Materials Science Forum
ISSN: 1662-9752, Vol. 1062, pp 146-151
doi:10.4028/p-369665

Submitted: 2021-12-09
Revised: 2022-03-10
Accepted: 2022-03-10
Online: 2022-05-31

Opening Through 200 mm Silicon Carbide Epitaxy

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Keywords: 200 mm, epitaxy, 4H-SiC, thickness uniformity, doping uniformity, run-to-run, defects

Abstract. In this paper, the performance of a new CVD reactor (called PE1O8) designed by LPE and developed in the European project REACTION to process uniform 4H-SiC homoepitaxy on 200 mm substrate is reported. Its tunable multi-zone injection system and new gas delivery configuration ensure the uniform gas distribution throughout the substrate. Excellent thickness and doping uniformity on 200 mm substrates are achieved with run-to-run variation less than 1.4% and 5.6% respectively.

Introduction

SiC outperforms Si in many applications, owing superior electronic properties such as high temperature stability, wide energy band gap, high breakdown electric field strength, and high thermal conductivity. Nowadays, electric vehicles traction systems are undergoing significant improvements upon availability of SiC metal–oxide–semiconductor field-effect transistors (MOSFETs), due to their higher switching speed, higher operation temperature, and lower thermal resistance [1-4]. In the last years, the market for SiC-based power devices has been grown very rapidly; consequently, the demand for a high quality, defect-free, and uniform SiC materials is increased.

In the last decades, 4H-SiC substrate suppliers were able to enlarge wafer diameter from 2 inch to 150 mm (keeping the same crystal quality). Today the mainstream wafer size for SiC devices is 150 mm while, in order to reduce the production cost per unit device, some device manufacturers are in the early stages of setting up 200 mm fabs [5]. To realize this aim, alongside the need for commercially available 200 mm SiC wafers, the ability of performing uniform SiC epitaxy is highly demanded. So, the next challenge after achieving decent quality 200 mm SiC substrates would be to perform high quality epitaxial growth on those substrates.

Engaging in REACTION project [6], LPE has designed and manufactured a horizontal single wafer hot-wall fully automatic CVD reactor (named PE1O8) equipped with a multi-zone injection system able to process up to 200 mm SiC substrates. Here we report its performance on 150 mm 4H-SiC epitaxy and the preliminary results of 200 mm epi-wafers.

Results and Discussion

PE1O8 system design and features. PE1O8 is a fully automated cassette-to-cassette system, designed to process up to 200 mm SiC wafers. Format switching between 150 and 200 mm has been made possible minimizing tool downtime. Heat up phase reduction fosters productivity, alongside automation reduces man labor improving quality and repeatability.

To ensure an efficient and cost competitive epi-process, three main factors are reported: 1) fast process, 2) high uniformity in thickness and doping, 3) minimized defect formation during the epi-process. In PE1O8, the small graphite mass and the automatic load/unload system permit to complete one standard run in less than 75 minutes (standard 10 μm Schottky diode recipe using a growth rate of 30 μm/h). The automatic system permits to load/unload at high temperature. As a result, rump up

and cool down time are very short, while bake out step has been suppressed. This ideal condition permits to grow real undoped material.

The compactness of the machine and its three-channel injection system lead to a versatile system with high performances in both doping and thickness uniformities. This is inquired through computational fluid dynamics (CFD) simulations in order to guarantee comparable gas flow and temperature uniformity both for 150 and 200 mm substrate format. This new injection system, as shown in Fig. 1, uniformly delivers the gas in the central and in the lateral parts of the deposition chamber. The gas blending system enables the modification of the locally distributed gas chemical composition, further expanding the number of process parameters tunable to optimize epitaxial growth.

