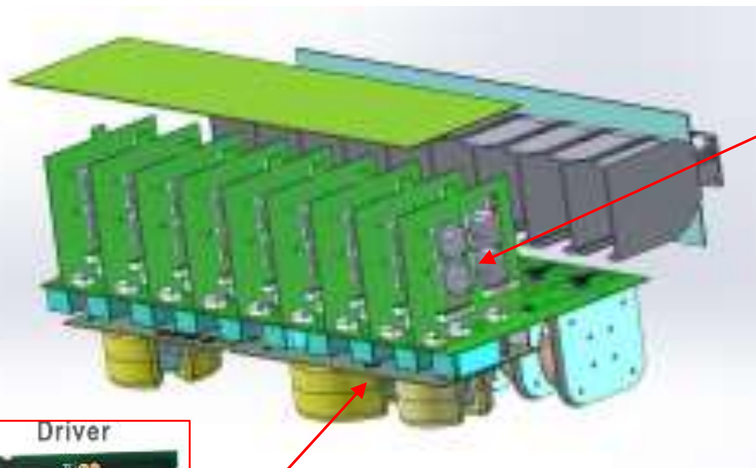

Topology converter

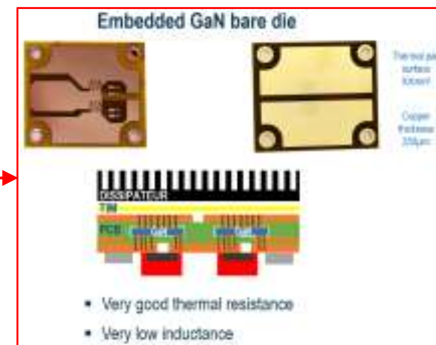

EMI, overvoltage & partial discharge impact evaluation

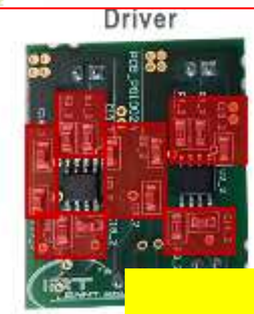
* Example: Multiple-Stage Flying-Cap Three phases 70KW 540V GaN (144 series & parallel) PCB Embedded Inverter (with reduced CEM passive integration) → IRT-Projects: ePowerdrive

Integration in Complex Systems

Multiple-Stage Flying-Cap Three phases 70KW 540V GaN (**144 series & parallel**)







- How to take into account the **drift** of **key parameter e.g. Vth**
- How to discriminate between **die and higher complex integration level failures**

fit FRENCH INSTITUTES OF TECHNOLOGY

OUTLOOK

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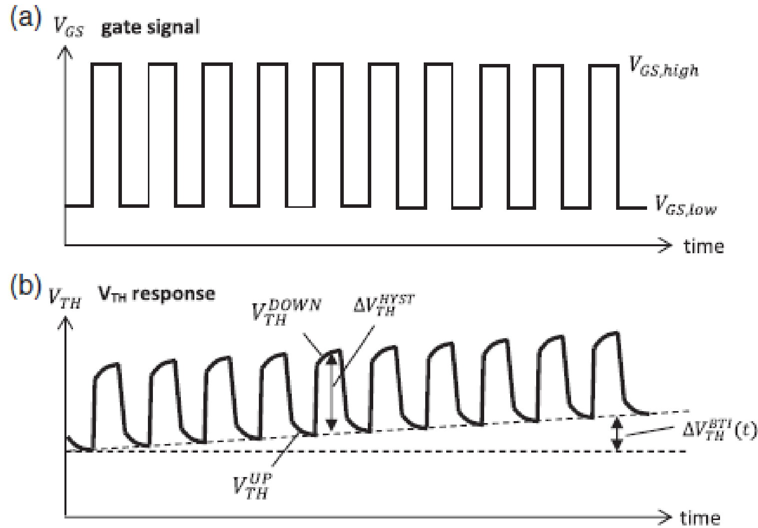
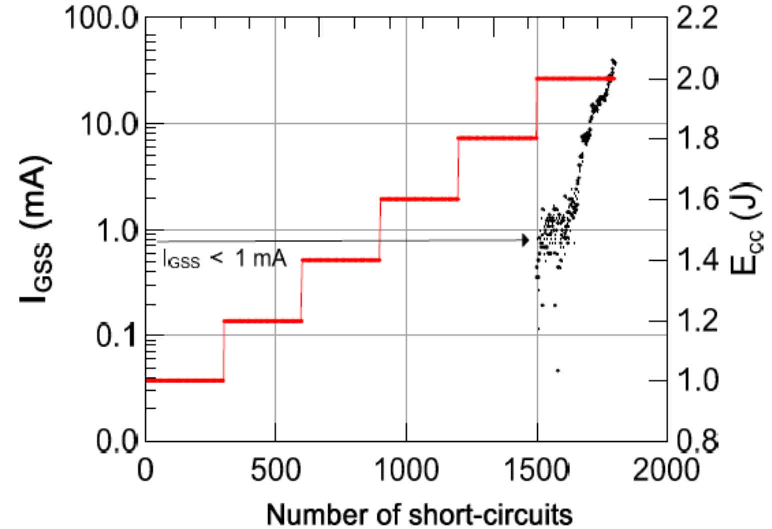
Need of reliability insight
at semiconductor (die) level



