Nitride EpiWafer Production in Europe

NEWPIE

Abstract

Reference:	Ab_4000104400/11/ NL/EM
Contract Number:	4000104400/11/ NL/EM
ESA Contract officer:	Andrew Barnes
Issue:	1
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Hasselt, Belgium
March 2015

ESA Study Contract Report

ESA Contract No.:	Establishment of a commercial GaN epitaxial production facility in Europe		Contractor:
4000104400/11/NL/EM			**EpiGaN nv**
ESA CR( ) No.	STAR CODE:	No. of Volumes:	Contractor's Ref.:

Abstract:

This document summarizes the activity performed by EpiGaN within the ESA project "Nitride Epiwafer production in Europe" (NewPie). The major objective of this project is to establish a commercial production facility in Europe for manufacture and supply of GaN epitaxy on large diameter Si and SiC substrates for electronics applications such as Power RF/Microwave or High Voltage Switching. EpiGaN, founded as an independent commercial spin-off from imec in 2010, is positioned as a pure-play epiwafer supplier active in the field of III-nitride materials for electronics. Its mission is to provide world-leading GaN-on-Si epitaxial material solutions for top performance devices, outperforming Si components. The aim of this ESA activity was to support EpiGaN in installing its new independent production site with its own reactors and characterization tools for wafer quality control, in transferring the technology from imec, and in testing adequacy of its product offering to target industrial customers. This document reports on the EpiGaN activity starting from the commissioning and installation of its production facility followed by the establishment of epi characterization techniques, the introduction of quality control procedures, the epitaxial growth trials and customer supply and, eventually, on the development of advanced epitaxial wafer manufacturing.

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Revision History

Revision Number	Date	History
1	March 2015	Initial release, Author: EpiGaN

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I. Introduction

EpiGaN nv is a spin-off of imec founded in 2010 as an independent commercial entity. It positions as a pure-play open market supplier of GaN-on-Si and GaN-on-SiC epiwafers to the semiconductor industry targeting fast-growing power electronics, RF ad sensor markets. Its mission is to provide world-leading GaN-on-Si epitaxial material solutions for top performance devices, outperforming Si devices. In 2011, EpiGaN answered to the ESA Announcement of Opportunity 1-17/11/NL/EM on the "Establishment of a commercial GaN epitaxy production facility in Europe" with statement of work QCT/ARB/SOW-2010-2, with the proposal "Nitride Epiwafer production in Europe" (NEWPIE). This document summarizes all the activities performed by EpiGaN within this ESA activity. The main purposes were (1) to ensure a successful technology transfer from the R&D environment of imec towards EpiGaN new production site and (2) to successfully implement a commercial production of GaN epiwafers, with high quality standards, appropriate quality control procedures and professional wafer fab management and (3) to establish EpiGaN in the market as a preferred material supplier for nitride electronics. The work logic was split in three phases which are shortly described.

II. Phase 1

This ESA activity started with a market analysis of GaN electronics, both for power and RF application, which reviewed EpiGaN competitors, target customers and/or potential partners. Next to this, EpiGaN has been working on the installation of its production facility. GaN epiwafers are manufactured by Metal-Organic Chemical Vapor Deposition (MOCVD). An existing clean room located in Hasselt (Belgium), larger than 500m^2, has been modified according to EpiGaN specific needs in order to install the MOCVD systems (Figure 1). Initially, two reactors were commissioned during Phase 1 of this project. A third reactor has since been installed in 2014. In order to qualify the wafers, a complete Wafer Qualification Line has been set-up in a dedicated clean-room (Class 10000). To determine the crystalline quality and estimate the defect concentration, a fully automated High Resolution-X Ray Diffraction (HR-XRD) tool was installed, operating in batch mode. The wafer bow is measured by using a high-speed and high-accuracy laser displacement sensor. To determine the electrical channel properties over the full wafer by non-destructive measurements, a contactless Hall and sheet resistivity tool was installed. To evaluate the wafer surface quality, a surface analysis tool, is systematically used. EpiGaN has also access in subcontract mode to external device processing for wafer evaluation. The commissioning of the clean-room, of the production and characterisation tools, as well as technology transfer, were very efficient and successful , as first wafers were available for external shipment in April 2012.

Figure 1 EpiGaN MOCVD area

III. Phase 2

After the acceptance and start-up phase of the MOCVD reactor and the installation of the characterization laboratory successfully performed within phase 1, phase 2 focused first on epitaxial reactor growth process stabilization, then on the wafers supply and evaluation by industrial partners. The first part of this phase addressed the epitaxial growth process stabilization. For each tool and for the key growth parameters, EpiGaN implemented a database where data coming from each tool are collected. Also, a real-time wafer traceability system was implemented to trace wafers from incoming substrate to outgoing wafers. The second part of Phase 2 consisted in an external wafer evaluation exercise by industrial target customers. Four industrial partners expressed their interest in this ESA activity, active either in RF/Microwave and/or in High Voltage switching components. Each partner processed EpiGaN wafers using its internal processes (incoming wafer acceptance tests, device process flow and process control monitoring procedures) and provided feedback on epi-wafer evaluation and related device performance.

As far as High Voltage wafers were concerned, industrial partners' feedback evidenced an excellent uniformity of the electrical wafer characteristics (sheet resistance, 2DEG mobility and carrier density). This further resulted in high uniformity of device electrical measurements: contact resistance, threshold voltage, gate leakage current, drain saturation current and drain leakage current in the off-state. The high voltage characterization was performed in terms of buffer and device breakdown voltage with either the Si substrate grounded or floating. As expected for GaN-on-Si based devices, the breakdown voltage is triggered by the vertical leakage current and, consequently, the breakdown voltage saturates for large ohmic contact distance. Within this project, the device was targeting 600V operation mode with a leakage current as low as 1uA/mm.

