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# Development of High Concentration Uniformity Epitaxial Growth on 200 mm 4H-SiC Wafers

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**Keywords:** 200 mm 4H-SiC, hot-wall reactor, high concentration uniformity.

**Abstract.** This study focuses on addressing the challenge of poor doping concentration uniformity during the epitaxial growth of 200 mm 4H-SiC substrates, which is primarily caused by difficulties in thermal field and flow field control. By systematically optimizing key process parameters, including $H_2$ flow rate, C/Si ratio, and growth temperature, a high uniformity concentration technology was developed. This technology has enabled a breakthrough in the performance of n-type epitaxial layers, with the doping concentration uniformity significantly improved to 0.67%. Based on the validation of this technology-encompassing 8,000 epitaxial wafers and thick epitaxial layers (≥30 μm)-the technology demonstrates excellent doping concentration uniformity. This research provides a reliable technical foundation for the large-scale application of large-size SiC materials in power devices.

## Introduction

Silicon carbide (SiC), with its exceptional electrical properties such as wide energy band gap, high breakdown electric field strength, and high thermal conductivity, exhibits revolutionary advantages over silicon (Si) in numerous applications [1]. As is well known, larger-diameter SiC wafers enable higher device counts per wafer with driving down per-unit device costs [2]. Therefore, in order to reduce the device cost and improve device performance, SiC wafer diameters have progressively evolved from 100 mm (4 inch) to 150 mm (6 inch), and are now advancing toward 200 mm (8 inch) technology [3].

The performance of power devices depends to a large extent on the quality of 4H-SiC epitaxial wafers [4], so the homoepitaxial growth of 4H-SiC is critical for the fabrication of 4H-SiC power devices. As the diameter of the 200 mm substrates increases, the difficulty of controlling multiple physical fields significantly multiplies in epitaxial growth process, especially with respect to the thermal field and flow field. The radial temperature gradient increases and the gas flow dynamics within the reaction chamber become more complex, which makes the problem of uneven nitrogen doping even more apparent [5]. Therefore, achieving high doping concentration uniformity (σ/mean) of epitaxial layers on 200 mm substrates is critical factor for minimizing device performance variation across large-diameter substrates.

In this work, a significant improvement in concentration uniformity are achieved by optimizing the epitaxial process parameters and introducing ammonia as n-type doping Source. And the latest results of 200 mm 4H-SiC epitaxial wafers are shown.

## Experimental

A horizontal hot-wall reactor was employed for epitaxial growth. The silicon precursor is trichlorosilane (TCS), while Ethylene ($C_2H_4$) serves as the carbon precursor. Hydrogen ($H_2$) acts as both the dilution and carrier gas, and ammonia ($NH_3$) provided n-type doping. Featuring an automatic loading/unloading system operating at 900°C, the reactor enabled high growth rates. Substrates are commercial domestic-made n-type 200 mm 4H-SiC substrates with a 4° off-cut toward the [11-20] direction.

Thickness and doping concentration of 4H-SiC epitaxial layer are evaluated by Fourier-Transform Infrared spectroscopy (FTIR) and Mercury Capacitance-Voltage (MCV) with 5 mm edge exclusion. Because the thickness and doping concentration show concentric distribution, these measurements are performed along the radial direction. Surface defect are evaluated with SICA88 with 3 mm edge exclusion.

## Results and Discussion

There is a significant challenge in achieving high concentration uniformity for epitaxial layers on 200 mm substrates. When scaling the substrate size from 150 mm to 200 mm, thermal field inhomogeneities and gas flow distribution inhomogeneities increase significantly. Meanwhile, the enlargement of the epitaxial chamber leads to elevated background concentration and reduced concentration stability.

Based on our previous research findings and epitaxial growth experience, these parameters (growth temperature, main $H_2$ flow rate, C/Si ratio) exert a significant influence on the epitaxial doping concentration. Increasing the main $H_2$ flow rate and optimizing the $H_2$ flow distribution between the central and side channels can suppress flow disturbances and improve the uniformity of flow field distribution [6]; Elevating the growth temperature can reduce temperature differences across different regions of the wafer surface and enhance the uniformity of thermal field distribution on the wafer surface [7]; According to the C/N site-competition theory [8], a slightly C-rich growth environment can suppress concentration fluctuations [9]. Following the optimization of the above-mentioned parameters, we finalized a comprehensive processing protocol. The detailed process parameters are provided in Table 1. This optimized process named as a high concentration uniformity (HCU) epitaxial growth technology for 200mm 4H-SiC wafers.