T. Aichinger, et al., Microelectronics Reliability 80 (2018) 68-78.

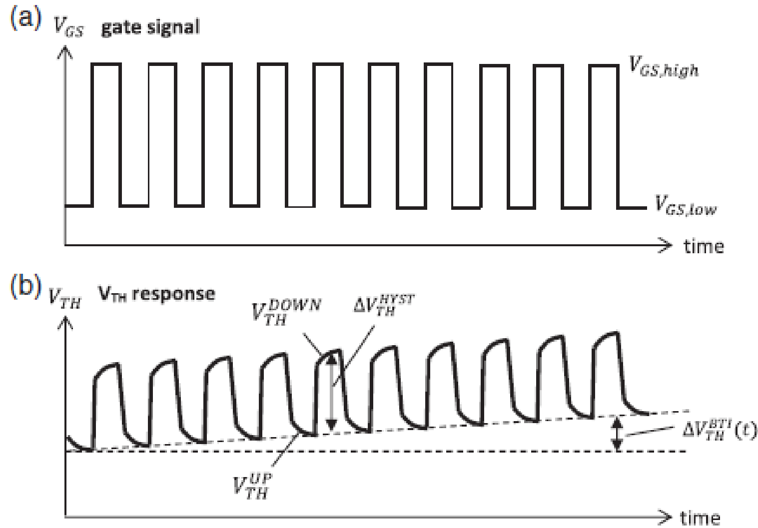


Thèse doctorat. 14/12/2019. Quentin Molin

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

Lack of SC induced aging indicator !!

Need of reliability insight
at semiconductor (die) level

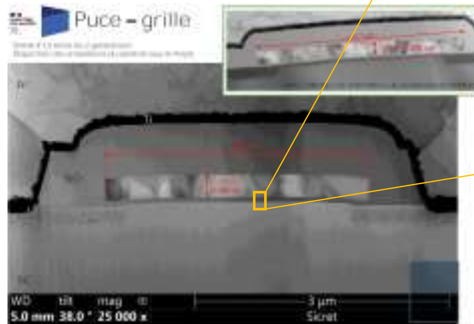


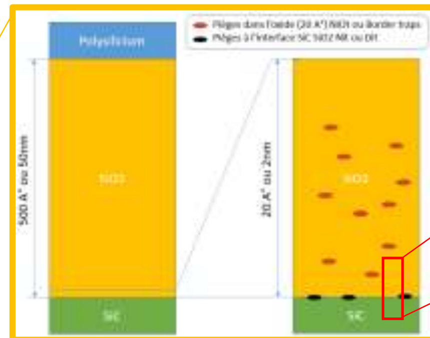
T. Aichinger, et al., Microelectronics Reliability 80 (2018) 68-78.

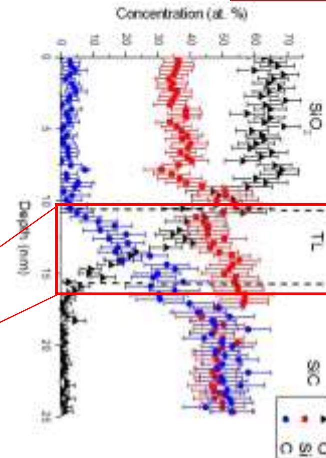
How to discriminate between reversible (recovery) and not reversible phenomena (aging) !!

