Characterization of Silicon Carbide Wafers

CNF Summer Student: Tyrone Chen
Student Affiliation: Department of Material Science and Engineering , Cornell University College of Engineering

Summer Program(s): 2025 Cornell NanoScale Facility Research Experience for Undergraduates (CNF REU) Program
Mentor(s): Phil Infante, Cornell NanoScale Science and Technology Facility, Cornell University
Primary Source(s) of Research Funding: National Science Foundation under Grant No. NNCI-2025233,
Contact: tc724@cornell.edu, pi12@cornell.edu
Summer Program Website(s): https://cnf.cornell.edu/education/reu

Abstract:

This project focused on characterizing silicon carbide (SiC) thin films deposited using low pressure chemical vapor deposition (LPCVD). The films were grown from a mixture of dichlorosilane (DCS) and acetylene (C_2H_2) gas, with hydrogen gas as the carrier gas aiding deposition, at two deposition temperatures: 800°C and 850°C. To help isolate the electrical properties of the SiC layer itself, two types of substrates were used—plain silicon wafers and silicon wafers with a deposited layer of silicon oxide. All wafers were cleaned using a standard MOS process and loaded into the A4 SiC furnace for deposition, where the ratio of DCS to acetylene was systematically varied. After deposition, the films were analyzed for thickness, refractive index, intrinsic stress, and resistivity. A noticeable drop in stress or refractive index at certain gas ratios suggested a potential change in film crystalline structure In the final phase, ammonia (NH_3) was introduced during deposition to explore in-situ doping. Some of these doped films showed unexpectedly low stress and very high conductivity. One particular sample could not be accurately modeled using standard optical fitting tools, suggesting an unusual film structure or electronic behavior. While more work is needed, these results point toward new ways to engineer SiC films with customized electrical and mechanical properties.

Summary of Research:

This project focused on the low-pressure chemical vapor deposition (LPCVD) of silicon carbide (SiC) thin films using dichlorosilane (DCS) and acetylene (C_2H_2) gas. This work aimed to investigate the effects of deposition conditions—specifically gas ratios and temperature—on film characteristics such as thickness, refractive index, stress, and resistivity, with the broader goal of tailoring SiC films properties for potential semiconductor applications. A secondary goal was to explore the effect of ammonia (NH_3) doping on electrical and mechanical properties. The wafers used for deposition included both bare silicon wafers and silicon wafers with deposited silicon oxide layers. The oxide-coated wafers served to isolate the electrical properties of the SiC film by minimizing current leakage into the substrate. Prior to deposition, all wafers underwent a cleaning sequence beginning with a sodium hydroxide (NaOH) base bath, followed by a rinse, then an acid bath using hydrochloric acid (HCl), and a final rinse until the surface resistivity reached approximately 16 MΩ·cm. These wafers were then spun dry and ready for depositions. This surface preparation ensured minimal contamination and enabled consistent film growth.

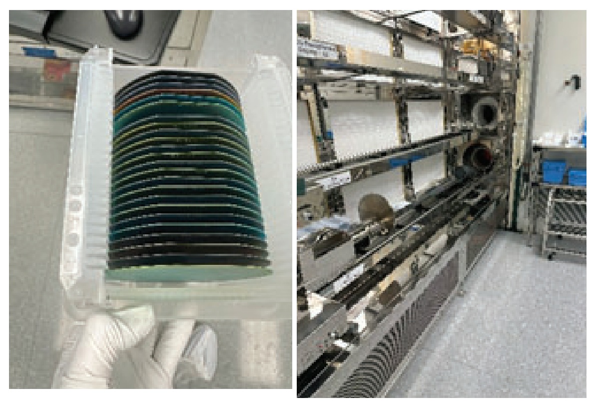

Figure 1: The picture on the right shows the furnace that was used for the deposition process. The picture on the left shows the resulted wafers that were deposited. As you can see the color of the wafers are an indicator of the thin film and this color may vary depending on the deposition conditions.

Deposition was carried out in the A4 SiC furnace under low-pressure conditions. The precursor gases—200 sccm of DCS and 50 sccm of acetylene had varying ratios where the DCS was kept at 31% max sccm while the acetylene ranged from 38% - 22% max sccm, while hydrogen was introduced as a helping gas. The hydrogen flow was found to be essential for achieving uniform films; wafers processed without it displayed black spots and non-uniform coverage. Depositions were performed at two temperatures: 800 °C and 850 °C. At 850 °C, deposition time was held around 70 minutes, while at 800 °C the process time was extended to approximately

140 minutes. These times were chosen to target a final film thickness of about 130 nm. Pressure within the furnace was actively controlled through a series of automated sequences including purging, pump-down, leak checking, and venting.

