Overview of the KORRIGAN project

Key Organisation for Research in Integrated Circuits in GaN Technology

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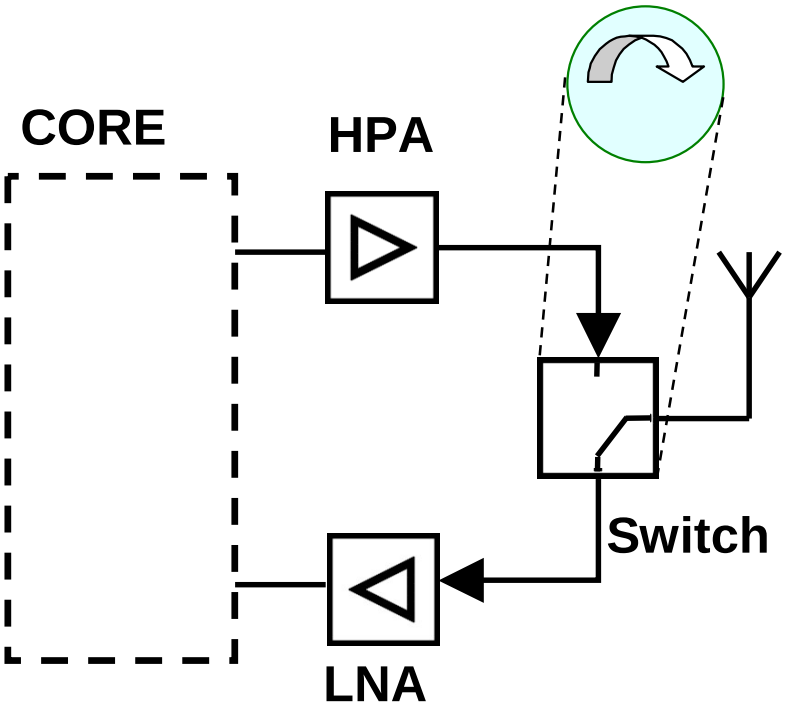
Antonio Cetronio, SP leader (Processing), Selex-SI _ Italy
Enrico Zanoni, SP leader (Reliability), University Padova _ Italy
Sylvain Delage, SP leader (Thermal Management), ATL3-5Lab _ France
Johan Carlert, SP leader (Demonstrators), Saab MS _ Sweden
Yves Mancuso, Thales Airborne Systems _ France
Iain Davies, Selex Galileo _ UK
Niklas Henelius, Norstel, _ Sweden
Marc Van Heijningen, TNO _ The Netherlands
Tibault Reveyrand, XLIM _ France

GaN in Europe before 2005

1. No simple route by which platform end users could gain exposure to GaN circuits
2. No clear supply chain from substrates - circuits
3. No opportunity to compare devices from different processes
4. No framework for understanding how to handle the high power densities associated with GaN
5. No unified approach to Reliability Assessment
6. No common approach to the development of GaN FET's for microwave systems

1. A route for platform end users



Demonstration on key applications X-band and Wideband Front End modules using GaN MMICs and advanced power assembly techniques

- **High power density and robust HPA**
- **High power handling SPDT: Circulator replacement**
- **Robust LNA: No (less) limiting needed**
- **For EW: Wideband performance**

MMIC Demonstrators

- **Building blocks for radar and EW front-ends**
- **S-Band designs (3 GHz)**
  - Power Bars for Hybrid HPAs
- **X-Band Designs (8.5 - 10.5 GHz)**
  - HPA MMICs
  - LNA MMICs
  - Switch MMICs
- **Wide band designs**
  - HPA MMICs (2-6 and 6-18 GHz)
  - LNA MMICs (2-18 GHz)
  - Switch MMICs (2-18 GHz)
- **A total of 29 circuits demonstrators and 6 modules developed, more than in any programme world wide**

- **Presentation on Monday afternoon:**
  "KORRIGAN MMIC Demonstrators Designs and Results"
  by Marc van Heijningen, TNO

2. A supply chain from substrates to circuits

- Korrigan addressed all the steps of the chain, many with more than one player:
  - Substrate (2”, 3”)
  - Epitaxy
  - Processing
  - Design guides and Model Library

SiC semi-insulating substrates

- **Norstel AB established in 2005 to industrialise Okmetic/LiU SiC crystal growth**

- **Significant investements in SiC technology initiated in 2005, partly motivated by the Korrigan requirements**
  - New custom-built facility commissioned in Norrköping, Sweden
  - New furnaces designed for 3” material and prepared for further diameter expansion
  - Complete wafering line
  - Extensive set of characterisation tools

