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GaN4AP – Gallium Nitride for Advanced Power Applications

First Newsletter – July 2022

Introduction

Power Electronics is a set of techniques associated with the efficient conversion, control and conditioning of electric energy from the source to the load. In this context, wide band gap semiconductors, like silicon carbide (SiC) or gallium nitride (GaN) are excellent materials for the next generation of high-power devices, offering superior properties with respect to the traditional silicon devices.

GaN-based technology delivers features that offer the perfect match to serve the challenges of future power systems with its **high efficiency and fast switching,** thanks to excellent physical characteristics in terms of energy gap, breakdown electric field, saturation electron velocity and mobility.

In this scenario, the three-year European project **GaN4AP (Gallium Nitride for Advanced Power Applications)**, funded in the framework of the EU call H2020-ECSEL-2020-1-IA, was launched in June 2021 by the ECSEL-JU, the Public-Private Partnership keeping Europe at the forefront of technology development.

GaN4AP has the ambitious target of making the GaN-based electronics to become the main driving power technology in all energy converter systems.

Objectives

GaN4AP project will develop…

… innovative Power Electronic Systems for power conversion and management with advanced architecture and circuit topology based on state-of-the-art GaN-based High Electron Mobility Transistors (HEMTs).

… an innovative material (Aluminium Scandium Nitride, AlScN) combined with advanced growth and process solutions, which can provide outstanding physical properties for highly efficient power transistors in terms of enhanced current density.

… a new generation of vertical power GaN-based devices on MOSFET architecture with vertical p-GaN inversion channel for safe power switching up to 1200V.

… new intelligent and integrated GaN solutions (STi2GaN) both in System-in-Package (SiP) and Monolithic variants, which will allow large-scale deployment of E-Mobility power converters.

Participants

The GaN4AP Consortium is composed of 36 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).

Project Structure: Clusters & WPs

The project activities are organized in **4 clusters**, strongly linked each other on the common path through the full development of the GaN-based technology up to a high TRL (6-9). This will allow the implementation of this technology in Automotive and Industrial systems to contribute to i) increasing the Energy Efficiency, ii) lowering system volume and weight, iii) lowering the system costs.

Cluster 1: Development of **innovative Power Electronic Systems for power conversion and management** with advanced architecture and circuit topology based on state-of-the-art GaN-based High Electron Mobility Transistors (HEMTs) available in a **new concept high-frequency packages** that can achieve the requested **99% power conversion efficiency**. Automotive and renewable energy power systems (On Board Chargers, Power converters, etc.) will be addressed.

Cluster 2: Assessment of **advanced lateral 650 V HEMTs**: an innovative material (Aluminium Scandium Nitride, AlScN) with much higher current and power density than with existing transistors will be studied. Ultra-low resistances and insulated (metal insulator semiconductor, MIS) gate devices yielding high efficiency and better robustness will be acquired from an external source. Innovative packaging solutions tailored to the new generation of lateral transistors will be developed.

Cluster 3: Assessment of a new generation of **vertical power devices** on **GaN substrates** based on MOSFET architecture with vertical p-GaN inversion channel for safe power switching up to 1200 V. After a detailed material benchmark and characterization, vertical GaN power MOSFETs will be developed and integrated in a couple of power switching system demonstrators (100 kW-800 V traction inverter, 1200 V (blocking voltage) half-bridge converter).

Cluster 4: Development of a **new generation of E-Mobility power converters** based on new topologies, taking benefiting from peculiar advantages of intelligent and integrated GaN solutions (STi^{2}GaN) both in System-in Package (SiP) and Monolithic formats.

The work of the 4 clusters is implemented through **9 Work Packages (WPs)**:

WP1 - Management and Coordination (DTSMNS): dedicated to the usual management activities, risk analysis, permanent and close monitoring with all partners of the activities, in order to enable the control of the project progress

WP2 - Requirements and Specifications (aPSi3D): definition of the application requirements and align them with each technology capabilities. The targeted requirements and specifications will address technologies, devices, tests and applications.

WP3 - Material, device technology and product development (IHPP): development of materials and device processing. This work package will have the vital role of assessing the capabilities of new GaN-based power devices (AlScN/GaN for lateral HEMTs and vertical-GaN Trench MOSFET) as well as the monolithic integration of GaN devices in a System-in-Package (SiP).

WP4 - Device modelling, characterization and reliability evaluation (IUNET): dedicated to device characterization, numerical simulations and reliability testing to a full understanding of device functionalities and limitations, to achieve the best exploitation of all targeted technologies for the development of efficient and reliable power systems.