Need of reliability insight

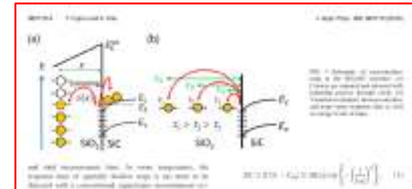
GATE OXIDE RELATED DRIFT: Causes indentification → Focus on the transition layer SiO_2/SIC







Source: Europen project (MobiSiC) on Nit improvement by passivation process (N2O, NO)



Source: KAKENHI Grant No. 15H03969 (Japan)

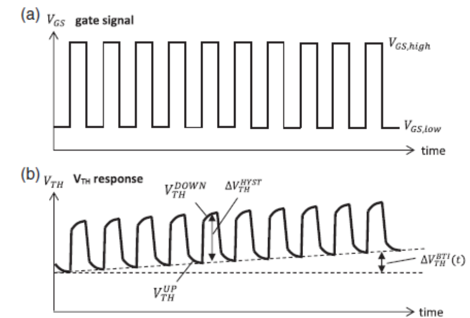
Dielectric trap relaxation) →Slow (far from SiO2) to Fast (close to SiO2)

Background: Existing Patents on gate oxide growth (1/2)

Patent Number: 5,506,421
Date of Patent: Apr. 9, 1996

Patent No.: US 6,246,076 B1
Date of Patent: Jun. 12, 2001

WO 02/29900 A2 2002



Source: T. Aichinger, et al., Microelectronics Reliability 80 (2018) 68-78.

The mechanism of defect creation and passivation at the SiC/SiO2 interface

Peter De´ak1, **Jan M Knaup**1, **Tam´as Hornos**2, **Christoph Thill**1, **Adam Gali**2 **and Thomas Frauenheim**1

1 Bremen 28334, Germany
2 Budapest H-1521, Hungary

SiCRET

Influence of pre-conditioning on Vth measurement

- Currently available SiC MosFET devices present Vth instability.
- Without precaution, the inherent and “normal” Vth instability could blur Vth parameter drift related to device aging.

➔ **A robust Vth indicator is mandatory for reliability studies.**

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D. Tremouilles

D. Hachem (PD-IRT)

- We have optimized a Vth measurement technique that ensures:
  - independent of previous device normal-operation-history
  - almost perfectly reproducible Vth value, that is based on:
    - device preconditioning-sequence
    - perfect measurements timing-control.

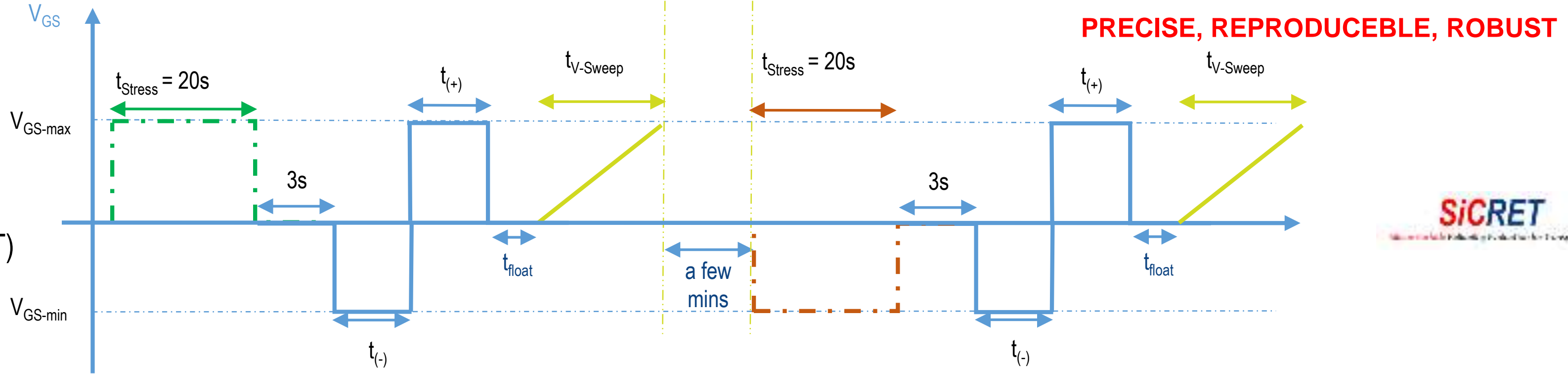
- While standard measurement technique could lead to several hundred of mV Vth instability, depending on previous device operating-conditions, our technique reduces this variation to a few mV range.

Influence of pre-conditioning on Vth measurement

PRECISE, REPRODUCEBLE, ROBUST

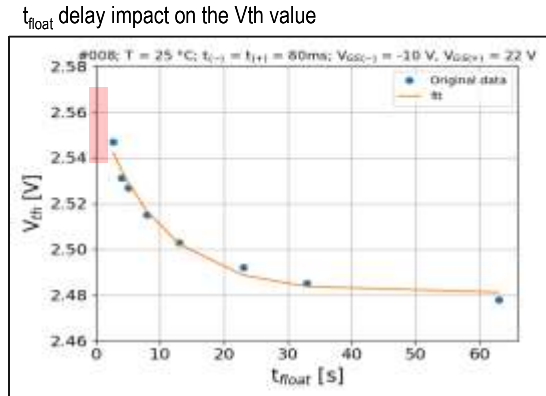
D. Tremouilles

D. Hachem (PD-IRT)



➢ Influence of Tfloat

t_{float} delay impact on the Vth value



➢ Influence of positive / negative stress

Pre-conditioning robustness against device “normal operation history”