- **Regular deliveries of 2” SiC substrates from Norstel to the Korrigan team showing progressive improvement**
  - Polytype inclusions virtually eliminated
  - Micropipe density < 2 cm^{-2} demonstrated
  - Improved crystalline quality as shown by reduced contrast in crossed polariser images
  - Device level feedback so far indicates performance comparable to Cree substrates
- **3” substrates sampled**

- **Strategic collaboration Norstel / AIST (Japan) established (2007) for large-diameter high-quality SiC substrate development and manufacturing**
  - Long-term effort with first results expected in 2009

Epitaxy in Korrigan

- **Epitaxy activity in Korrigan had 3 main objectives**
  - Supply of standard structures for processing
  - Diameter enlargement – from 2” to 3”
  - Development of advanced structures

			Advanced structure development				
Epitaxy partner	**Growth of Korrigan std structures**	**Wafer diameters**	**AlN exclusion layers**	**Super lattice upper barriers**	**AlInN upper barriers**	**Double hetero-structure buffer layers**	**Fe-doping of buffer layers**
QinetiQ	✓	**2” & 3”**	✓			✓	✓
III-V Labs	✓	**2”**	✓		✓	✓	
Picogiga (MBE)	✓	**2” & 3”**	✓	✓		✓	
Linkoping University	✓	**2”, 3” & 4”**	✓			✓	
Lecce university	✓	**2”**	✓				

- **More than 250 epi-layers on SiC supplied for processing**
  - Plus 45 epi-layers on sapphire and 20 epi-layers on Si supplied for process trials
- **Yield of Korrigan std structures ≈90% for most partners in final stages of program**
  - Including growth on 3” substrates
- **Device benefits demonstrated for advanced structures in many cases**

