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High-performance multi-wafer SiC epitaxy – First results of using a 10x100mm reactor

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Abstract. In this paper, we present first results of epitaxial layer deposition using a novel warm-wall CVD multi-wafer system AIX 2800G4 WW from AIXTRON with a capability of processing 10x100mm wafers per run. Intra-wafer and wafer-to-wafer homogeneities of doping and thickness for full-loaded 10x100mm runs will be shown and compared to results of the 6x100mm setup of our hot-wall reactor VP2000HW by AIXTRON used for device production since 2001.

Introduction

In the last years the market for SiC-based power devices has been developed very rapidly. Schottky Barrier Diodes (SBD) with blocking voltages up to 1200V are established on the market, SBD for higher reverse voltages and high-voltage PiN-Diodes are evaluated and qualified for potential applications. The cost/performance ratio was improved due to progress in the quality and size of the wafer material as well as by significant advances in the epitaxial growth of active layers. The epitaxial process plays an essential role for the device fabrication having strong influence on the electrical properties, process costs and yield.

The requirement of a cost-effective, reproducible and reliable epitaxial process led to the introduction of multi-wafer systems in 1998. Starting with multiple 35mm capability, multi-wafer systems for processing up to six or even eight large-area wafers with diameters up to 100mm are used for production today [1,2]. Important key parameters like homogeneities of doping and thickness, run-to-run reproducibility, surface roughness, and wafer throughput must be considered when evaluating epitaxial reactors and processes for industrial applications. For the production of SBD in the voltage range up to 3 kV multi-wafer systems were proven to fulfill the criteria given above for several years, whereas the first successful growth of low-doped epitaxial layers with a layer thickness of more than 70 µm on 4° off-oriented substrates in a 7x3" multi-wafer reactor was presented by SiCED not before 2008 [3].

To fulfill the increasing demand for high-quality and cost-effective epitaxial layers especially for the production of SBD in the voltage range up to 1700V a novel warm-wall multi-wafer reactor AIX 2800G4 WW by AIXTRON was installed at SiCED in 2009. With its capability of processing up to 10x100mm SiC wafers and an upgrade option for a 6x150mm setup this reactor plays an important role in a further reduction of the epitaxial costs and in a remarkable increase of the wafer throughput. Furthermore, it gives us the important ability of processing the next-generation SiC wafers with a diameter of 150mm.

Experimental details

A schematic of the new warm-wall multi-wafer AIX 2800G4 WW Planetary Reactor® is shown in Fig. 1. In contrast to the 6x100mm hot-wall reactor VP2000HW with an actively heated ceiling (for details see [4]), this new reactor exhibits a rotating RF-heated susceptor and a highly insulated ceiling. The ceiling is passively heated to temperatures above silicon's melting point (1410°C) in order to minimize silicon supersaturation in the gas phase and the associated growth-rate reduction that would otherwise result [5]. The actively cooled triple gas injector allows the variation of the gas flow pattern.

Epitaxial layers were grown at temperatures between 1550 °C and 1650 °C using silane and propane as precursors, hydrogen as carrier gas, and argon or hydrogen for the Gas Foil Rotation of the wafer carriers. Nitrogen served as n-dopant.

Commercially available 100 mm n-type 4H-SiC wafers with (0001) orientation (Si-face) and an off-orientation of 4° towards the <11-20> - direction were used as substrates.

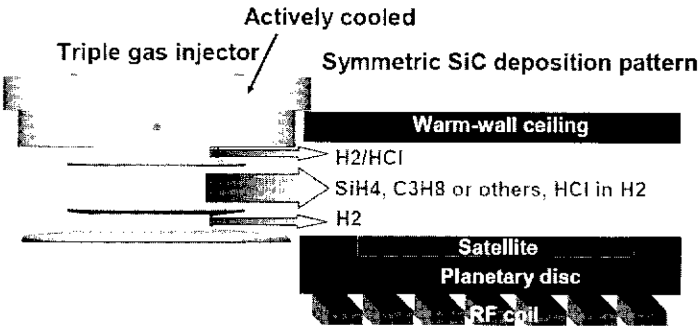


Fig. 1: Schematic of the AIX 2800G4 WW multi-wafer reactor.

