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GaN4AP – Gallium Nitride for Advanced Power Applications

Third Newsletter – March 2025

Introduction

Power Electronics is a set of technologies associated with the efficient control and conversion of electric energy from the source to the load. In this context, **electronic devices based on Gallium Nitride (GaN) material** can offer excellent performances for the future power systems, owing to the high efficiency and fast switching performances.

In this scenario, the European ECSEL-JU project **GaN4AP (Gallium Nitride for Advanced Power Applications)** has been running since June 2021, with the ambitious goal of making the GaN-based electronics to become the main driving power technology in most of the energy conversion systems.

The GaN4AP Consortium is composed of 35 partners and 9 linked third parties, including large companies, SMEs, Universities and Public Research Centers from 6 different European countries (Czech Republic, France, Germany, Italy, the Netherlands and Poland).

The project activities are organized in **4 Clusters**, operating for the development and optimization of different GaN-based technologies. Their work is implemented through **9 Work Packages (WPs)**.

This newsletter summarizes the main achievements reached within GaN4AP project in the third year.

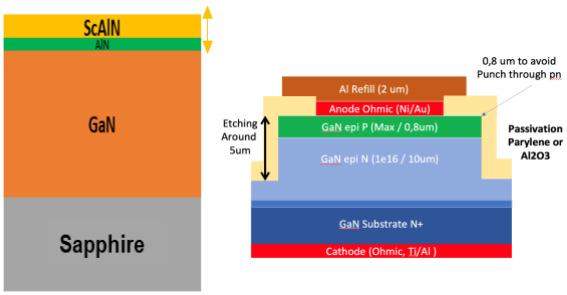
Main results achieved during the third year

Material, device technology and product development

Intensive activities on materials and devices technology development have been carried out by the partners during the third year. The main achievements are summarized below:

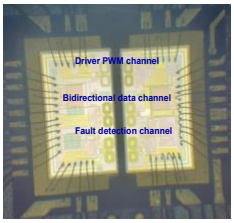
AlScN/GaN heterostructures grown by MBE were deeply studied and characterized on blanket samples and electrical test devices. Electron **mobilities superior to 600 cm²/Vs on silicon and up to 1000 cm²/Vs on sapphire** were obtained with Hall effect measurements. Scandium oxide at the surface is not stable, so work on finding the best capping layer (AlN, GaN, SiNx) is crucial.

The calibration of low n-type and high p-type doping in view of achieving **p-n junctions and fabricating diodes for bulk GaN substrate evaluation** continued with the comparison of the homoepitaxial layers grown of different substrates, investigating the electrical behavior of the GaN Schottky diodes at high reversed applied bias, which allowed to estimate breakdown voltage-V_{BR}.



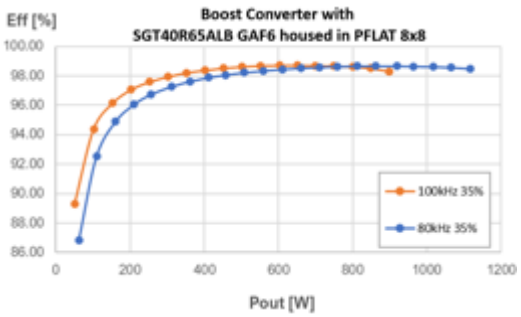
Recessed gate MIS-HEMTs transistors (650 V / 30A) were fabricated and delivered to the application partners for module development. All the samples delivered were functional.

The final design of the proposed **galvanic isolation interface** was released. The interface was enhanced with an additional bidirectional diagnostic channel, beyond the initial driver and power supply control channels. The interface was measured, exhibiting correct behavior.

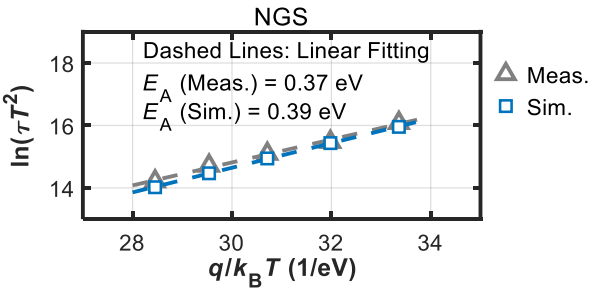


Device modelling, characterization and reliability evaluation

Double-pulse and Boost converter testing of 650V p-GaN HEMTs were performed both in soft- and hard-switching.