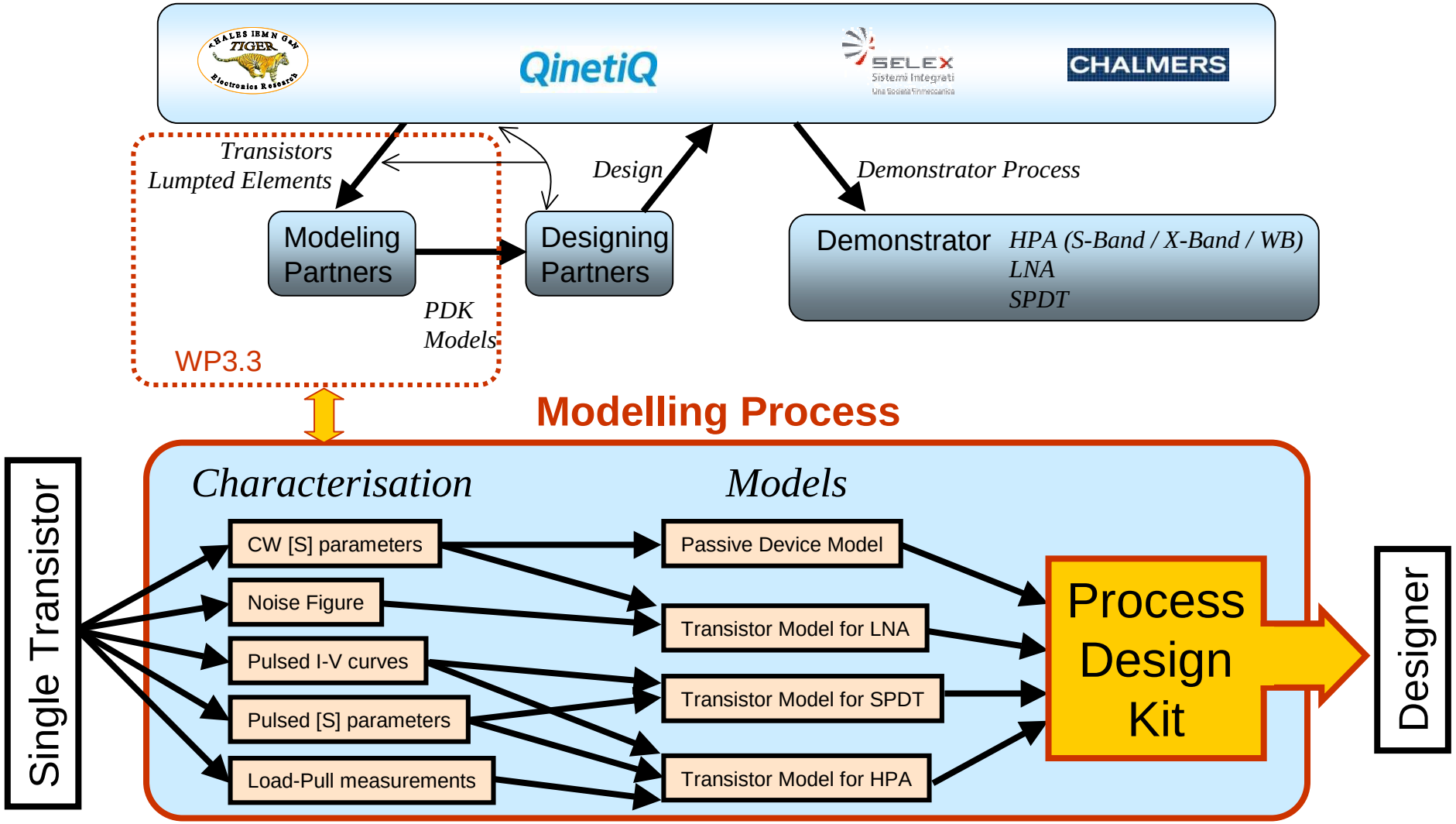
Korrigan standard wafer specification

Parameter	Value	Wafer to Wafer Variation
Surface particles and contamination	Zero particles> 10 microns high	
Upper barrier thickness (including GaN cap for MBE grown layers)	25nm	±10%
Channel carrier density	$1x10^{13}$ cm^{-2}	±10%
Channel sheet resistivity	420 ohms/sq	±10%
Vpinch	-5.2V	±20%
Isolation of GaN buffer layer	Insulating, No free carriers	<2pF 1Volt above pinch-off measured by HgCV @ <10kHz

- **Stable layer structure crucial to allow development of stable device processes**
- **Korrigan standard wafer specification defined at To+18**
  - Allowed best practice in each lab to be used whilst giving a common electrical performance
  - Used for all MMIC circuits in Korrigan
- **Significant activity undertaken to ensure measurement consistency across epitaxy partners**
  - Common samples exchanged between 6 centres to validate material measurements (Hg CV, Al%, Rsheet..)
  - Best practice defined across laboratories

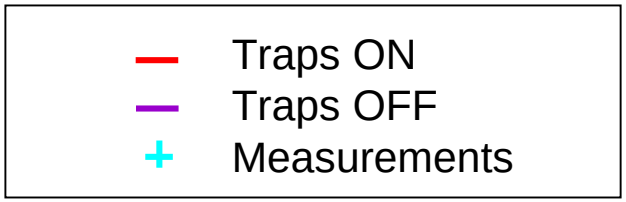
Modelling: Partnership

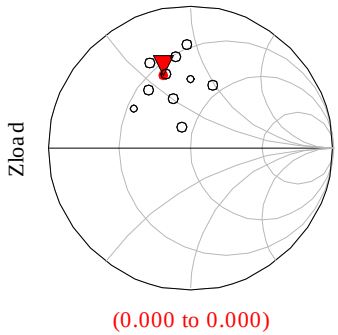
Four foundries are implied in Korrigan final demonstrators



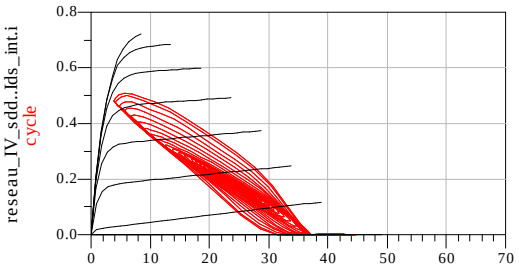
Modelling: Result example

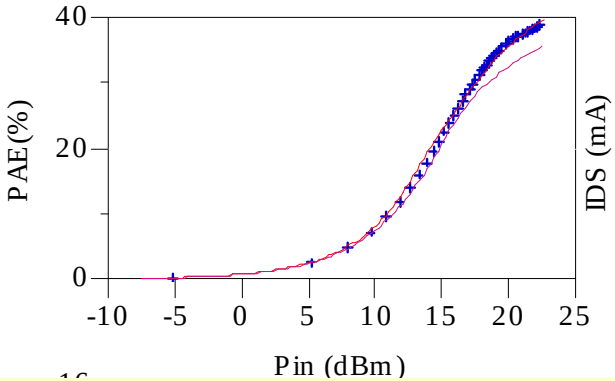
Modeling Trapping Effects at Large Signal