As a result of the above process optimizations, the doping concentration uniformity (σ/mean) of the 10 μm epitaxial layer has been improved from an initial 3.56% to an exceptional 0.67%, as illustrated in Fig. 1(a). Meanwhile, an extremely high thickness uniformity (σ/mean) lower than 0.81% and low surface defect count fewer than 3 pieces (pcs) have been achieved on the epitaxial layer, as shown in Fig. 1(b) and (c). The stability verification of the HCU technology was evaluated with 25 consecutive runs (one PM (preventive maintenance) cycle). As shown in Fig. 1(d), the doping concentration uniformity of epitaxial layers were consistently maintained below 1.5% with an average value of 0.88%. The data confirmed the robustness of the HCU technology in maintaining superior uniformity control throughout one PM cycle.

Using the HCU technology, over 8,000 200 mm epitaxial wafers have been produced. The statistical analysis of these epitaxial wafers is shown in Figs. 2(a) to (c). In Fig. 2(a), the mean doping concentration uniformity of the epitaxial wafers is approximately 1.59%, with over 75% of the wafers exhibiting concentration uniformity below 2%. Fig. 2(b) reveals that the mean thickness uniformity is approximately 1.39%, with over 75% of the epitaxial wafers demonstrating thickness uniformity below 1.57%. What is more, Fig. 2(c) shows that the mean total usable area (TUA) is approximately 97.6%, with over 75% of the epitaxial wafers achieving a TUA exceeding 97.1%. The TUA is calculated by ideally dividing the wafer surface in $5\times5$ $mm^2$ and counting the percentage of squares not containing any defect (defects considered include downfalls, triangles, carrots, and micropipes). During mass production, slight quality fluctuations of the epitaxial wafers are unavoidable due to factors such as variations in PM operations, equipment differences, and personnel operation inconsistencies in the production process. Thus, the mass production data are slightly inferior to the experimental data. These mass production data demonstrate industry-leading repeatability in our 200 mm 4H-SiC epitaxial growth process.

It is well-known that the higher the voltage rating of power device, the lower the doping concentration of the epitaxial layer, and the greater the difficulty in controlling the uniformity of the doping concentration. To further evaluate the HCU technology, 3300 V epitaxial wafers have also been grown using this technology with a doping concentration of 3E15 $cm^{-3}$ and thickness of 30 μm.

As shown in Fig. 3(a) the doping concentration uniformity of epitaxial layers were consistently maintained below 1.7%. Fig. 3(b) shows the thickness uniformity were consistently maintained below 1.3%, Fig. 3(c) shows TUA (5 mm × 5 mm) were consistently maintained exceeding 98.56%. These results confirm that the HCU epitaxial growth technology is applicable to a wide range of doping concentrations.

**Table 1.** Specific process parameters of HCU growth technology for 200 mm 4H-SiC wafer.

| Growth Temperature (°C) | Pressure (mbar) | Main $H_2$ flow rate (slm) | C/Si ratio |
|---|---|---|---|
| >1600 | 100 | >150 | >0.8 |