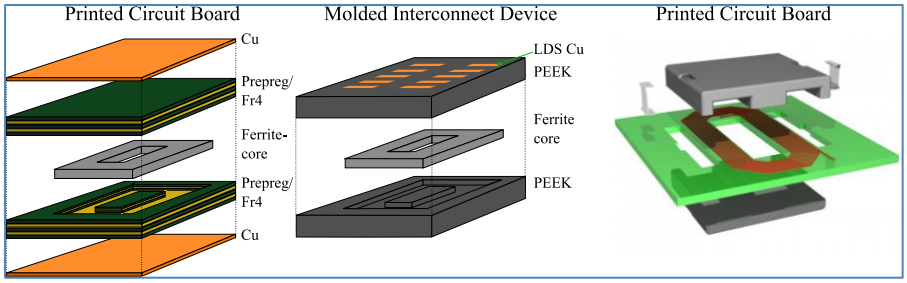
Measurements and material characterization setup have been developed or further improved. In addition, simulations to predict for the first time the HTRB stress measurements have been performed. In this way, a deeper understanding of the role of negative and positive gate bias on the R_{ON} degradation in p-GaN HEMTs was achieved.



Finally, a HTRB reliability investigation of p-GaN HEMTs (up to 900 devices tested) and an analysis of OFF- state reliability in vertical GaN TMOS were carried out.

System integration, packaging and passive

Package solutions play a key role in GaN-based applications, to increase power density and efficiency. In fact, to increase the power density, GaN transistors must work at very high switching frequency and, to limit the switching losses, commutations have to be extremely fast (in the range of 50V-100V/ns). To avoid voltage spikes, this requires packages with low inductive values. At the same time, for efficiency, it is essential to have very performing thermal resistance R_{th} package solutions and to be able to guarantee a total R_{th} between the device's junction and heatsink compatible with the power rating of the application. In this context, depending on the application, the voltage range, and target device power dissipation, different package solutions have been identified for discrete and integrated devices (100V and 650V). The most demanding solutions in terms of switching speed will use innovative wireless packaging technologies such as Direct Copper Interconnect (DCI), while those in which the dominant factor is power dissipation will use larger packages with clips on the Power signals. In this context, physical analysis on PowerGaN™ devices that were assembled using the DCI technology demonstrated the need to further mature this technology for stringent standards such as Automotive. In addition, new technology for passive elements (Inductor, Transformer...) were developed to provide a complete solution for a new generation of power converters.



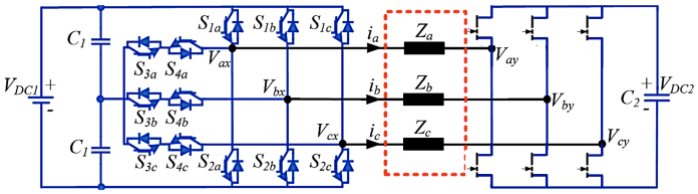
Demonstrators

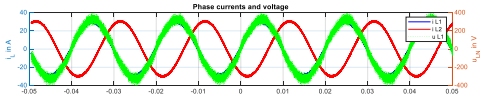
Demonstrators are an important outcome of GaN4AP. In fact, 19 demonstrators integrating GaN components and dispatched in four tasks are planned to be developed and tested in order to demonstrate the benefice of the GaN compare to the state of art.

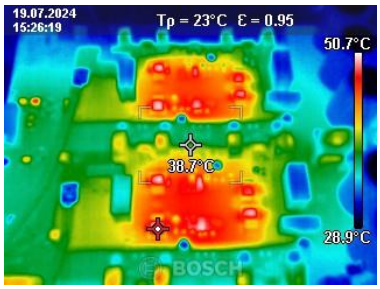
At this stage, real progress is visible with 6 demonstrators already validated. Most of the rest are under testing or optimization. The demonstrators embedding the 650V GaN-HEMTs (Cluster 1) and the integrated GaN solutions (STi2GaN) (Cluster 4) are the most advanced, showing encouraging efficiency results and compactness reduction - both critical factors for the future of power systems. The main challenges are for the power switching system demonstrators to solve issues due to the parallelization configuration, sounds tricky but essential for scaling up the demonstrators.