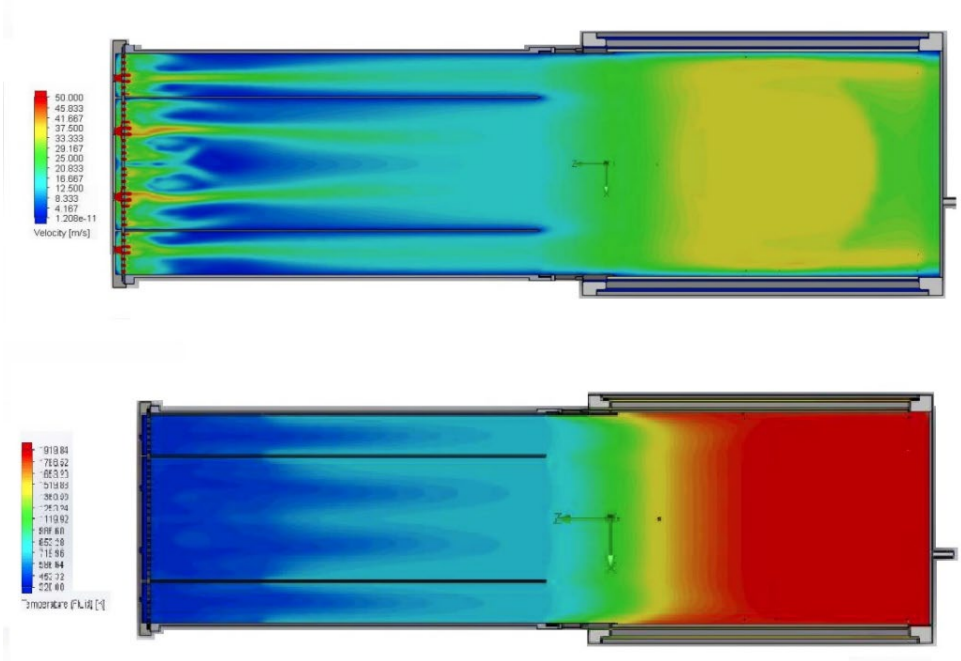


Figure 1. Simulated gas velocity magnitude (top), and gas temperature (bottom), in PE1O8 process chamber on a plane placed 10 mm above the substrate.

Additional features involve an improved gas rotation system, which uses a feedback control algorithm in order to smooth the performances and have a direct measurement of the rotation speed, and a new generation PID for temperature control.

Epitaxial process parameters. A n-type 4H-SiC epitaxial growth process was developed in a prototype chamber. Trichlorosilane and ethylene are used as silicon and carbon atoms precursors; H_2 is used as the carrier gas and Nitrogen for n-type doping. Si-face commercial 150 mm SiC substrates and research grade 200 mm SiC substrates were used to grow 6.5 µm thick 1×10^{16} cm^{-3} n-doped 4H-SiC epilayers.

In-situ etching of the substrate surface are applied using H_2 flow at elevated temperatures. After that etching step, n-type buffer layer is grown using low growth rate and low C/Si ratio to prepare a smooth layer. On top of this buffer layer, a high growth rate (30 µm/h) active layer is deposited, using higher C/Si ratio.

The process developed was then transferred to the PE1O8 reactor installed at ST-Sweden premises. Similar process parameters and gas distribution are used for both 150 mm and 200 mm samples. Due to the limited number of 200 mm substrates available, the fine-tuning of the growth parameters is postponed for future studies.

Epi thickness and doping performance of the samples are evaluated by FTIR and CV mercury probe, respectively. Surface morphology is investigated by Nomarski differential interference contrast (NDIC) microscope, and the defect density of the epilayers is measured by Candela.

Preliminary results. The preliminary results of doping and thickness uniformity of 150 mm and 200 mm epi-grown samples processed in the prototype chamber are shown in Fig. 2. Epilayers are grown uniformly along the 150 mm and 200 mm substrate surface with a thickness variation (σ/average) as low as 0.4% and 1.4%, and doping variation (σ/average) as low as 1.1% and 5.6%, respectively. The intrinsic doping value is approximately 1×10^{14} cm^{-3}.