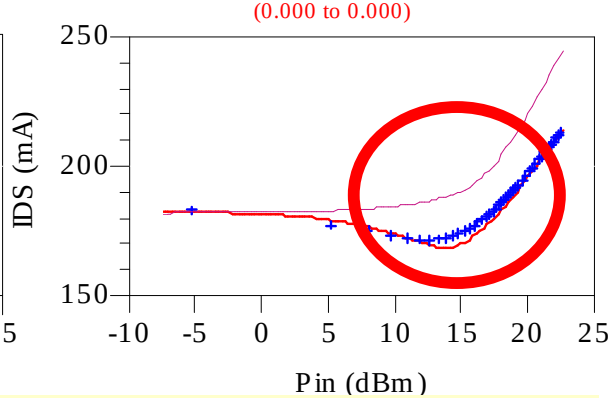


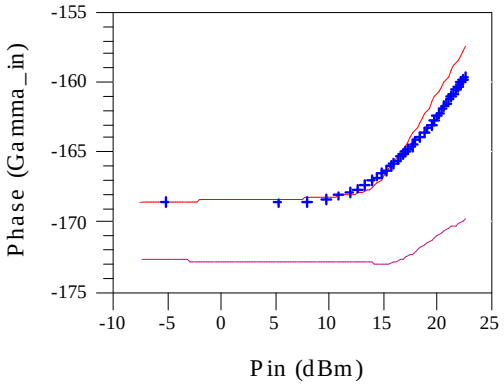


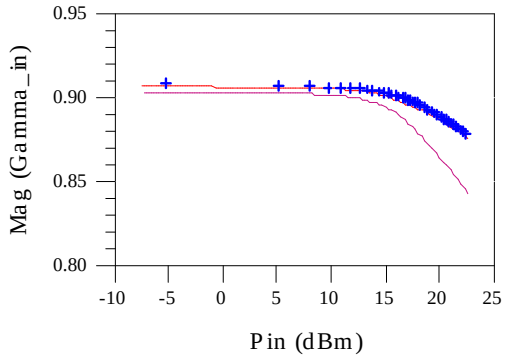
Measurements @ power optimal load impedance









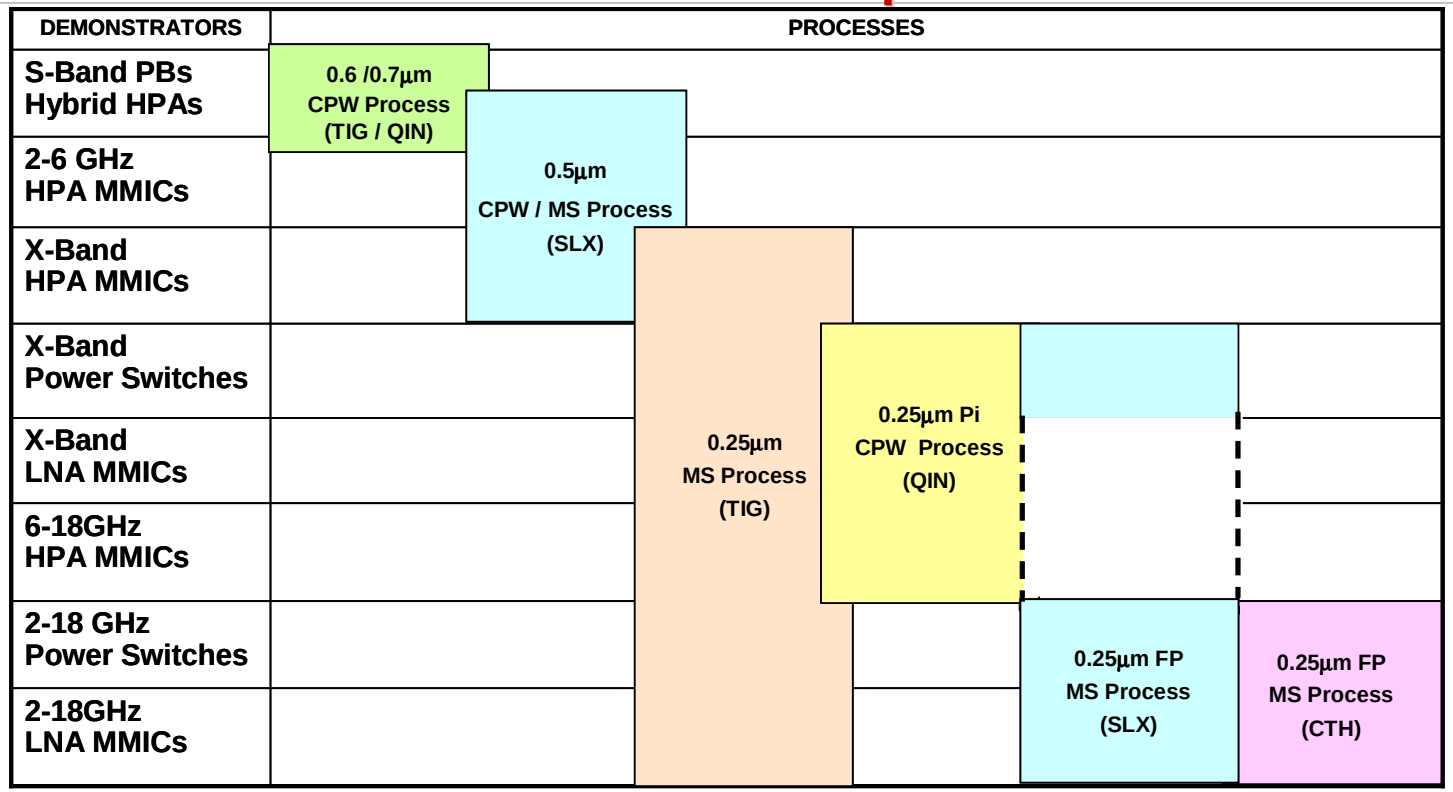


O. Jardel, F. De Groote, T. Reveyrand, J.C. Jaquet, C. Charbonniaud, J.P. Teyssier, D. Floriot, R. Quéré

«An electrothermal model for AlGaN/GaN Power HEMTs including trapping effects to improve large-signal simulation results on high VSWR»