Results

Temperature homogeneity. A key requirement for achieving satisfying epitaxial layer properties is excellent temperature homogeneity on each wafer and from wafer to wafer. Whereas in the hot-wall reactor a determination of the temperature homogeneity was only possible with time-consuming silicon melting tests, the new warm-wall reactor offers the possibility for an easy measurement of the wafer temperature via in-situ pyrometry (Epitune™). The measurement takes places through a small hole in the ceiling located directly above the wafer center.

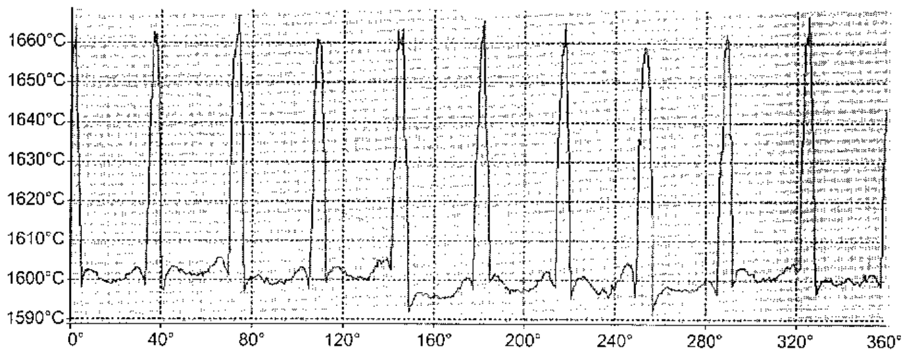


Fig. 2: Temperature distribution across the 10 wafers at 1600°C.

After each complete rotation of the susceptor the temperature distribution along the 360° turn can be analysed. Fig. 2 shows the temperature variation from wafer to wafer at 1600°C. Then ten wafers can easily be identified showing a lower temperature compared to the small susceptor ridges in-between. An excellent temperature variation of less than 6°C on each wafer and around 4°C from wafer to wafer can be determined.

Background doping level. For the production of SiC power devices with a blocking voltage up to 1700V a nitrogen doping concentration in the low to mid $10^{15}cm^{-3}$ range is necessary. This requires a considerably lower background doping level of not more than $1x10^{15}cm^{-3}$. In Fig. 3 the background doping concentration of an undoped epitaxial layer grown at a suitable carbon to silicon ratio is shown. The n-type doping concentration is highest at the center of the wafer ($5e14cm^{-3}$) and decreases towards the wafer edge to a level below $10^{14}cm^{-3}$.

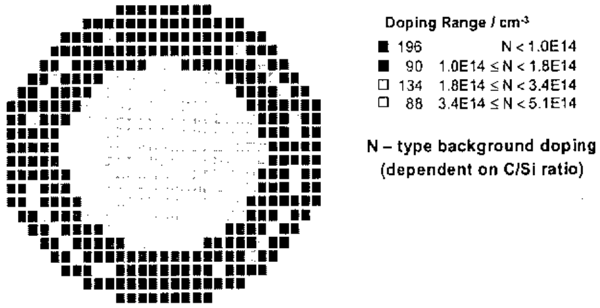
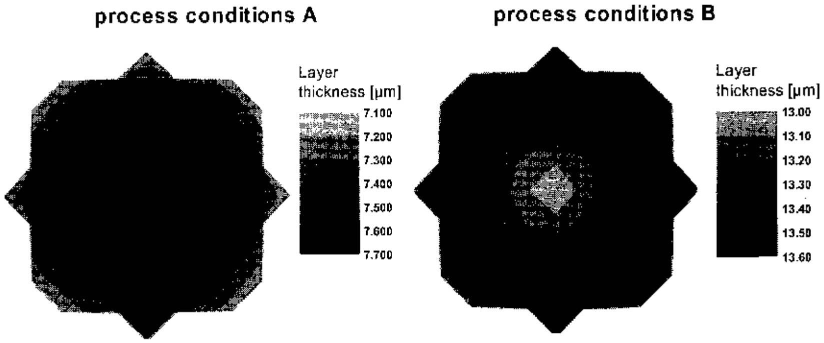


Fig. 3: Background doping concentration on a 100mm wafer (10x100mm reactor).