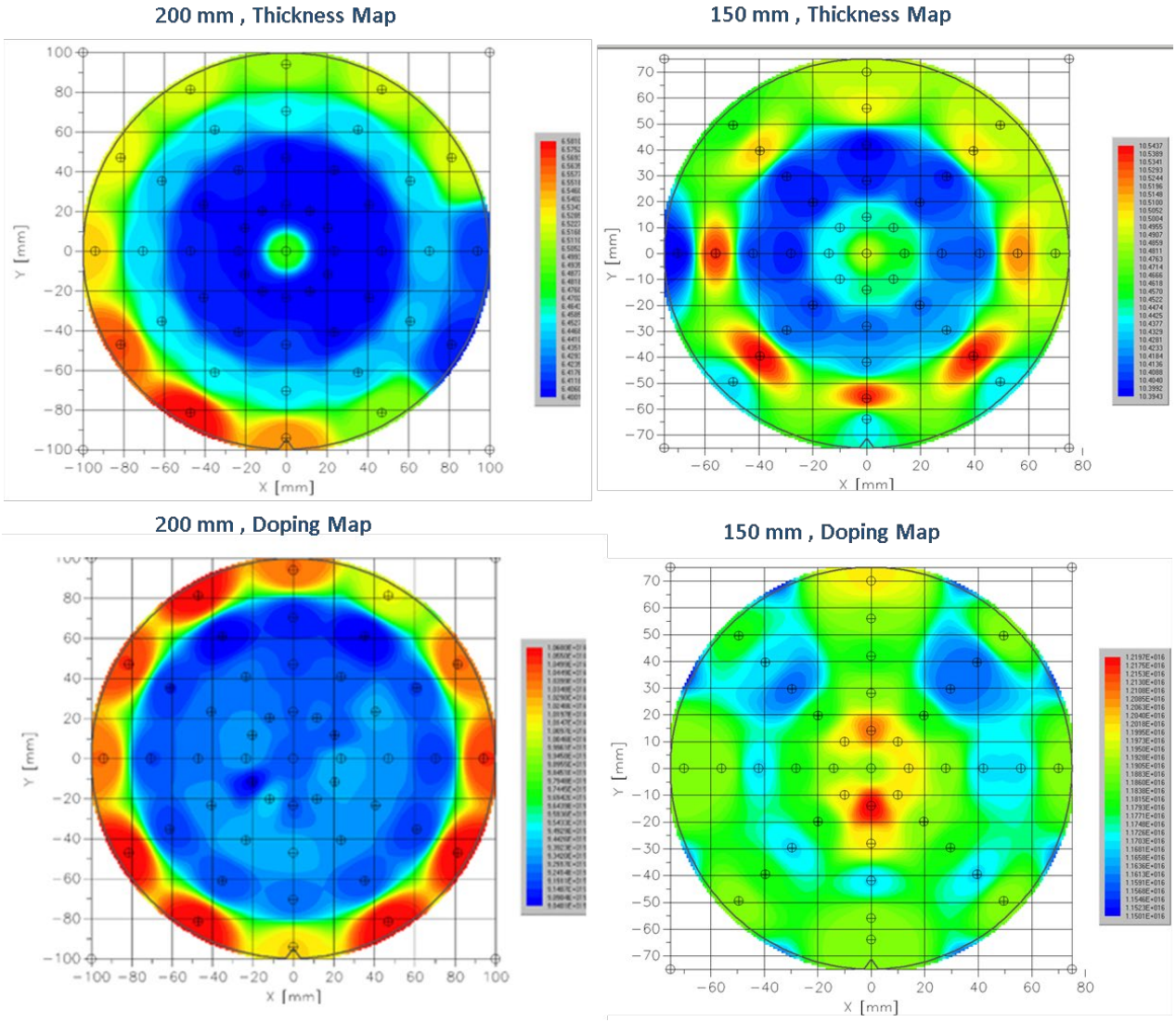


Figure 2. Thickness and doping distribution of 200 mm and 150 mm epi-wafers

The process repeatability is investigated by comparing run-to-run variation, resulting in a variation as low as 0.7% in thickness and 3.1% in doping. As shown in Fig. 3, the new 200mm process results are comparable with the state of art results previously achieved on 150 mm by PE1O6 reactor.