WP5 - System integration, packaging and passive (ST-I): development of new packaging concepts and assembly techniques of GaN power devices for their use in the selected demonstrators. Other efforts include the integration of transformer into printed circuit board (PCB) by planar design to save space, design and simulation of high-frequency inductors and finally inductor prototypes for demonstrators.

WP6 – Demonstrators (Valeo Siemens – F): design and development of system demonstrators, realized in order to evaluate and promote the potential of GaN devices and advanced packages on system functionality level. GaN-based inverters, converters and battery onboard chargers for Automotive.

WP7 - System Testing & Reliability (Valeo-Siemens DE): experimental characterization of the GaN-based demonstrators and prototypes. The demonstrators realized within GaN4AP will be compared and benchmarked with state-of-the-art systems based on Si or SiC transistors. This will be driven, for example, in terms of (part-load) efficiency, dynamic behavior, thermal properties as well as system reliability and robustness.

WP8 - Communication & Dissemination (DTSMNS-CNR): definition and execution of the communication and dissemination strategies in a logical sequence during the project duration, both towards the scientific community and potential stakeholders, as well as to the wide public.

WP9 – Exploitation (Würth): support all partners to get the maximum impact on their business from the technical and scientific actions conducted within the project, and to be competitive in the rapidly developing GaN market.

Main results achieved during the first year

Samples

A large number of 650V samples have been handed out to partners, primarily academic institutions, but more are available for any other partner. A report has also been issued that compares different packaging options available from cluster 1

Requirements and Specifications

The definition of requirements and specifications has been carried out in the first year, in order to have state-of-the–art demonstrators in the 4 clusters. The team has shared knowledge and expectations to define achievable targets for the various demonstrators. Die technology targets, packaging, and maturity of the solutions were identified as critical challenges.

Material, device technology and product development

First analyses of recessed-gate AlGaN/GaN lateral HEMTs was performed. Moreover, the requirements for the precursors needed for AlScN/GaN growth have been defined, along with the characterization methods for AlScN/GaN heterostructures and AlScN layers. The activities devoted to vertical power devices dealt with the development of GaN substrates, homoepitaxy of GaN films for drift layers and the first benchmarking activities using Schottky diode fabrication and evaluation.

Device modelling, characterization and reliability evaluation

Characterization of “on-wafer” and “packaged” normally-off GaN HEMT devices started during this first year, considering several aspects, e.g. from the validation of the elementary bricks and characterization of gate stack in normally-off HEMTs, to the setting of V_{TH} and R_{ON} analyses during switch mode operation, up to preliminary characterization in Half Bridge Pack including 2 GaN devices. Simulation activity on vertical GaN devices has also been started.

System integration, packaging and Passive

The main and distinctive characteristics of normally-off HEMTs to be made available by ST to the partners for different purposes have been defined. Originally, packages such as the new 2SPAK and PowerFLAT8*8 had been proposed with only two chip sizes at 650V. Moreover, also 100V GaN switches, not considered in the original GaN4AP plans, have been added to expand the project scope.

Demonstrators

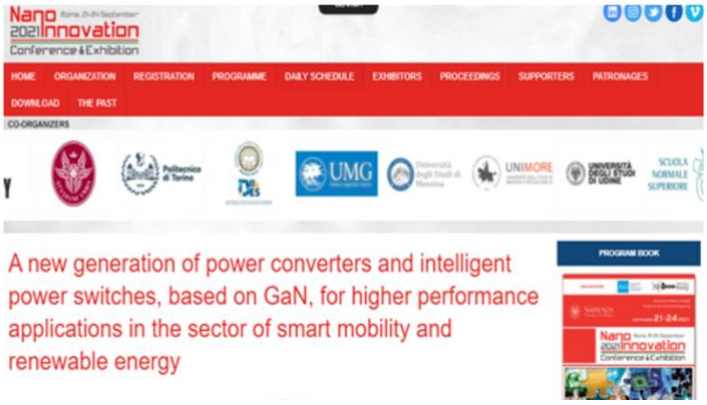
The activities in WP6 have aimed at identifying the requirements and definition of the several demonstrators. In particular, a clear view of GaN devices from cluster 1 was given, allowing the partners to synchronize their activities with this new update. A specific interest was shown on passive and magnetic topic to identify several link between the partners. Regarding demonstrators, several topologies / architectures and designs were studied and launched to allow the integration of these GaN devices coming from cluster 1 to 4.