As far as RF applications are addressed, the focus of the evaluation is at core of the GaN technology most critical issue, the so-called “dispersion effect”, also often referred as gate lag and drain lags. One of the partners showed the superiority of in-situ SiN passivation, on EpiGaN wafer, over the ex-situ SiN PECVD passivation provided by an external wafer supplier in terms of dispersion effects. The recovery time was 6.2ms in the wafers supplied by the third-party, where ex-situ PECVD SiN was used to passivate the RF structures. This recovery time significantly reduces to 22µs in the EpiGaN wafers thanks to the in-situ SiN passivation layer. This benchmark exercise evidenced the advantage of using in-situ SiN passivation to achieve low dispersion devices on EpiGaN wafers.

This external evaluation exercise has been very fruitful allowing external industrial partners to evaluate EpiGaN wafers and has set up a good basis for further supplier-customer relationships. The development of GaN devices on EpiGaN wafers by European device manufacturers represents the first establishment of a European value chain with the combination of GaN European Wafer supplier and European foundries/device manufacturers.

In this phase, EpiGaN also worked on the implementation of its Quality Assurance System. While formalising Quality Assurance Policy for ESA manufacturing line survey, EpiGaN, focused on setting up procedures in view of ISO9001 qualification. This is perfectly in line with one of the key objectives of this project, i.e. to become a recognised industrial player in Europe.

IV. Phase 3

Phase 3 addressed the development of advanced epitaxial wafer manufacturing in order to remain competitive and satisfy the future needs of customers. Three areas were selected for advanced GaN epitaxy investigation: (i) optimised epi for mm-wave devices on larger SiC substrates; (ii) growth on large diameter 200mm Si substrates; (iii) exploration of advanced engineered structures.

First, EpiGaN further improved the epitaxial growth of GaN based HEMT on 4 inch semi insulating SiC substrate for RF applications. It focused in particular on a pure ultrathin AlN barrier layer grown on GaN-based. These wafers were supplied to a university partner for device testing. Electrical data showed a maximum oscillation frequency of 120 GHz and a cut-off frequency of 60 GHz. CW measurements were performed up to 40 GHz where a PAE above 30%, a power density around 2.5W/mm and a linear gain of 7 dB was achieved (F. Medjdoub (IEMN), to be published). Due to the ultrathin AlN barrier layer, these devices represent a unique combination of high current density, high polarization charge, high breakdown, high frequency devices grown on SiC for RF applications.

A second activity within this phase was the epitaxy growth trials of nitride materials on 200mm Si substrate. The technology already assessed on 6 inch substrates for both RF and HV applications was successfully transferred on 200mm substrate. The RF buffer was developed on 725um thin 200mm substrate and the thick buffer for HV applications are developed on two types of substrate having different thickness. The wafers were crack-free and had a bow below 30 µm which is acceptable for Si CMOS fabs. They show high crystal quality and excellent uniformity. From an electrical point of view, they showed excellent leakage performance with buffer leakage current below 0.1µA/mm up to 700V. Moreover, the destructive vertical breakdown is above 1000V.

A third activity in this phase reported on advanced epitaxy structure development regarding three main fields of the GaN on Si-based devices such as high frequency, high voltage and low conduction losses and thermal management. EpiGaN studied the advanced structure based on in-situ SiN/AlN/GaN for high frequency and, if combined with the back local Si removal technology, also for high voltage switching applications. The pure ultra-thin AlN barrier layer grown on top of a GaN buffer leads to a high current density, associated to high oscillation frequency for RF structures and low conduction losses in the on-state of a switching device. Moreover, in high voltage applications the achievement of high breakdown voltage for GaN on Si device has been a challenge due to the limitations of the Si substrate itself. The back local Si removal technique is a good advanced solution to achieve high breakdown voltage because it allows the use of thin buffer layers structure. Therefore, the in-situ SiN/AlN/GaN structure together to the back local Si removal technology is a unique combination of low specific on resistance and high breakdown voltage. Next to that, thermal management is also an important topic for GaN on Si devices due to the poor thermal conductivity of the Si substrate. EpiGaN investigated the use of CVD grown diamond to cap the full structure to reduce self-heating effect.

V. Conclusion

This document summarizes the all activity performed by EpiGaN within this ESA activity “Nitride Epiwafer production in Europe” (NEWPIE). After successfully installation of its production and characterization line, EpiGaN demonstrated a successful technology transfer from the R&D environment of imec towards EpiGaN new production site. They also successfully implemented a commercial production of GaN epiwafers, with high quality standards, appropriate quality control procedures. .

NewPie project has thus significantly contributed to the set-up of a European pure-play, open-market GaN wafer manufacturer for electronics. Today, EpiGaN employs 10 people and is delivering wafers worldwide for Power, RF or Sensor type of applications, either on Si or SiC substrates, addressing very fast-growing markets. Excellent device results have been demonstrated either at mm-wave operation (40GHz) or high voltage (600V) on EpiGaN wafers, showing their adequacy for demonstrating GaN devices outperforming current Si components. This is in particular thanks to the in-situ SiN passivation capping layer offered by EpiGaN. Exploration of advanced structures further evidenced the suitability of in-situ SiN for growing very low sheet resistivity wafers, based on a binary barrier AlN. More importantly, within this project, possible commercial routes to fully independent European value chain for producing GaN components have been evidenced.