Intra-wafer homogeneity of thickness and doping. In Fig. 4 typical thickness uniformity profiles of a 7 µm and a 13 µm thick layer on a 100 mm wafer are shown. For process conditions A the thickness decreases from the center towards the wafer edge whereas for process conditions B the thickness increases from the wafer center towards the outside. Process B is characterized by a change of temperature, pressure, and total flow in order to achieve a higher growth rate. Clearly, the axial symmetric distribution, caused by the wafer rotation, can be seen. Typical values of sigma/mean and max-min/mean with an edge exclusion of 5 mm are 1.0-1.5 % and 4.1-4.9 %, respectively, only slightly depending on process conditions.

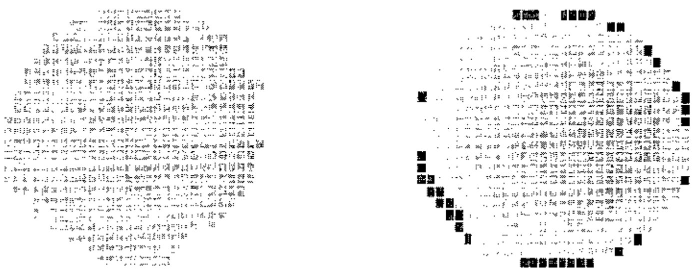


growth rate	= 5.0 µ/h	growth rate	= 6.6 µ/h
mean thickn.	= 7.4 µm	mean thickn.	= 13.4 µm
σ/mean	= 1.5 %	σ/mean	= 1.0 %
Δ/mean	= 4.9 %	Δ/mean	= 4.1 %

Fig. 4. Intra-Wafer thickness uniformities of a 7 µm (process A) and a 14 µm (process B) thick epitaxial layer on a 100 mm wafer (10×100mm setup) determined by FTIR measurements.

Fig. 5 shows typical doping uniformity profiles of a 7 µm and a 13 µm thick layer on a 100 mm wafer at a depth of 1 µm from the surface. For process A the doping concentration slightly decreases from the center of the wafer towards the outside until approximately 1/2 r (r: radius of the wafer) and then increases reaching its maximum at the wafer edge. For process B the doping concentration has its maximum at the center of the wafer and decreases steadily towards the wafer edge. Again, the axial symmetric distribution, caused by the wafer rotation, can clearly be seen. Considering an edge exclusion of 3 mm the mean doping value N_D-N_A and sigma/mean are 8.7e15 cm^{-3} and 2.7 %, respectively, for process A and 6.0e15 cm^{-3} and 5.6 %, respectively, for process B. These results are comparable to the excellent data we reported in [2] for the 6x100mm setup of the hot-wall reactor VP2000HW showing that the on-wafer results do already fulfill the production needs.

process conditions A **process conditions B**



Doping Range / cm^{-3} (process conditions A)

- 128 $8.0E15 \le N < 8.5E15$
- 307 $8.5E15 \le N < 9.0E15$
- 45 $9.0E15 \le N < 9.5E15$

doping conc. = 8.7e15cm^{-3}
σ/mean = 2.7 %
Δ/mean = 11.6 %

Doping Range / cm^{-3} (process conditions B)

- 34 $5.0E15 \le N < 5.5E15$
- 209 $5.5E15 \le N < 6.0E15$
- 194 $6.0E15 \le N < 6.5E15$
- 49 $6.5E15 \le N < 7.0E15$

doping conc. = 6.0e15cm^{-3}
σ/mean = 5.6 %
Δ/mean = 21.6 %

Fig. 5. Intra-Wafer doping uniformities of a 7 μm (process A) and a 14 μm (process B) thick epitaxial layer on a 100 mm wafer (10×100mm setup) determined by CV measurements.