IEEE Transactions on Microwave Theory and Techniques, Vol. 55, No 12, pp.2660-2669, December 2007.

3. An opportunity to compare devices from different processes

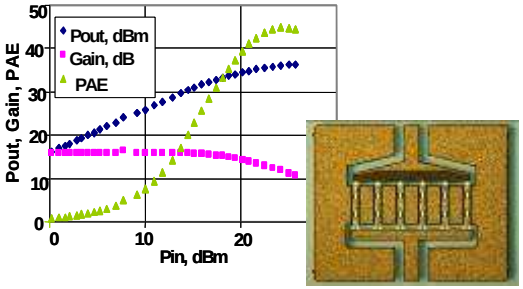


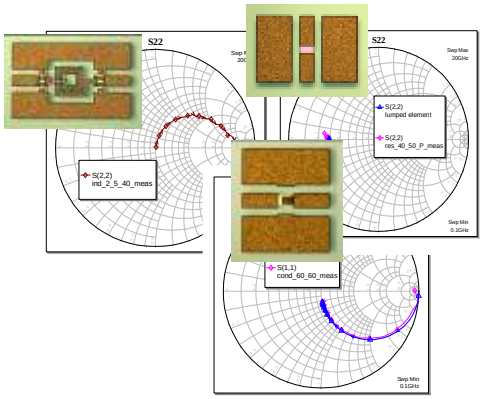
Six processes have been developed by KORRIGAN Foundries for Demonstrator fabrication

- 0.6/0.7µm Power for CPW Power Bars (QIN/TIG)
- 0.5µm Power CPW/MS (SLX)
- 0.25µm General Purpose MS (TIG)
- 0.25µm (T-gate) General Purpose CPW (QIN)
- 0.25µm (Field Plate) LNA/Switch MS (CTH)
- 0.25µm (Field Plate) LNA/Switch MS (SLX)

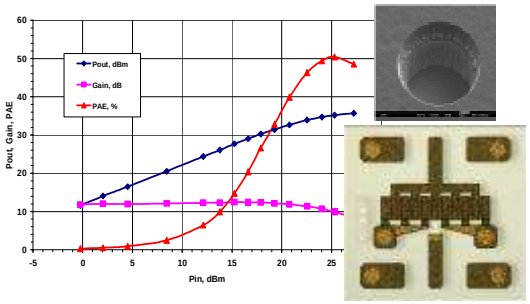
KORRIGAN Foundry DKs

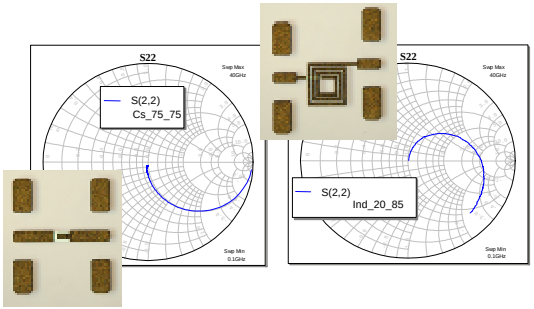
Co-Planar Waveguide Technology





Micro-Strip Technology





QinetiQ
SELEX Sistemi Integrati
Una Società Finmeccanica
THALES IBMN GaN TIGER Electronics Research

CHALMERS
SELEX Sistemi Integrati
Una Società Finmeccanica
THALES IBMN GaN TIGER Electronics Research

Active device library from 0.1 to 2.4mm gate-width for small-signal, switching and power applications

Passive component library composed of high voltage breakdown MIM capacitors, inductors and thin-film resistors

