ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership

This project has received funding from the Electronic Component Systems for European Leadership Joint Undertaking (ECSEL JU), under grant agreement No.101007310. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, and Italy, Germany, France, Poland, Czech Republic, Netherlands.

GaN4AP – Gallium Nitride for Advanced Power Applications

Second Newsletter – August 2023

Introduction

Power Electronics is a set of technologies associated with the efficient control and conversion of the 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 during the second year.

Main results achieved during the second year

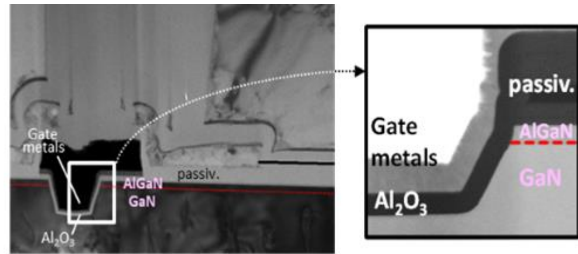
Requirements and Specifications

The definition of requirements and specifications has been mostly carried out already in the first year, in order to target state-of-the–art demonstrators in the four Clusters. Several technologies were reviewed for the different applications. A coordinated effort has checked supposedly available die sources outside of the project. A comprehensive understanding was issued, designing a decision making process for a future technology roadmap for die technology and packaging.

Material, device technology and product development

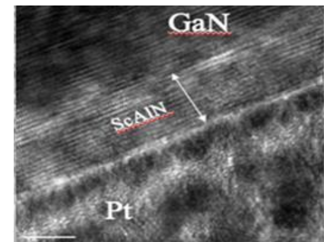
Significant scientific and technological advancements have been achieved concerning material and device development, with a focus on recessed-gate AlGaN/GaN lateral MISHEMTs, novel AlScN/GaN heterostructures and vertical devices based on bulk GaN.

In particular, ultra-low resistance recessed gate AlGaN/GaN MISHEMTs, employing an optimized Al_2O_3 layer as gate insulator, yielding high efficiency and better robustness have been developed. The target specification in terms of on-resistance has been successfully achieved (Ron.Wg = 20 ohms.mm at 150°C). MIS-gate devices are now being implemented in power module demonstrators.



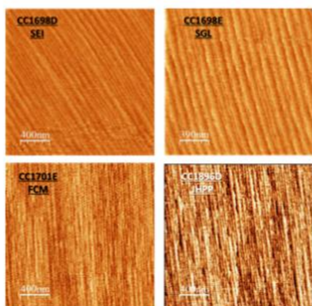
Recessed gate of AlGaN/GaN MISHEMT employing Al_2O_3 as gate insulator

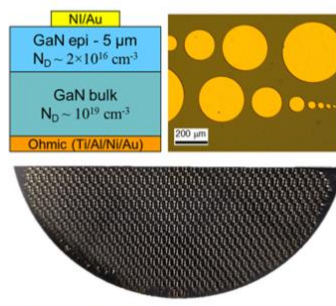
During the second year, the investigations on the innovative barrier material (Aluminium Scandium Nitride, AlScN) has continued, targeting a much higher current and power density than with existing transistors. Heterostructures exhibiting 2DEG resistances as low as 240 ohm/sq and an enhanced GaN buffer quality on Silicon have been demonstrated using MBE, and the development of a dedicated MOCVD reactor is on-going. A spice model for AlScN-based HEMT devices under stress conditions allowed evaluating the impact of the device degradation on the converter performances.



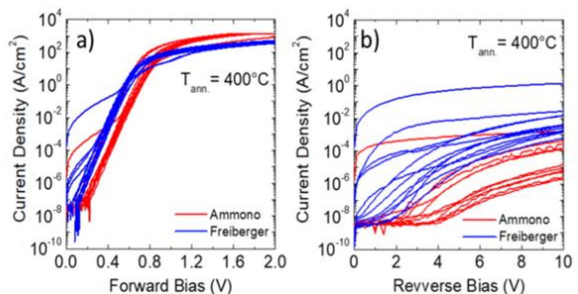
AlScN/GaN heterostructure

Finally, a benchmark on the material quality of the bulk GaN has been carried out by means of the cross-correlation of different morphological/structural/electrical analyses of the material (CL, AFM, C-AFM, TEM, HR-XRD, …) with the behavior of Schottky diodes fabricated on the epitaxial layers.