Pre-conditionning Method with tfloat=0	$\Delta V_{th\text{-}pos}$ Positive Stress of 20s	$\Delta V_{th\text{-}neg}$ Negative Stress of 20s	V_{th} (V)
Positive only	77 mv	144 mV	3.19
Negative + Positive	1 mV	14 mV	3.15

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Influence of pre-conditioning on Vth measurement

➢ Open questions

- What is the real Vth behavior during application use case : with switching, with off time,… ?
  What is permanent drift ?
  How hysteresis is evolving during use case ?
- What is impact of Vth variations on conduction (RDSon/leakage) and switching losses ?
- How this phenomenon affects behavior of components in parallel or in series?
  Is Vth the proper parameter for selection of components used in parallel?

D. Tremouilles

D. Hachem (PD-IRT)

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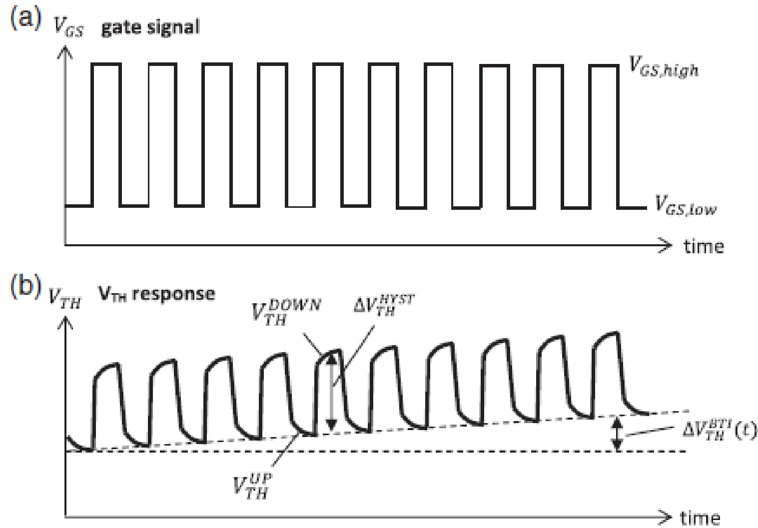
Need of reliability insight



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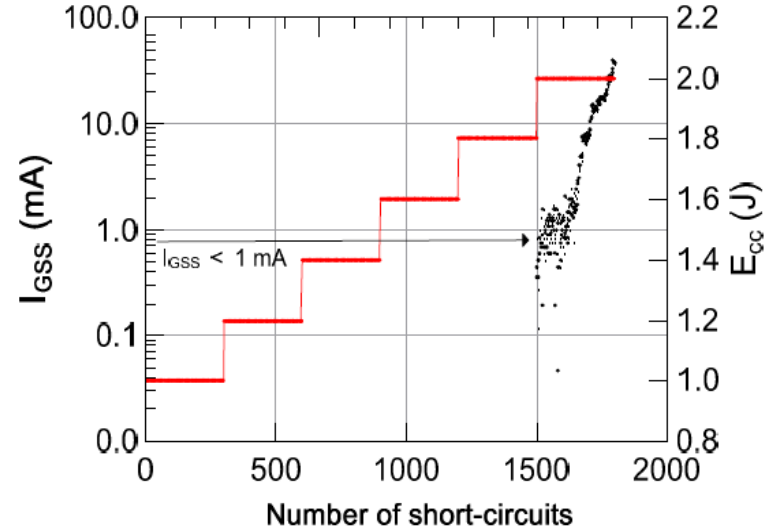
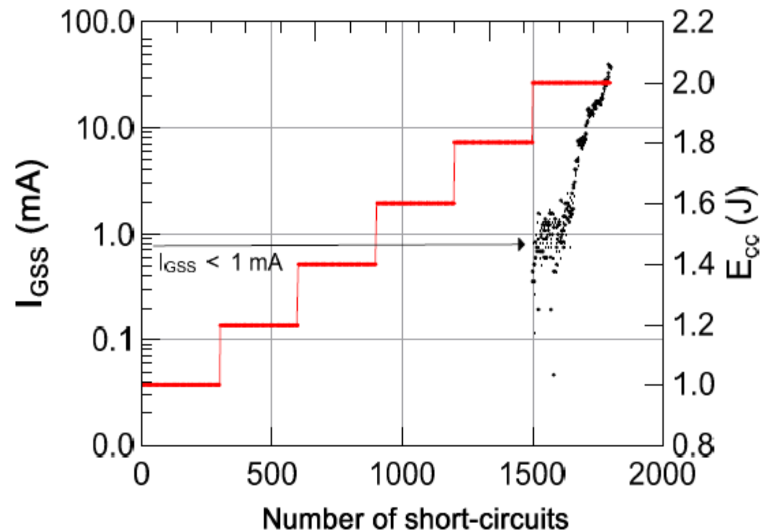


Thèse doctorat. 14/12/2019. Quentin Molin

Lack of SC induced aging indicator !!