Foundry PDKs on KORRIGAN web-site for ADS and AWR workstations

Demonstrator Mask-Sets Processed in KORRIGAN

DEMONSTRATORS	CPW MASK-SET	MS MASK-SET
S-Band Hybrid HPA	➢ **TIG1, QIN1, SLX1,TIG4, QIN4, SLX8**	➢ **SLX8**
X-Band LNA MMIC	➢ **QIN3, QIN5**	➢ **TIG2, TIG5**
X-Band HPA MMIC	➢ **SLX2**	➢ **TIG2, SLX5, TIG5, SLX11**
Wide-Band LNA MMIC	➢ **QIN3, QIN5**	➢ **CTH1, CTH2** ➢ **TIG3, SLX7, SLX9**
Wide-Band HPA MMIC	➢ **SLX3, QIN2, QIN6** (2-6 GHz) ➢ **QIN2, QIN6** (6-18GHz)	➢ **SLX6, SLX10** (2-6 GHz) ➢ **TIG3, TIG6** (6-18GHz)
Switch MMICs	➢ **SLX4, QIN3, QIN5** (X-Band) ➢ **SLX4** (Wideband)	➢ **TIG2, SLX7, TIG7, SLX)** (X-Band) ➢ **CTH1, TIG3, SLX7, CTH2, TIG7, SLX9** (WB)

SUMMARY

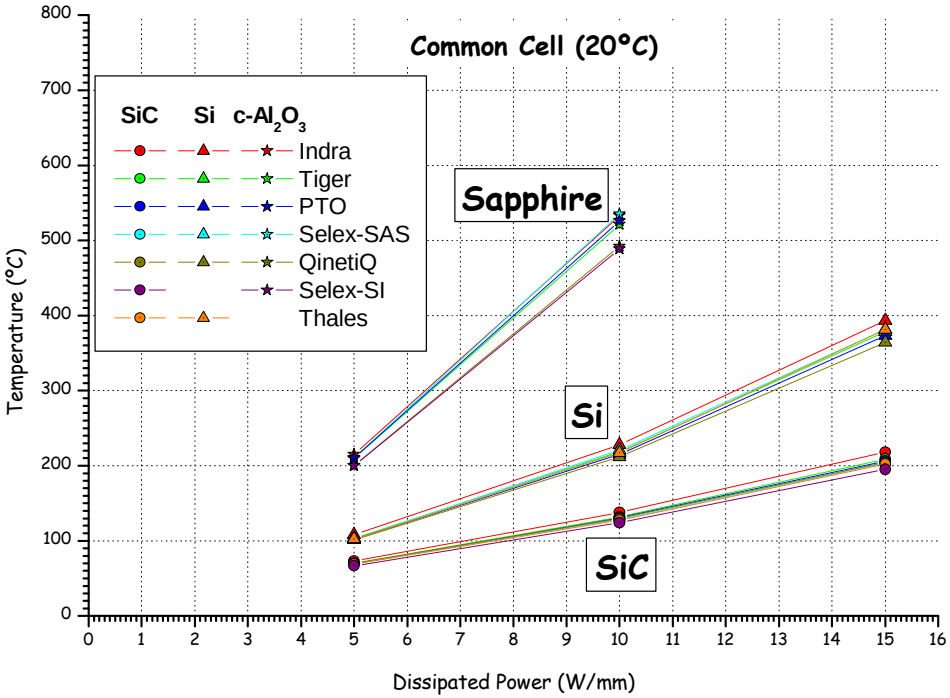
- **N°of Demonstrators 29**
- **N°of Mask-sets 26**
- **N°of Processes 6**
- **Circa 80 wafers processed for Demonstrators**

2 GATE-LENGTHS (0.5 and 0.25μm) ← **4 FOUNDRIES** → **2 TECHNOLOGIES (CPW and MS)**

4. A framework for understanding and managing thermal issues with GaN

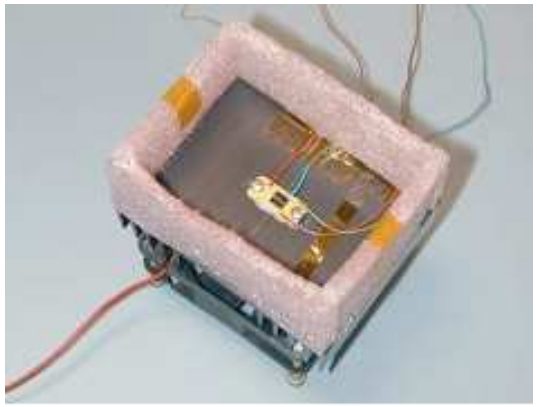
- Definition of a common cell for tool validation
- Simulation parameters / simplifications
- Stationary and transient simulations
- Comparison of simulations with real measurements

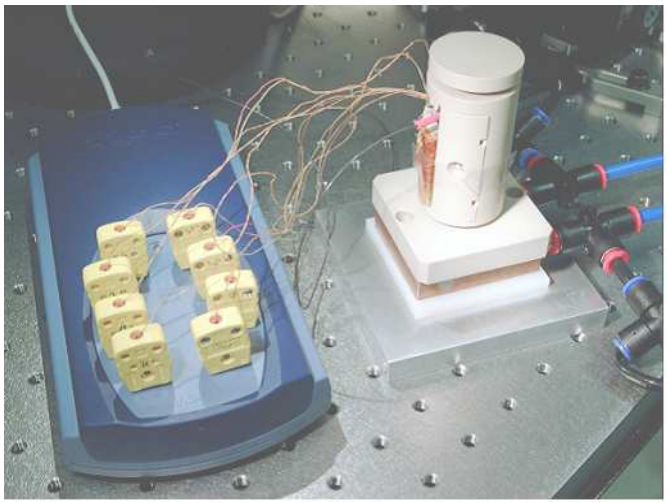
Very good agreement for all partner's results and experimental measurements