After deposition, multiple characterization techniques were used to assess the films. The RC Woollam ellipsometer was first used to measure the thickness and refractive index from the reflective surface of the wafer using a SiC optical model. The Filmetrics F50 tool was used to evaluate the thickness uniformity across the wafer surface. For stress analysis, the wafer backside was etched using the Oxford 82 system with a CF_4/O_2/Ar gas mixture to expose the front-side curvature. The curvature was then measured using the Flexus tool to calculate intrinsic film stress. Finally, the electrical resistivity of the SiC layers was measured using the Filmetrics R50 system, particularly on the oxide-coated wafers to ensure that the readings were specific to the film itself.

Across both the 800 °C and 850 °C deposition conditions, the silicon carbide thin films demonstrated consistent deposition rates, with no significant fluctuations observed as the gas flow ratio between dichlorosilane (DCS) and acetylene (C_2H_2) was varied. The refractive index of the deposited films remained relatively stable, ranging from 2.7 to 2.9 throughout all runs. In contrast, the resistivity of the films showed a clear downward trend as the DCS-to-acetylene ratio increased, indicating a correlation between gas ratio and film conductivity. Similarly, film stress exhibited a decreasing trend with increasing gas flow ratio at both temperatures. These trends were consistently observed across both sets of wafers and suggest reproducible control of key film properties through process parameter variation. These graphs are shown collectively in Figure 2.

In the doping experiment, ammonia (NH_3) gas was introduced in the deposition process at varying flow rates to explore its effect on the properties of the silicon carbide thin films. Across both 800 °C and 850 °C deposition temperatures, specific NH_3 gas flow settings resulted in films that exhibited high conductivity. At a deposition temperature of 800 °C, a flow rate of 20% max sccm resulted in a film that was highly conductive, as confirmed through resistivity measurements using the Filmetrics R50. Similarly, at 850 °C, a flow rate of 60% max sccm produced a film with high conductivity. These points of interest were repeated to confirm the observed results, and in each case, the outcome remained consistent. However, under these particular doping conditions, the RC Woollam ellipsometer was unable to return a valid model fit or measure the thickness of the films. This in turn resulted in no stress, refractive index, and deposition rate measurements for these wafers. Despite the incomplete optical characterization, the electrical measurements potentially indicate that NH_3 doping successfully altered the electronic properties of the silicon carbide films in certain cases.

Conclusions and Future Steps:

In conclusion this characterization demonstrates that the properties of SiC wafers can be tuned depending on gas ratios, temperatures and even external doping. As the acetylene gas concentration got lower, stress and resistivity also dropped. The introduction of ammonia gas can potentially lead to a more conductive wafer. Future work could focus on specific structural microscopy as the RC Woolam was not able to perfectly characterize some wafers. Other future work could also be in the introduction of ammonia and optimizing the conditions for the best conductivity.

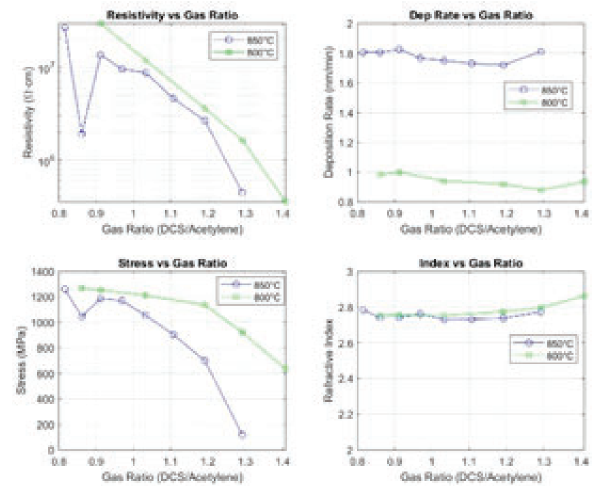

Figure 2: The graphs and their trends are shown above where blue represents 850 °C and green represents 800 °C.

Acknowledgements:

Special thanks to the 2025 Cornell Nanoscale Facility Research Experiences for Undergraduates (CNF REU) Program funded by the National Science Foundation (NSF). I would also like to thank the CNF staff, especially Phil Infante, for their incredible mentorship.

PROCESS & CHARACTERIZATION