Need of reliability insight
at semiconductor (die) level

Lack of SC induced aging indicator !!



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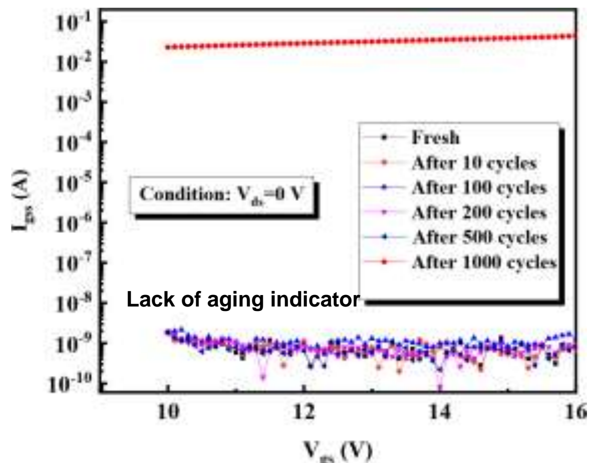
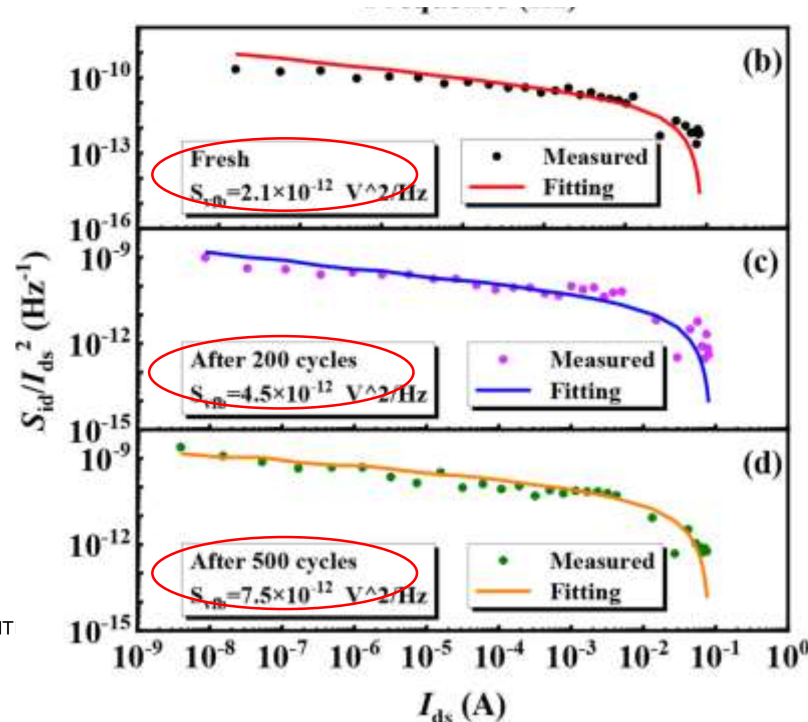
Need of Characterization Tools & Methods

PRECISE, REPRODUCEBLE, ROBUST

NEED of investigation technique / Approach
→ LFN based technique !



WANG *et al.*: TRAP ANALYSIS BASED ON LFN FOR SiC pOWER MOSFETs UNDER REPETIT CIRCUIT STRESS



the *SI*/*I*2 at 10 Hz versus *I*ds for the fresh device, 200 and 500 SC cycles device, respectively.