Assembly materials characterization

Thermal and physical test performed on various assembly stack-up

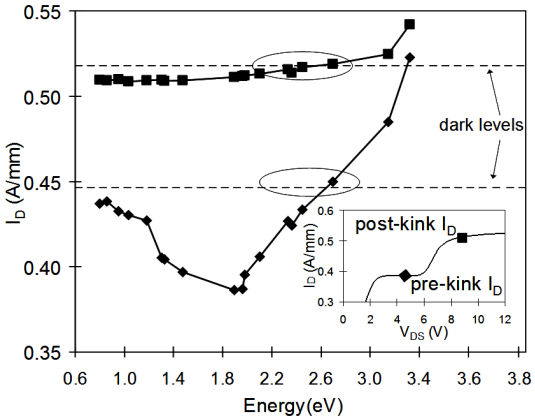




* These measurements have been performed on test chips designed and manufactured at the beginning of the project with the only scope of optimization of the flip chip process, the electrical characteristics of these devices are not at the state of the art of GaN technology.

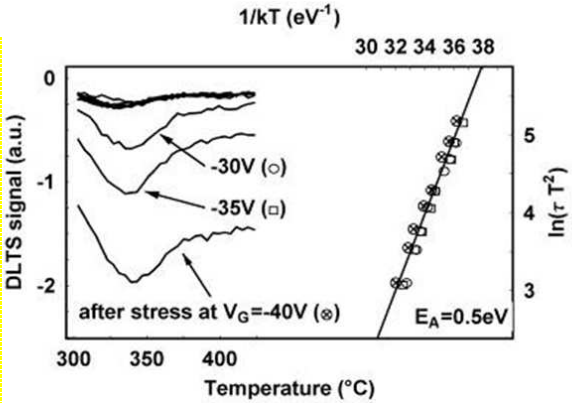
5. A unified approach to reliability assessment

- A unique database exploited by highly skilled partners
- Approximately 20 long-term accelerated life tests exceeding 1000 hours and a large number of short-term reliability experiments
- A methodology for the study of trap-induced effects; failure modes of AlGaN/GaN HEMT's identified
- First analysis of correlation between DC aging and rf aging

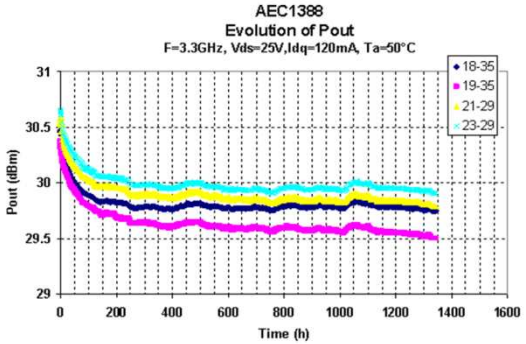


Photocurrent spectroscopy

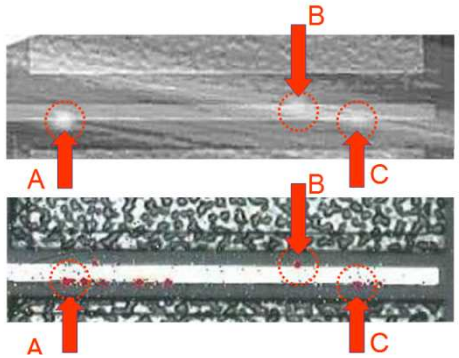
➢Presentation on Tuesday morning: "Trap related instabilities and localised damages induced by reverse bias"
by Enrico Zanoni, Univ. Padova