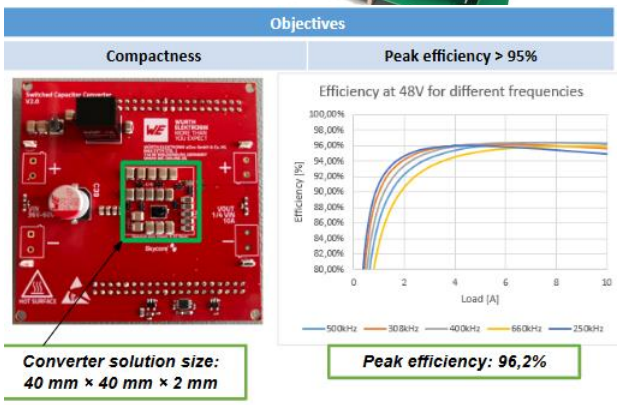
It is worth noting a strong relationship with the system integration, packaging and passive components partners for demonstrators' optimization. Passive components are key in managing losses, improving efficiency, and ensuring thermal stability, all of which are critical in high-performance and reliable power systems, especially with GaN-based devices.

The project is reaching a pivotal stage with the finalization of the tests for the remaining demonstrators. This phase will be critical for confirming all the improvements and optimizations made throughout the development process. The in-depth analysis of the test results will allow us to validate the overall performance of the demonstrators, ensuring that they meet the necessary benchmarks for efficiency, stability, and scalability.





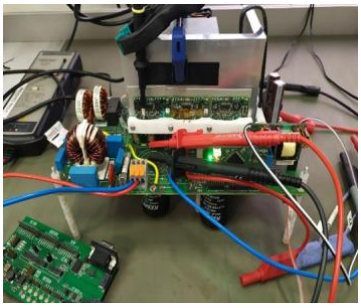


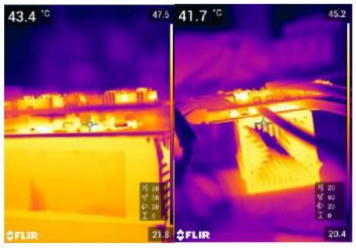


This phase will likely involve identifying any remaining issues, particularly around things like power switching, thermal management, or integration with passive components, and addressing them. The results of this analysis could also inform any potential adjustments to design or components choices for future iterations or similar projects.

System Testing and Reliability

GaN power HEMTs are conceived to be used for high power and extremely fast switching commutations. This ambitious target was verified first at bench and at the automatic testing and then during reliability phase. To reproduce system-like conditions, an extraordinary effort was needed to reconceive standard silicon solutions. Double pulse characterization of several GaN HEMTs produced in the consortium were compared experimentally with commercial devices on the merit of efficiency in single-phase PFC topology also including thermal characterizations for bottom side cooled configuration. Moreover, experimental test bench has been created for GaN ANPC inverter leg with sinusoidal PWM modulation strategy implemented on programmable control board. Results of efficiency vs load current confirmed an efficiency higher than 97% at low-loads and increasing to 98.5% for higher current values. Thermal imaging monitoring was also used to verify the stabilities of devices. In terms of “system





reliability", several aspects were considered, e.g. devices switching behavior characterization, study of the properties of planar inductive MID components under stress, as well as simulations and failure analysis of degradation phenomena.

Market Analysis and Future Exploitation

The most important findings of the market analysis' evolution, carried out over the past 18 months, can be summarized as follows:

- The forecast CAGR has fallen from 70% to 49% in the past 2 years
- Consumer electronics remains the biggest market segment for GaN power components
- Automotive will become 2nd biggest market segment and growth driver with CAGR of 110%

Despite the somewhat weaker market forecast, there have also been notable acquisitions in the recent past:

- Infineon acquired GaN systems for US$830M
- Transphorm has been acquired by Renesas for US$339M
- Navitas acquired GeneSiC for US$100M
- Globalfoundries acquired GaN IP portfolio from Tagore

Communication and Dissemination Activities

During the last months, GaN4AP partners participated in several international conferences and workshops, presenting the project results. Among them, it is worth mentioning the presence of GaN4AP in the following events with a strong focus on GaN:

- International Conference on Nitride Semiconductors (ICNS-14), Fukuoka (Japan), November, 12-17, 2023.
- WOCSDICE-EXMATEC 2024, Heraklion (Greece), May 19-23, 2024.
- GaN Marathon 2024, Verona (Italy), June, 12-14 2024.
- International Workshop on Nitride Semiconductors (IWN 2024), O'ahu, Hawaii, November 3-8, 2024.