IRT SAINT EXUPERY

WBG Projects

- ➢ **Future electrification technologies** will require drastic **improvements of power electronics**, with higher power density & efficiency, but without negative impact on **Reliability.**
- ➢ **SiC Wide Bang Gap (WBG) technologies will be key enablers** thanks to their higher electrical performances (at 1200V toward 3300V)
- ➢ However **not enough knowledge** and standards test allowing their introduction exist → **High Risks !!!**

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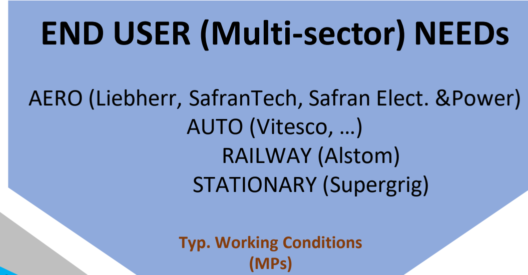
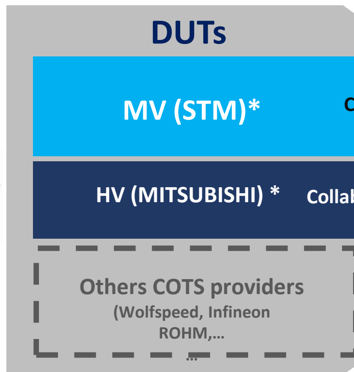
Project Structure

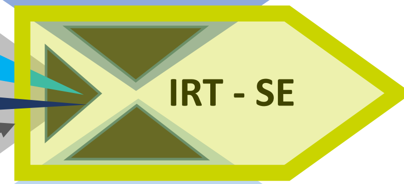


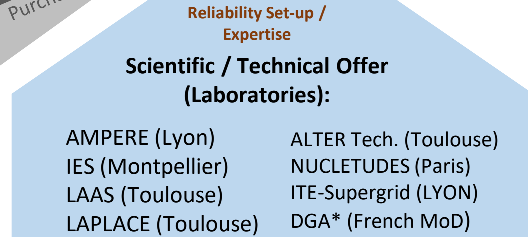


Collaboration Agreement

Collaboration /Purchase Agreement

Purchase





* Agreement under discussion

IRT SAINT EXUPERY · SAFRAN · vitesco · LIEBHERR · SiCRET Silicon Carbide Reliability Evaluation for Transport · EMOTORS · ALSTOM · ALTER TECHNOLOGY · SuperGrid Institute

afnor · IEC · AEC-Q · JEDEC

nucletudes ananegroup · DGA · ies · laplace · LAAS CNRS · Ampere · ECPE · CPES

4 (18MM) Post Doc hired at 4 laboratories + 4 PD supervisors

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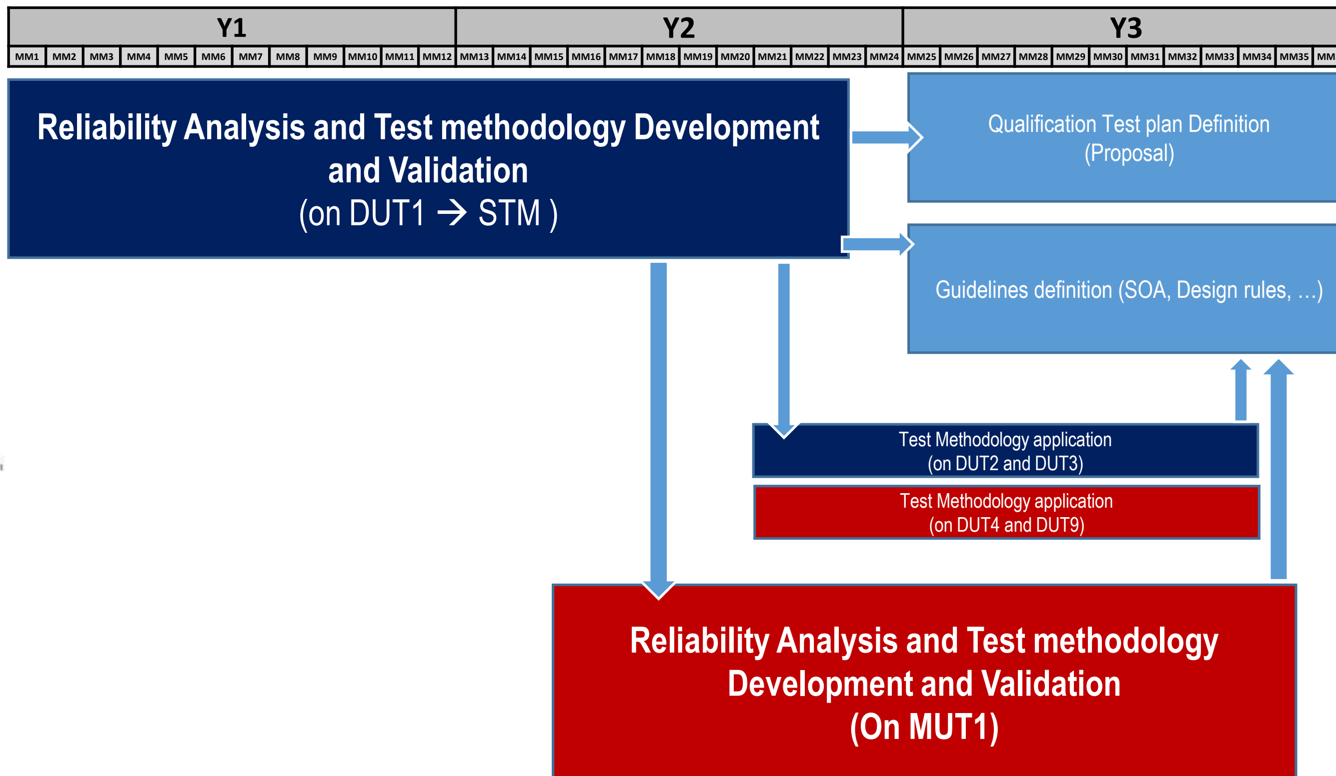
Project WBS: SICRET vs SICRET+