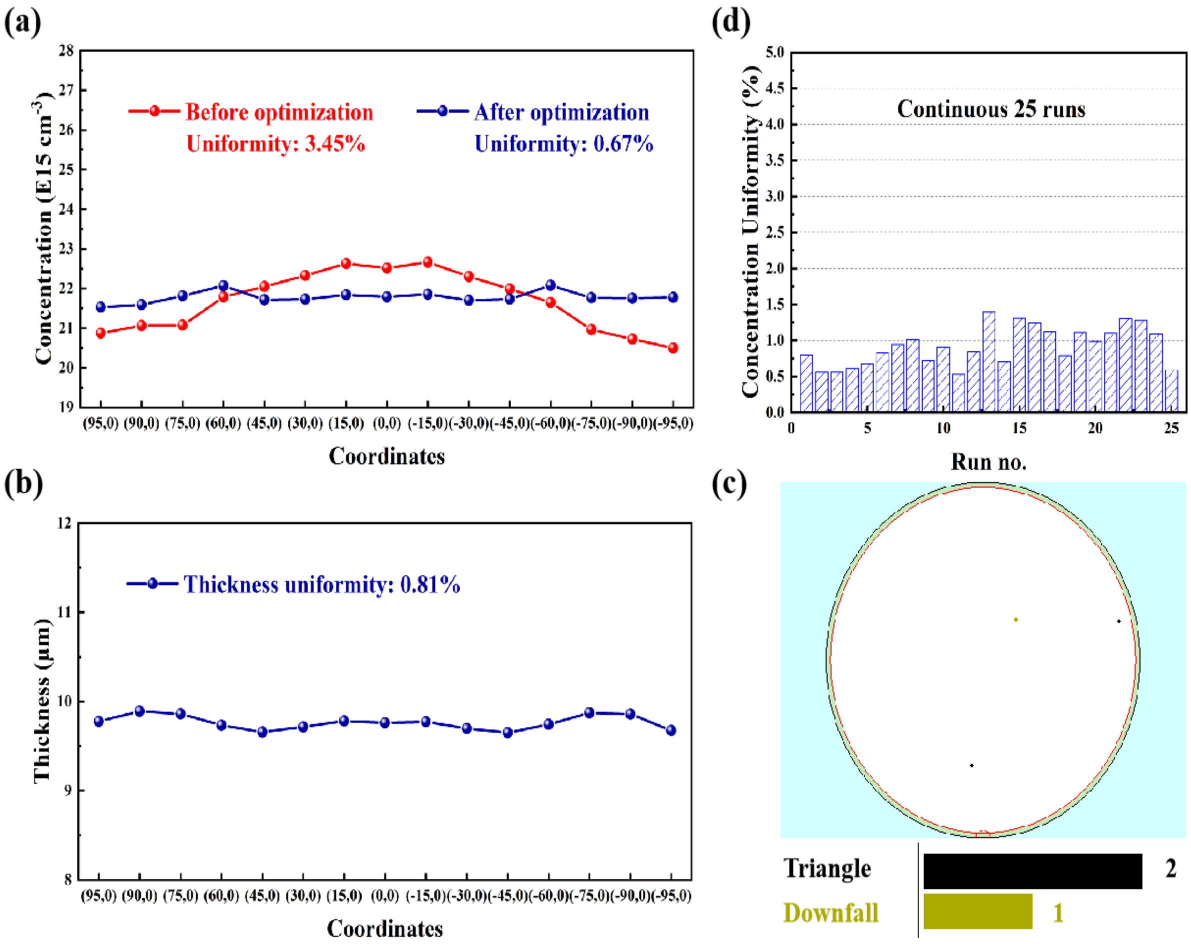

**Fig. 1.** (a) The radial doping concentration distribution before and after optimization. (b) The radial thickness distribution after optimization. (c) The map of triangle and downfall defects after optimization. (d) The doping concentration uniformity statistics of continuous 25 runs epitaxial wafers.