The technical results obtained in almost four years resulted in several publications in international journals with high impact factors, both in material and device fields (Appl. Phys. Lett., IEEE Electron Device Letters, Materials MDPI, etc.).

A list of selected papers published during the last year is reported below:

M. Zak, P. Kempisty, B. Lucznik, K. Grabianska, Robert Kucharski, M. Iwinska, Michal Bockowski, *"Modeling of convective transport in crystallization of gallium nitride by basic ammonothermal method"*, Journal of Crystal Growth **627**, 127525 (2024).

Isabel Streicher, Stefano Leone, M. Zhang, T. Slimani Tlemcani, M. Bah, P. Straňák, L. Kirste, M. Prescher, A. Yassine, Daniel Alquier, O. Ambacher, *"Understanding Interfaces in AlScN/GaN Heterostructures"*, Adv. Funct. Mater. **34**, 2403027 (2024).

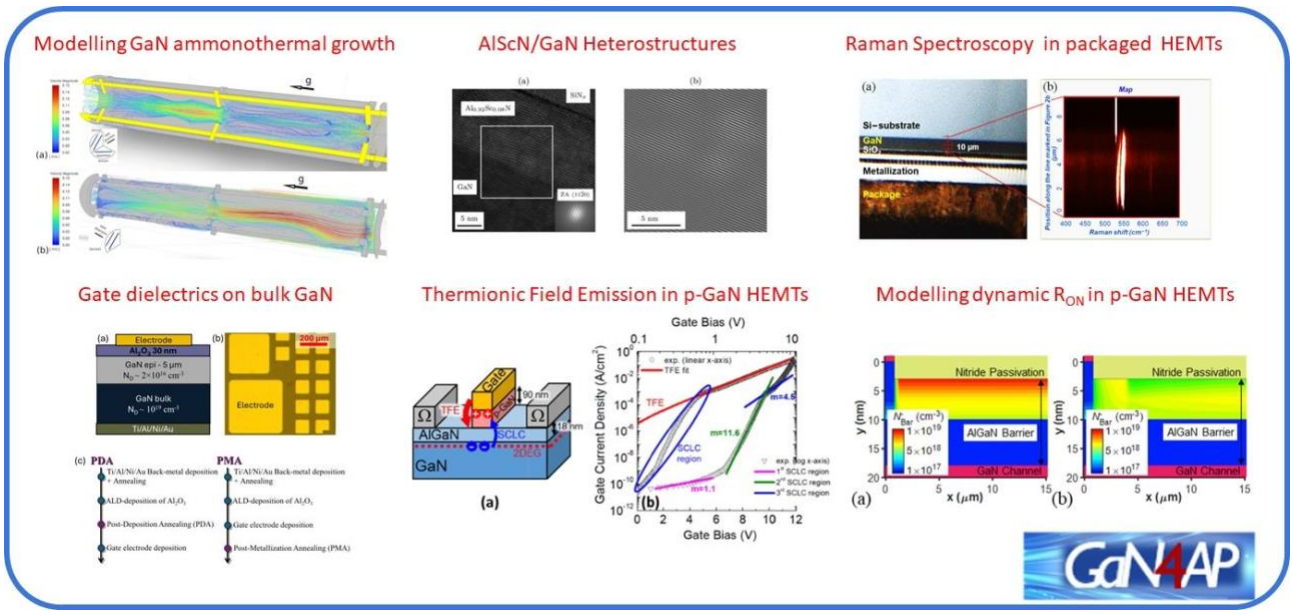
Z. Dahrouch, Giuliana Malta, M. d'Ambrosio, Angelo Alberto Messina, M. Musolino, A. Sitta, Michele Calabretta, Salvatore Patane, *"Assessing the Stress Induced by Novel Packaging in GaN HEMT Devices via Raman Spectroscopy"*, Appl. Sci. **14**, 4230 (2024).