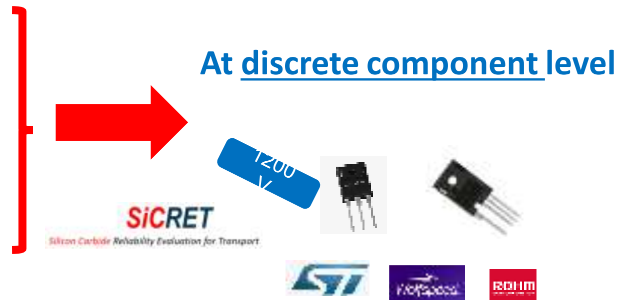
Projest Status and Perspectives

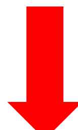
- *Establish a reference body of knowledge (database DUT for Automotive usage profile) of*

Qualification Test plan Definition
(Proposal)

Guidelines definition (SOA, Design rules, ...)

At discrete component level





At Power Module level including other studies/tests.

- Low pressure, humidity,
- Thermal management (power cycling, temperature cycling)
- EMC emission/immunity

SiCRET +

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

Source: ST Microelectronics

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Application Scenario

- ➢ **GaN Wide Bang Gap (WBG) technologies will be key enablers**
- ➢ However **not enough knowledge NOR “proven-in-use”** and standards test allowing their introduction exist → **High Risks !!!**

GaNRET

GaN (Power Transistor) Reliability Evaluation for Transport

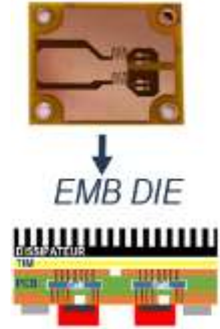
Project Set-up Team:

TENTATIVE: BUDGET: **TBD M€ -** DURATION: **36MM** Start Date: **2021-Q2**

❖ Main Challenges:

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

Source: Schweizer and Infineon



Source: IRT- EPOWERDRIVE Project

❖ Application domain:

❖ Project Rational:

cea fit FRENCH INSTITUTES OF TECHNOLOGY VEDECOM IRT NANOELEC

Major Challenges wrt SiC

Lack of standard packaging

❑ NO-STANDARD PACKAGING (FROM PROPRIETARY TO NO-PACKAGE)

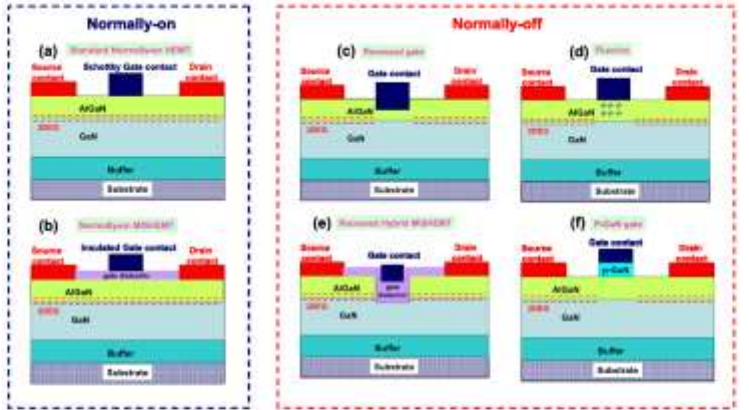
- Difficulty to separate semiconductor and packaging Failure Mechanism
- No standard test available*

NO-HIGH-POWER PACKAGING ?
(die-size (couts) VS. Perf. (freq., Rds_on,))
high-RDS_on→ low die size → high Freq. →Thermal!
Low RDS_on → Large die size → low freq → No-thermal!