Surface morphology of epilayers on bulk GaN substrates



Schottky diodes fabricated on bulk GaN for material benchmark

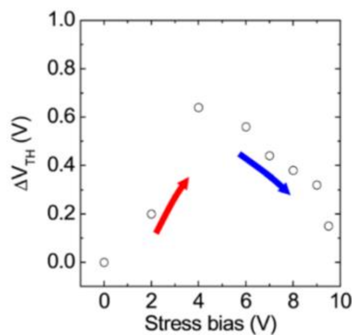


Examples of I-V characteristics of Schottky structures fabricated on different materials

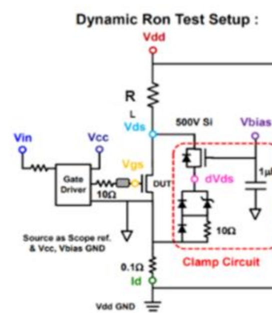
The results obtained using the substrates produced within the consortium were comparable in terms of both surface morphology, defect density and electrical parameters of Schottky diodes with those achieved with commercial state-of-the art material.

Device modelling, characterization and reliability evaluation

Intensive characterization, both at "wafer level" and on "packaged" devices, as well as modeling activities were carried out during the second year. In particular, several measurement methodologies and setups were optimized, to evaluate the R_{ON} behavior and trap-related V_{TH} instabilities in GaN HEMTs, and to pave the way for the TCAD simulation setup to be used for the GaN devices modelling. Particularly, the HW and SW debug of the automated wafer testing (EWS) for STi2GaN technology has been completed as well as the realization of custom setup for dynamic characterization both of single- and half-bridge configurations. Gate bias related instabilities have also been investigated for a better comprehension of the mechanism limiting device operation but also potentially their reliability.



Wafer-level measurements of the threshold voltage variation as a function of the stress bias in GaN HEMTs



Dynamic R_{dson} measurement setup for 650V GaN HEMT

Developed board for packaged device dynamic characterization

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). In order 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. During the second-year, particular attention was paid to these aspects. In particular, 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 the *new DCI package technology*, while those in which the dominant factor is power dissipation will use larger packages with clips on the Power signals.

Demonstrators

After having laid the foundations of the project needs through market studies, fixed the definition of the various demonstrators and identified the links between the various partners, this second year was dedicated to the demonstrator development. All demonstrator owners had close collaboration with device manufacturers to define the integration of GaN components within the systems. The expression of the device needs for each demonstrator was shared with the different Clusters, each of which proposed the adapted

components according to its portfolio. Based on that, a procurement tracking has been established to synchronize the development activities of the demonstrators. Hence, each partner is now involved in the development of their first prototype and their debugging activities. The targeted demonstrators are grouped in the following classes:

On-Board charger for smart Grid Automotive demonstrator:

- 7kW – 400V reversible on-board charger
- 22kW – 800V reversible on-board charger
- 3kW – 400V PFC stage topology evaluation
- 3kW - On-board charger

Powertrain Inverter Demonstrators

- 100kW - 400V and 800V Automotive inverter
- 8kW – 800/1000V Multilevel Inverter for Electric Traction
- 10kW – 800V Automotive inverter

Demonstrators for automotive and industrial applications

- 22kW - 400V and 800V Servo-drive Power supply
- 2kW/5kW – 400V Half-bridge converter
- 10kW – 400V Power actuator for industrial applications
- 1,8/3,6kW – 400V DCDC converter 400/12
- 100kW – 400V DCDC converter High power
- POL Dc/DC converter (48V/1,2-5V)
- 4kW – 48/12V DCDC converter
- 240W (PFC+LLC) for consumer application

For some of them, characterization activities are underway in order to start the first tests at the beginning of the third year.

System Testing and Reliability

Thanks to the close collaboration between all system development stakeholders, during the second year activities and after the definition of power application specifications and targets, electrical test equipment and reliability solutions have been consolidated. 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, in previously mentioned testing solutions, an extraordinary effort was needed to reconceive standard silicon solutions.

Market Analysis and Future Exploitation

An "*Intermediate Market Analysis*" has been completed by the industrial partners, confirming the great potential of GaN technology. In fact, the GaN market is expected to grow more than 10 times from $78 M in 2021 to about $1 B in 2026. This assumption is strongly supported by the significant investments done in the last year from large semiconductor manufacturers like STMicroelectronics and Infineon.

The potential of GaN is also confirmed by the industrial partners from the System Level & Packaging segment.

For space constraint consumer applications with power levels up to 1kW the benefits of using GaN are obvious and already demonstrated in the market.

Communication and Dissemination Activities

The technical results, obtained during the two years of this project activities, have resulted in several publications, appeared in international journals with high impact factor, both in material and device fields (Appl. Phys. Lett., IEEE Electron Device Letters, Materials MDPI, etc.).