System Testing and Reliability

The development of application-driven test systems on an extensive analysis of available power electronics topologies in the literature was carried out as a basis for further investigations and on the enhancement of a double-pulse test-bench for GaN power modules. VSeA-DE became part of the wide bandgap - GaN workgroup in the AQG 324 standardisation committee to spread the project results in the technical community.

Communication and Dissemination Activities

During the first year, GaN4AP partners started advertising the running activities at international conferences and workshops. First, the project was presented by partners DTSMNS, IUNET, Valeo and Würth in a dedicated session of Nanoinnovation 2021 (Rome, 23 September, 2021).



Then, DTSMSN-CNR and IUNET-UNIMORE have been involved as Guest Editors in following Special Issues: (1) *Feature Papers in Electronic Materials Section* - Materials MDPI, Published on February 2022. (2) *Wide-Bandgap Semiconductors* - Crystals MDPI, Deadline for submission: 30 November 2022. (3) *Wide Bandgap Based Devices: Design, Fabrication and Applications, Volume III* – Micromachines MDPI, Deadline for submission: 31 December 2022.

In May 2022, some of the project partners (DTSMNS-CNR, CNRS-CRHEA, UNITOU, IUNET-UNIPD, ST-I and CEA) presented their results in the International Conference WOCSDICE EXMATEC 2022, held in Ponta Delgada (Azores, Portugal), showing preliminary achievements obtained in the framework of the project activities. One of these oral presentations, given by M. Fregolent (IUNET-UniPD), was recognized with the Student Award of the Portuguese Physics Society for the Best Presentation in the area of Physics and Applications.

Open Access Publications

The first papers related to the GaN4AP research activities have been published by the partners in open-access journals:

- F. Roccaforte, F. Giannazzo, F. Greco, *Ion Implantation Doping in Silicon Carbide and Gallium Nitride Electronic Devices*, Micro **2**(1), 23-53 (2022).

- R. Lo Nigro, P. Fiorenza, G. Greco, E. Schilirò, F. Roccaforte, *Structural and Insulating Behaviour of High-Permittivity Binary Oxide Thin Films for Silicon Carbide and Gallium Nitride Electronic Devices*, Materials **15**, 830 (2022).
- K. Grabianska, R. Kucharski, T. Sochacki, J.L. Weyher, M. Iwinska, I. Grzegory, M. Bockowski, *On Stress-Induced Polarization Effect in Ammonothermally Grown GaN*, Crystals, **12**, 554 (2022).
- M. Bockowski, I. Grzegory, *Recent progress in crystal growth of bulk GaN*, Acta Physica Polonica A, **141 (3)**, 167-174 (2022).
- L. Liggio, *The material of the future*, Platinum on-line, pag. 107, March 2022.

Events Organization

During this year, the partners will be strongly involved also in the organization of interesting technical events.

In June 2022, IUNET-UNIPD organized the traditional GaN Marathon 2022 – Venice, Italy, June 20-22, 2022.

The conference was attended by about 150 scientists from all over the world involved in Gallium Nitride research. In particular, 63 talks from experts from academy and industry (some of them were GaN4AP partners) enabled to discover the last milestones of GaN.

Then, in July 11-15, 2022 the Summer PhD School of Information Engineering (SSIE) was organized by IUNET-UNIPD in Bressanone, Italy.

This year's edition have seen record numbers with a whopping 145 participants from all over Italy. A dedicated session entitled “Gallium Nitride and semiconductors for power conversion: present and future of materials for energy efficiency” has been organized.

In the coming months, DTSMNS-CNR, CNRS-CRHEA and IUNET-UNIPD will be involved in the organization of the Symposium G *"New frontiers in wide-band-gap semiconductors and heterostructures for electronics, optoelectronics and sensing"*, to be held at EMRS 2022 Fall Meeting in Warsaw, Poland, September 19-22, 2022.

First Review Meeting in Brussels

After one year of project, the GaN4AP Consortium had finally the possibility to meet in person during the first review meeting held in Brussels (Belgium) on June 29-30, 2022, at the KDT-JU premises. They were two days of intensive and fruitful discussions on the first achievements and the future activities of our ambitious project, in the presence of the KDT-JU Project Officer and two independent experts.

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

GaN4AP – GaN for Advanced Power Applications

GaN4AP project details

Call for proposal: H2020-ECSEL-2020-1-IA-two-stage
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EU Contribution : € 15 320 914,36
Project Coordinator: Ing. Leoluca Liggio (DTSMNS)
Scientific Coordinator: Prof. Gaudenzio Meneghesso (IUNET)