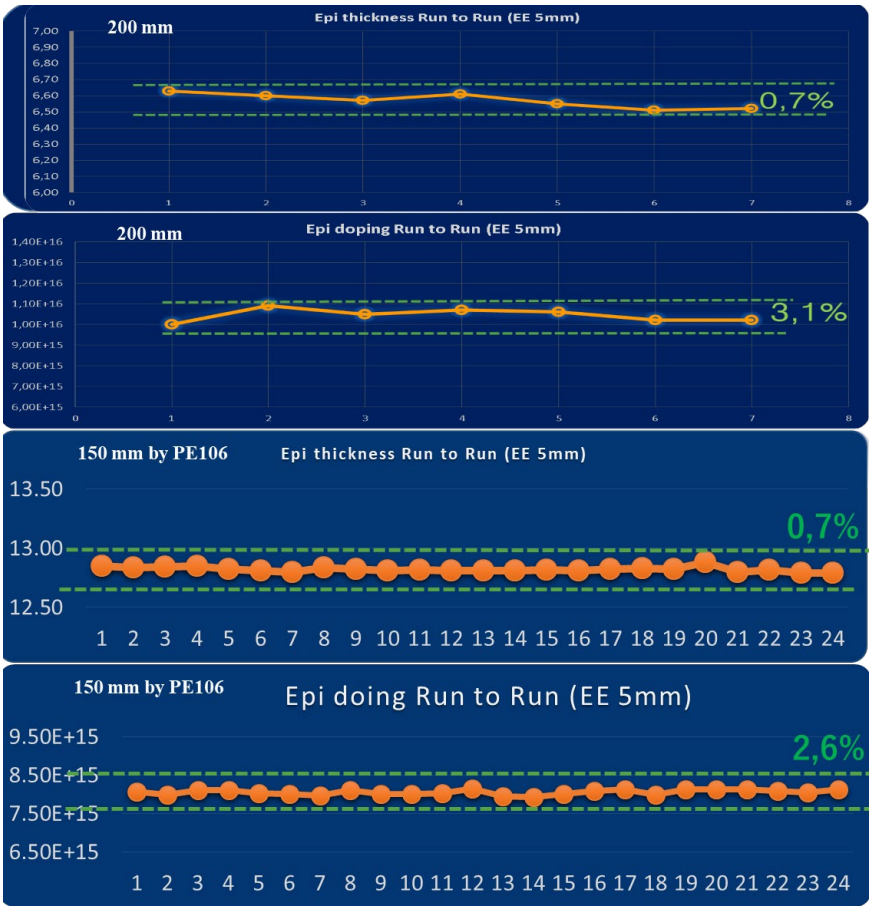


Figure 3. Run to Run thickness and doping uniformity of 200 mm samples processed by prototype chamber (Top), and the state of art 150 mm samples made by PE1O6 (Bottom)

Regarding to the samples surface morphology, NDIC microscopy confirms a smooth surface with roughness below the detectability range of the microscope.

PE1O8 results. The process was then transferred to the PE1O8 reactor. The thickness and doping uniformity of 200 mm epi-wafers is shown in Fig 4. Epilayers are grown uniformly along the substrate surface with a thickness and doping variation (σ/average) as low as 2.1% and 3.3% respectively.