During the second year, GaN4AP partners participated in several international conferences and workshops, presenting the project results.

Among all the attended events, it is worth mentioning that in May 2023, at the conference WOCSCDICE-EXMATEC 2023, held in Palermo 21-25 May 2023, GaN4AP was a significant protagonist with 13 regular presentations and one invited talk.

Scientific Publications

Several papers related to the GaN4AP research activities have been published by the partners. A list of selected papers published during the second year is reported below:

- T. Sochacki, R. Kucharski, K. Grabianska, J. L. Weyher, M. Iwinska, M. Bockowski, L. Kirste, *"Fundamental Studies on Crystallization and Reaching the Equilibrium Shape in Basic Ammonothermal Method: Growth on a Native Lenticular Seed"*, Materials **15(13)**, 4621 (2022).
- C. Elias, M. Nemoz, H. Rotella, F. Georgi, S. Vezian, M. Hugues, Y. Cordier, "*Influence of the temperature on growth by ammonia source molecular beam epitaxy of wurtzite phase ScAlN alloy on GaN*", APL Mater. **11**, 031105 (2023);
- C. Mauduit, T. Slimani Tlemcani, M. Zhang, A. Yvon, N. Vivet, M. Charles, R. Gwoziecki, D. Alquier, "*Importance of layer distribution in Ni and Au based ohmic contacts to p-type GaN*", Microelectronics Engineering **277**, 112020 (2023).
- G. Greco, P. Fiorenza, F. Giannazzo, C. Bongiorno, M. Moschetti, C. Bottari, M.S. Alessandrino, F. Iucolano, F. Roccaforte, "*Threshold voltage instability by charge trapping effects in the gate region of p-GaN HEMTs*", Appl. Phys. Lett. **121**, 233506 (2022).
- Chini, N. Zagni, G. Verzellesi, M. Cioni, G. Giorgino, M. Nicotra, M.E. Castagna, F. Iucolano, "*Gate-Bias Induced R_{ON} Instability in p-GaN Power HEMTs*", IEEE Electron Devices Letters **44(6)**, 915-918 (2023).
- A. Vella, G. Galioto, G. Vitale, G. Lullo, G.C. Giaconia, "*GaN and SiC devices characterization by a dedicated embedded measurement system*", Electronics **12**,) 1555 (2023).

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

Event Organization

In the last year, GaN4AP partners were strongly involved in the organization of scientific events, related to the project activities. In particular, in September 2022, during the EMRS-Fall Meeting 2022 (Warsaw, Poland, 19-23 September 2022), DTSMNS-CNR, with the collaboration with CNRS-CRHEA and IUNET-UNIPD, organized the Symposium G entitled *"New frontiers in wide-band-gap semiconductors and heterostructures for electronics, optoelectronics and sensing"*. With about 100 participants, this symposium was one of the most successful of the entire EMRS-Fall 2022 Meeting. Bulk GaN and AlScN materials were among the topics discussed in this forum in dedicated invited talks and sessions. Moreover, in the framework of the annual conference Nanoinnovation 2022 (Rome, Italy, 19-23 September 2022), DTSMNS organized a workshop entirely dedicated to the project activities and entitled *"The contribution of GaN4AP project for power conversion in smart mobility and energy consumption"*.

Finally, in May 2023, some of GaN4AP partners (DTSMNS, DTSMNS-CNR, DTSMNS-UNIPA, IUNET-UNIPD) organized the international conference WOCSCDICE-EXMATEC 2023, held in Palermo 21-25 May 2023. This event had a strong scientific focus on wide band gap semiconductors, and in particular on nitride materials, devices and applications. The conference was attended by around 130 participants from academia and industry, and 98 oral presentations were given. GaN4AP project was actively present with 13 regular oral presentations and 1 invited talk. During the conference, the project was advertised with a desk located in the exhibition area, where the flyers were distributed to the participants and the project outcomes illustrated by means of two posters.

Second Review Meeting in Cergy

The second review meeting of GaN4AP was held in Cergy (France) on July 4-5, 2023, at the Valeo premises. The partners were involved in two days of intensive and fruitful discussions on the most relevant results and future activities of this ambitious project, in the presence of the KDT-JU Project Officer and of the two independent experts.

Follow us on the web

https://www.gan4ap-project.org/

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
Total Cost: € 64 021 545,82
EU Contribution: € 15 320 914,36
Project Coordinator: Ing. Leoluca Liggio (DTSMNS)
Scientific Coordinator: Prof. Gaudenzio Meneghesso (IUNET)