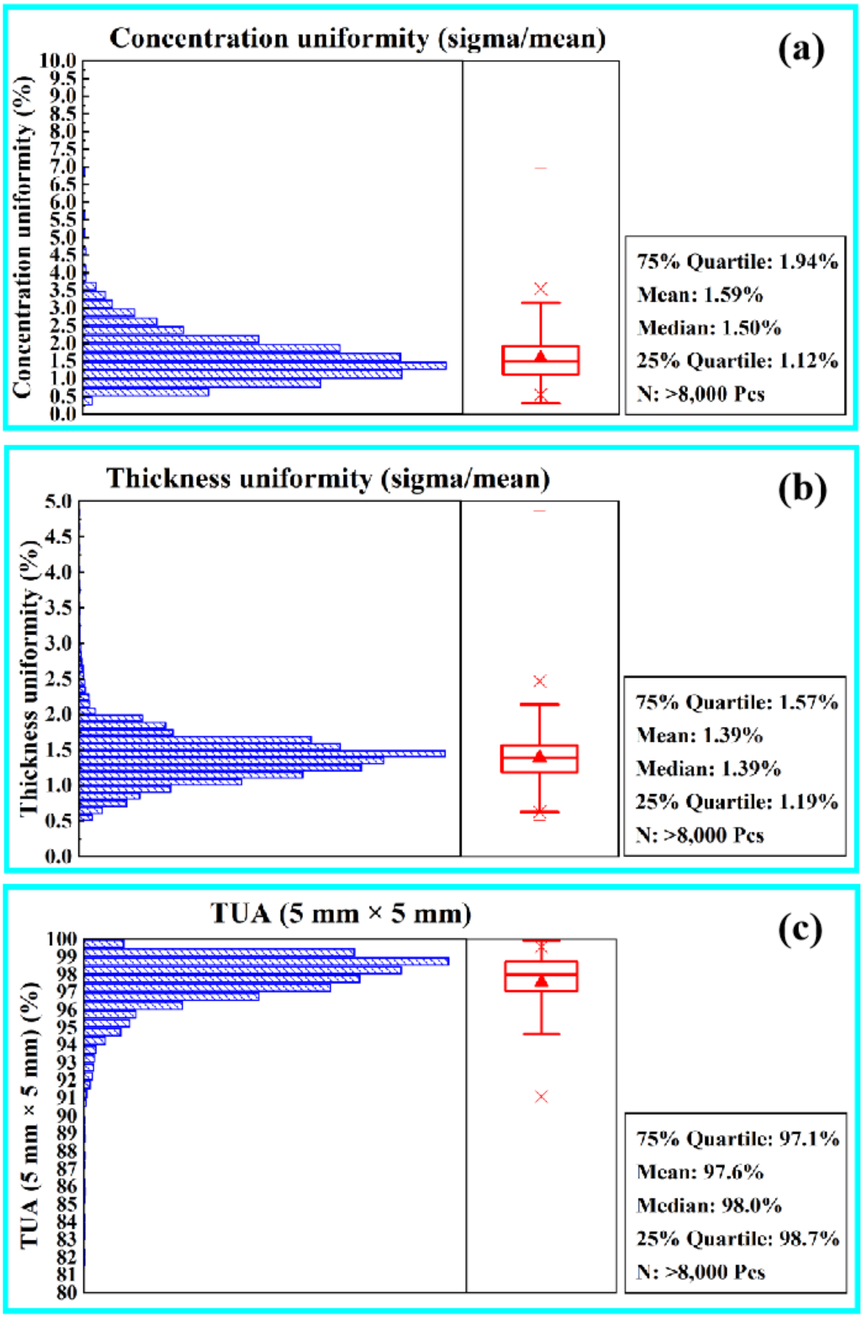

**Fig. 2.** The statistical results of : (a) doping concentration uniformity, (b) thickness uniformity and (c) TUA (5 mm × 5 mm), based on over 8,000 epitaxial wafers.

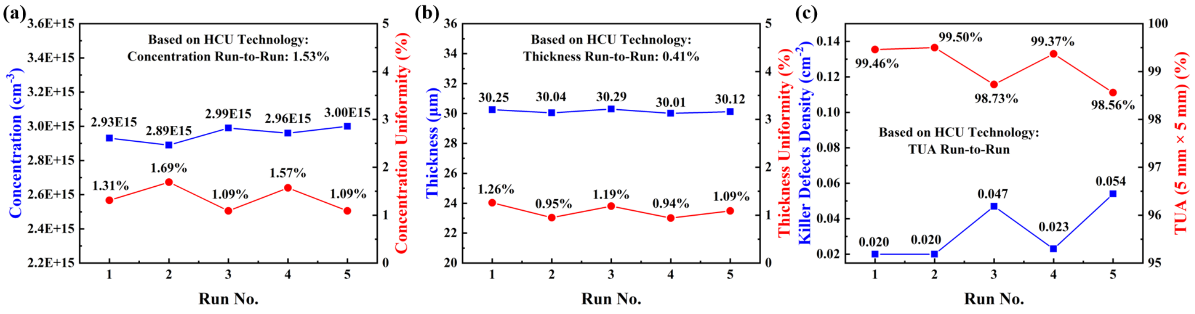

**Fig. 3.** Results for 30 μm-thick 4H-SiC epitaxial growth: (a) average concentration and uniformity per run; (b) average thickness and uniformity per run; (c) killer defect density (KDD) and TUA (5 mm × 5 mm). All measurements were based on HCU technology.

## Summary

This study successfully resolved the thermal/flow field co-control challenges in the epitaxial growth of 200 mm 4H-SiC substrates. Through optimization of process parameters, it significantly improved the doping concentration uniformity to 0.67%, while achieving a thickness uniformity of 0.81% and an ultra-low defect density. Mass production validation (>8,000 wafers) confirmed process stability, with 75% of wafers meeting stringent specifications of doping uniformity <2% and TUA >97.1%. The developed HCU technology further overcame process window limitations for high-voltage thick epitaxial layers (30 μm, 3E15 $cm^{-3}$) under low doping conditions. It achieved the simultaneous optimization of inter-wafer/intra-wafer doping and thickness uniformity along with fatal defect density <0.1 $cm^{-2}$ and TUA >98.56%, laying the foundation for mass production of high-voltage SiC devices. This technological breakthrough comprehensively advances the industrialization of 200 mm SiC epitaxial processes and provides core material support for next-generation power semiconductor applications.

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