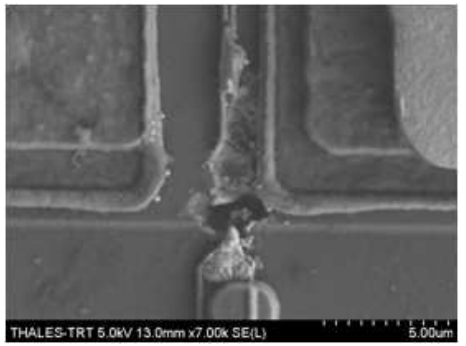
Deep Level Transient Spectroscopy



DC and rf life testing



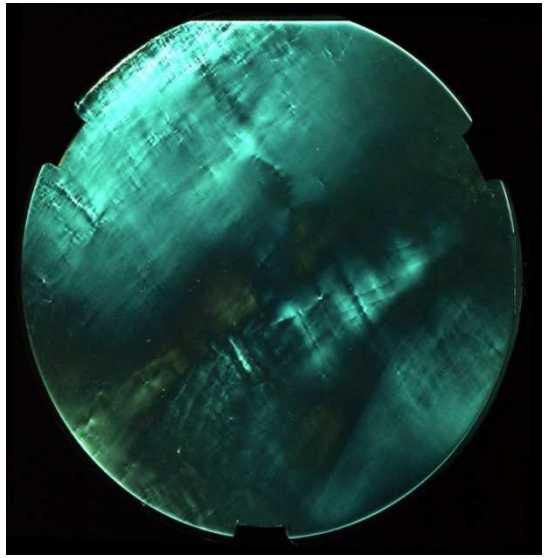
EBIC and Electroluminescence

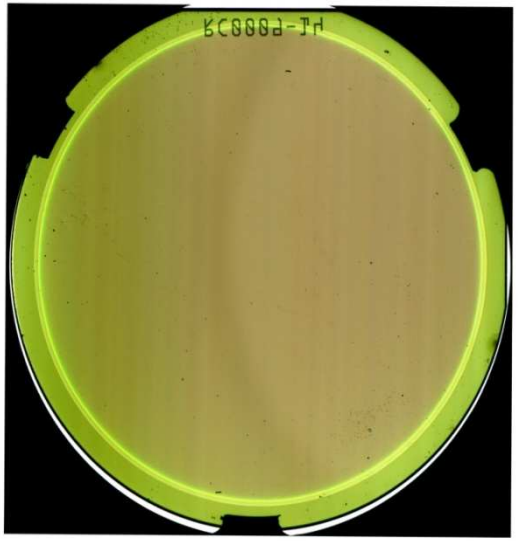


Rf robustness testing

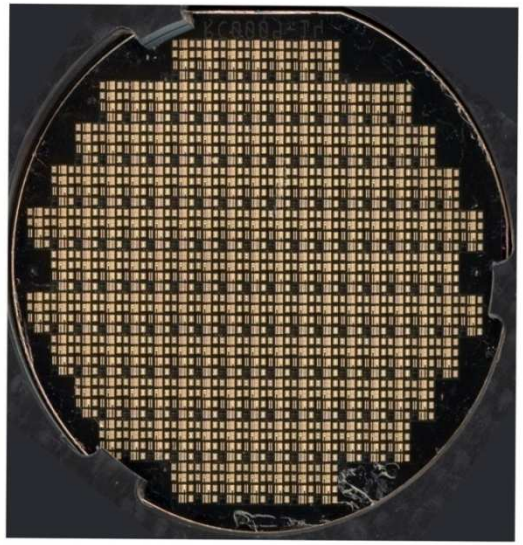
6. An experiment for the study of substrate quality influence on yield and reliability

- **Wafer is imaged at various points during process**
  - Substrate
  - Epi-layer growth
  - Device processing
  - Device characterisation

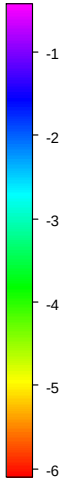




- **Each image may be correlated with previous stage**
  - Devices containing defects in their active regions can be identified



➢ **Presentation on Monday morning:**
” Quantitative cross-wafer characterisation of SiC substrates and its correlation with GaN H-FET device performance ”
by David Wallis, **QinetiQ**



Conclusion _ Part I

GaN in Europe after Korrigan: (6.) A common approach to the development of GaN FET's for microwave systems

- **A robust supply chain has been established, from substrates through foundries to circuits.**
- **The establishment of common procedures such as a common PCM, design rules and reliability testing allows different processes and devices to be directly compared**
  - (One question still pending: what about the feedback from ESA about the PCM provided by Korrigan?)
- **Models have been established for a wide range of devices and processes, and placed on a generally accessible WEB site**
- **A large database for reliability and parasitic effects is available**

Conclusion _ Part I (cont'd)

GaN in Europe after Korrigan: A common approach to the development of GaN FET's for microwave systems

- There is unified approach to thermal modelling and simulation, captured in a common design guide for packaging techniques and thermal management
- A large number of demonstrator circuits has been designed and tested, demonstrating in many cases state-of-the-art performance, with circuit data made generally available within Europe.
- Korrigan has taken the technology to a stage where circuit system designers can have a clear view of the potential of GaN, detailed guidance on the way the technology is used, and the detailed performance data needed to carry out simulations at the system level.

Conclusion _ Part II

Prospective for continuation of the effort in Europe

- A project on substrates / materials already on the tracks
- Ongoing discussion on device-centered follow-up