Wafer-to-wafer homogeneity of thickness and doping. To demonstrate the wafer-to-wafer homogeneity of thickness and doping results of a full-loaded run (process conditions A) are shown in Fig. 6 and Fig. 7. In Fig. 6, the thickness homogeneity is presented by high-resolution (11×11) FTIR-maps showing the individual intra-wafer uniformities. A reasonable wafer-to-wafer thickness homogeneity can be seen, indicated by sigma/mean of 2.4 % and max-min/mean of 6.2 % with an edge exclusion of 5 mm. In Fig. 7 the corresponding high-resolution maps of the doping concentration determined by CV measurements are presented. With an edge exclusion of 3 mm sigma/mean and max-min/mean values are 3.7 % and 10.7 %, respectively, at a mean doping of 8.39e15 cm^{-3}.

For process conditions B with a higher growth rate of almost 7 μm/h the measured wafer-to-wafer homogeneity increases to a sigma/mean of 2.9 % and 10.4 % for thickness and doping, respectively, indicating that the process conditions may have an influence on the reproducibility within a run. These results for the wafer-to-wafer homogeneity show that a careful process tuning and hardware adjustments have to be performed to achieve the homogeneity necessary for production requirements.

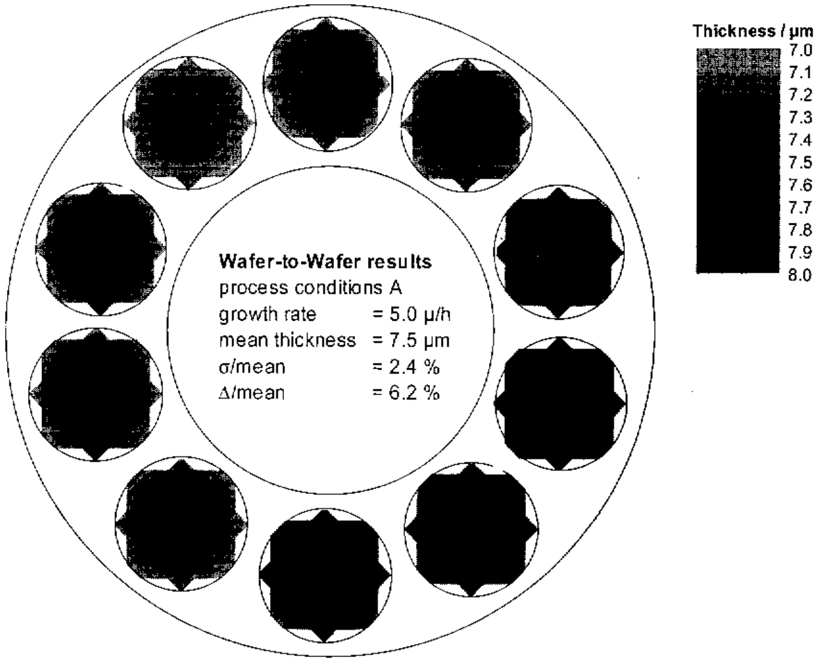


Fig. 6. Schematic of wafer position and thickness homogeneity of a full-loaded 10×100mm run.