* JEDEC Dynamic High Temperature Operating Life (DHTOL) --> JEP180 (Fevrier 2020)

POWER GAN SUPPLY CHAIN & BUSINESS MODEL

Many technological choices



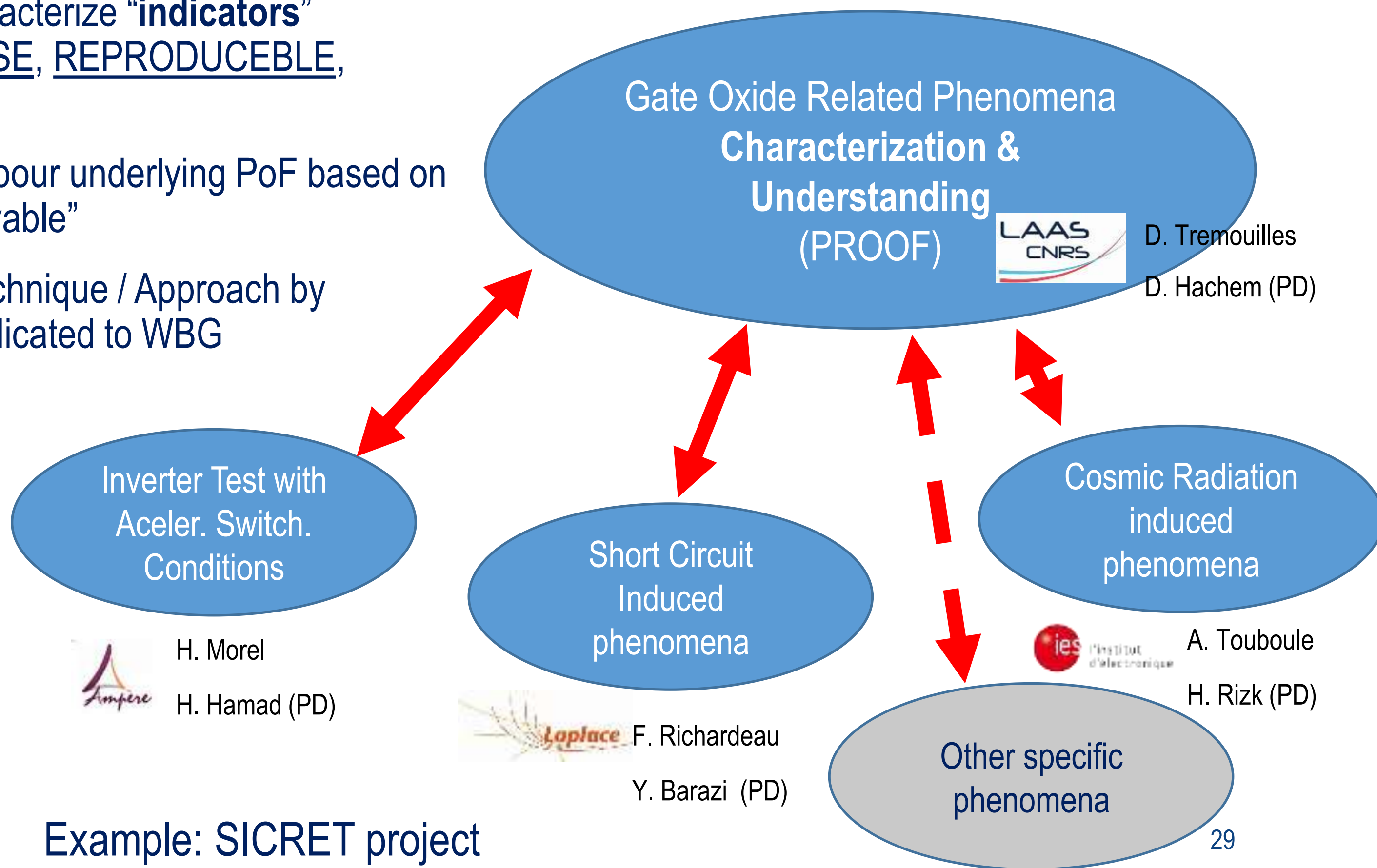
The landscape is populated by many providers (SME often fabless) using large foundries with established Silicon legacy !

Exploitation and Lighthouse Activities

- **Consolidation** of a reliability and risk assessment tool (capitalization)
- **Structuring** National reliability network (CFF, NRTW, …)
- **Supporting** international standardization (JEDEC, EIC, JEITA, …)
- **Connecting** with major international players/networks (AEC, ECPE, CPES, …)

CONCLUSIONS

- Need to identify and characterize “**indicators**” **observables**” by PRECISE, REPRODUCEBLE, ROBUST methods
- Need to understanding abour underlying PoF based on above “indicators” observable”
- NEED of investigation technique / Approach by specialized platforms dedicated to WBG



Example: SICRET project

Acknowledgements

Project:

ePowerdrive, Integration, Feline, SiCRET

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