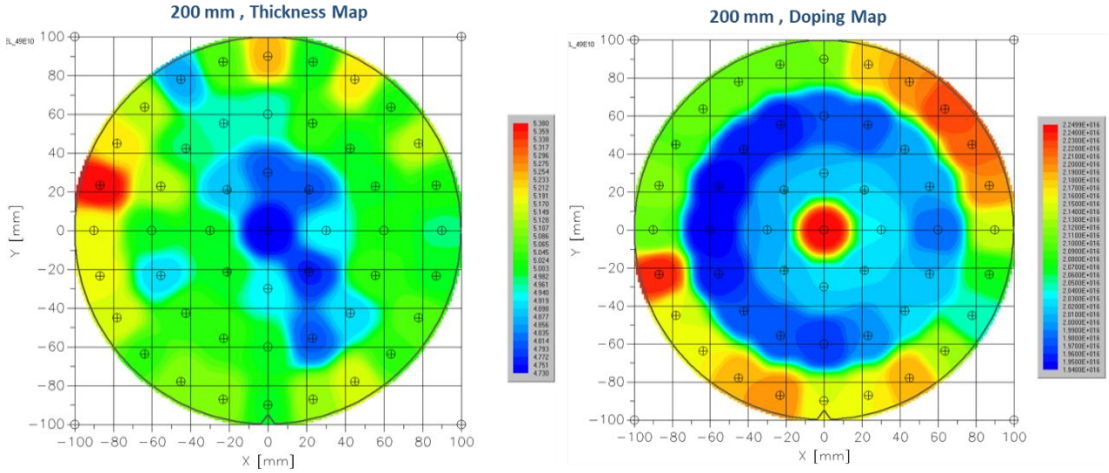
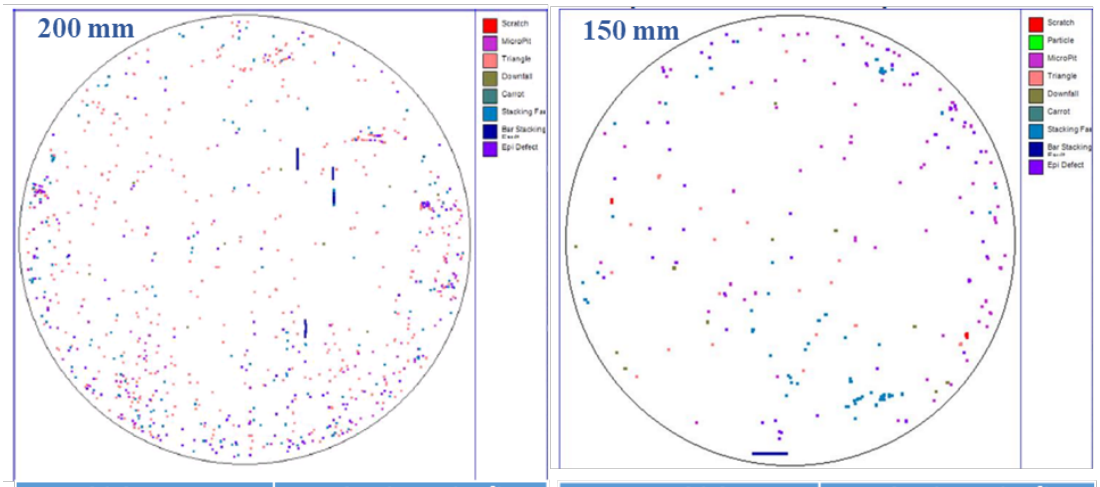


Figure 4. Thickness and doping distribution of 200 mm epi-wafer processed in PE1O8 reactor

To investigate the defect density of the epi-grown wafers candela is employed. As presented in Fig. 5 total defect density as low as 1.43 cm^{-2} and 3.06 cm^{-2} are achieved on 150 mm and 200 mm samples, respectively.

Accordingly, the Total Usable Area (TUA) after epitaxy is calculated 97% and 92% for 150 mm and 200 mm samples respectively. It worth to mention again that these results are achieved only after a few runs and further improvement is expect by fine tuning the process parameters.



Type of defect	Defect density (cm^{-2})
Scratch	0
Micropit	0.33
Triangle	1.33
Downfall	0.02
Carrot	0
Stacking fault	0.52
Bar stacking fault	0.02
Epi defect	0.63
Total	3.06

Type of defect	Defect density (cm^{-2})
Scratch	0.01
Micropit	0.52
Triangle	0.10
Downfall	0.06
Carrot	0
Stacking fault	0.37
Bar stacking fault	0
Epi defect	0.34
Total	1.43

Figure 5. Candela defect map of 6 µm thick 200 mm (left) and 150 mm (right) epi-wafers grown by PE1O8

Conclusions

The new designed PE1O8 hot-wall CVD reactor and its ability to perform uniform 4H-SiC epitaxy on 200 mm substrates is described in this paper. The preliminary results on 200 mm are very promising with a thickness variation as low as 2.1% over the sample surface and doping performance with a variation as low as 3.3% over the sample surface. The TUA after epitaxy is calculated to be 97% and 92% for 150 mm and 200 mm samples respectively, while an improvement is predicted in case of 200 mm TUA having higher substrate quality in future.
Considering that the results on 200 mm substrates reported here are based on a handful set of tests, we believe by fine-tuning the growth parameters, it is possible to further improve the results which are already close to the state of arts results achieved on 150 mm samples.

Acknowledgment

This activity is a part of the REACTION project (grant number 783158). The authors thank all the REACTION project collaborators and in particular II-V Inc. for supplying 200 mm SiC wafers and STMicroelectronics for Candela measurements.

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