Nicolò Zagni, Giovanni Verzellesi, Alessandro Bertacchini, Mattia Borgarino, Ferdinando Iucolano, Alessandro Chini, *"Hole Virtual Gate Model Explaining Surface-Related Dynamic RON in p-GaN Power HEMTs"*, IEEE Electron Device Letters **45 (5)**, 801-804, (2024).

Giuseppe Greco, Patrick Fiorenza, Filippo Giannazzo, Marilena Vivona, Carlo Venuto, Ferdinando Iucolano, Fabrizio Roccaforte, *"Thermionic Field Emission in the lifetime estimation of p-GaN gate HEMTs"*, IEEE Electron Device Lett. **45(10)**, 1724-1727 (2024).

Emanuela Schiliro', Giuseppe Greco, Patrick Fiorenza, Salvatore Ethan Panasci, Salvo Di Franco, Yvon Cordier, Eric Frayssinet, Raffaella

Lo Nigro, Filippo Giannazzo, Fabrizio Roccaforte, *"Comparing post-deposition and post-metallization annealing treatments on Al2O3/GaN capacitors for different metal gates"*, AIP Advances **14**, 105109 (2024).



The complete list of the publications related to GaN4AP, released from the beginning of the project, can be found on the project website.

Events' Organization

In the last year, GaN4AP partners were strongly involved in the organization of scientific events, related to the project activities. IUNET-UNIPD organized the traditional *GaN Marathon 2024*, which was held in Verona (Italy) 10-12 June 2024, and received a high number of contributions. Moreover, the same partner was involved in the organization of the *"Summer PhD School of Information Engineering (SSIE)*, which will be held in Bressanone (Italy), July 8-12 2024. During this School a track dedicated to Gallium Nitride will be organized as "GaN4AP Summer School", where some of the Partners (IHPP, DTMNS-CNR, IUNET, Valeo) contributed giving comprehensive lectures on materials, devices and applications.

During the Nanoinnovation2024, held in Rome (Italy), September 9-13, 2024, DTSMNS-CNR organized a dedicated symposium entitled *"Wide-bandgap semiconductors and heterostructures for power and RF electronics"*, where excellent invited talks were given by DTSMNS-CNR, UNITOU, CNRS-CRHEA and IUNET-UNIPD.

DTSMNS-UNICT organized two events. First a Special Session on GaN at the *XXXIX Conference on Design of Circuits and Integrated Systems (DCIS)* that was held in Catania (Italy) November 13-15, 2024. Then, the **International GaN4AP Workshop**, held in Catania (Italy) February 2021-2025. This

latter event, organized in the wonderful location of the Benedictine Monastery of San Nicolò l'Arena, was attended by more than 90 participants, from 8 European countries, presenting 52 outstanding technical contributions. GaN4AP partners were present with 2 invited talks, 13 oral presentations and 15 posters, showing the latest achievements on GaN materials, devices and applications.

Participation in the EFECS 2024

It is also worth mentioning the participation in the European Forum for Electronic Components and Systems (EFECS 2024), a brokerage event held in Ghent (Belgium) on December 5-6, 2024, where the project was showcased by the coordination team and some of the partners.

In relation to the outstanding results so far achieved and presented during EFECS 2024, the idea of launching a "new project" as an evolution of GaN4AP to be submitted at the next 2025 Chips JU Calls, was successfully welcomed both by the organizers and by the numerous participants in the event.

Third Review Meeting held in Münich

The third review meeting of GaN4AP was held in Münich (Germany) on September 12-13, 2024, kindly hosted at the Würth premises. The partners were involved in two days of intensive discussions on the most relevant achievements and future activities, in the presence of the Project Officer and of the two independent experts. A showcase of all demonstrators fabricated so far was also organized during these days.

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GaN4AP – GaN for Advanced Power Applications

GaN4AP project details

Call for proposal: H2020-ECSEL-2020-1-IA-two-stage
Funding scheme: ECSEL Innovation Action
Grant Agreement ID: 101007310
Duration: 36 months, June 1, 2021 to May 31, 2024 (extended to August 31, 2025)
Total Cost: € 64 021 545,82
EU Contribution: € 15 320 914,36
Project Coordinator: Ing. Leoluca Liggio (DTSMNS)
Scientific Coordinator: Prof. Gaudenzio Meneghesso (IUNET)