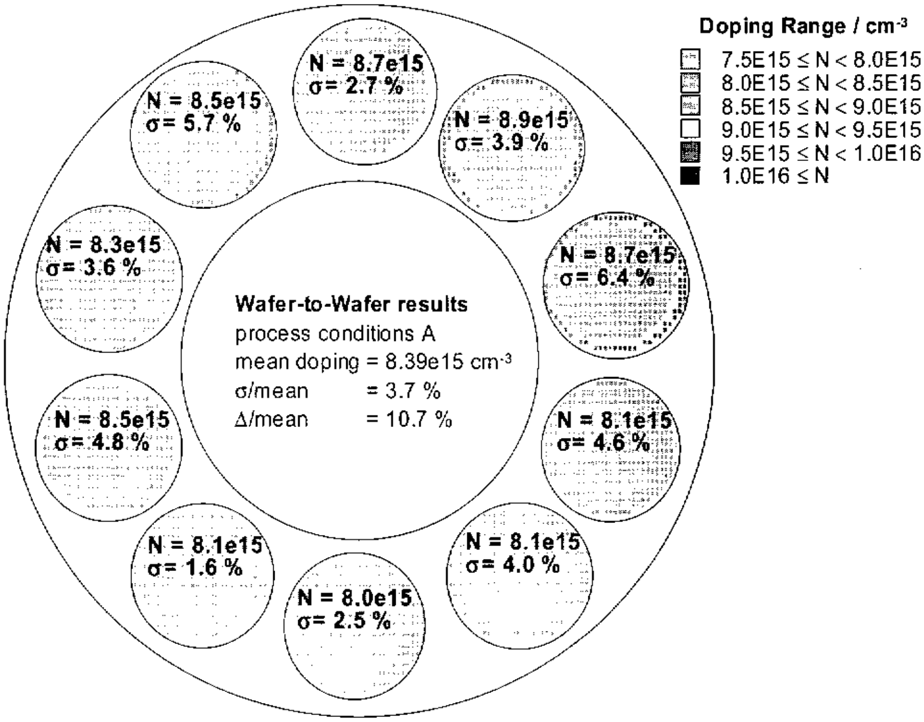


Fig. 7. Schematic of wafer position and doping homogeneity of a full-loaded 10×100mm run.

Surface quality. Although all growth runs in the warm-wall reactor were performed with 4° off-oriented substrates usually exhibiting stronger step-bunching, a very smooth surface was regularly observed. Atomic force microscopy (AFM) measurements were performed on a 7 μm thick epitaxial layer (process conditions B) showing only a very weak step-bunching and an RMS value of around 1nm for a 10μmx10μm scan (Fig. 8a). On an epitaxial layer grown with process conditions A a step-bunching free surface with an RMS value of 0.2 nm could be observed (not shown). The typical surface roughness for epitaxial layers grown in the hot-wall reactor is around 2nm indicating a considerably larger step-bunching for this type of reactor (Fig. 8b).

Furthermore, the number of in-grown particles observed after growth runs in the warm-wall reactor is considerably and consistently smaller than for the epi layers grown in the hot-wall reactor. This might be attributed to the fact that the reactor parts of the warm-wall reactor were carefully designed to prevent any mechanically-caused particle generation.

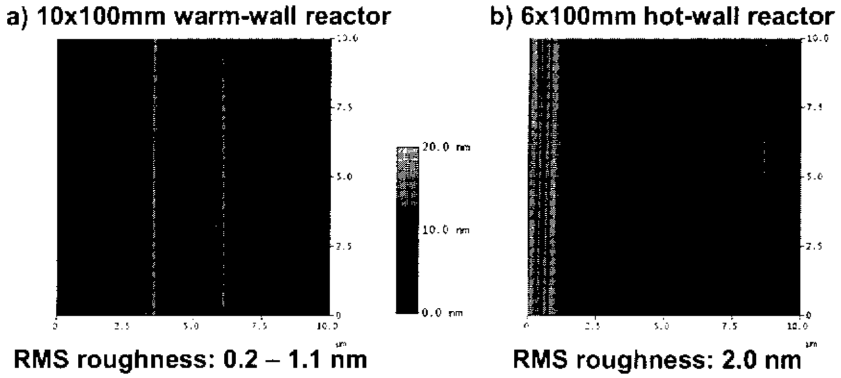


Fig. 8. AFM measurements on epitaxial layers processed in the 10x100mm warm-wall reactor (left) and in the 6x100mm hot-wall reactor (right).

Summary

For the first time, results of epitaxial SiC layers grown in a novel warm-wall AIX 2800G4 WW multi-wafer reactor with a capacity of processing 10×100mm wafer within a run could be presented. Results of full-loaded runs processed at different process conditions were shown. The intra-wafer thickness and doping uniformities of 1%-2% and 2%-6%, respectively, fulfill the demands on layer properties for high-voltage power devices. A further improvement of the measured wafer-to-wafer uniformity of thickness and doping (2%-3% and 4%-10%, respectively) is necessary for production purposes. The surface quality was shown to be better than in the hot-wall reactor used for power device production at SiCED today. These first results demonstrate that the new AIX 2800G4 WW reactor will be a milestone on the way to achieve a cheaper epitaxial process with a high wafer throughput while maintaining the excellent layer properties reported for the hot-wall reactor.

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