From Research to Reality – The Path of Compound Semiconductor Manufacturing Innovation

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Keywords: Capacity Expansion, Fab Operations, Fully Automated, Silicon Carbide

INTRODUCTION

Wolfspeed's Silicon Carbide technology didn't technically begin in a dorm room on North Carolina State University's campus in the late 80s, but it's not far from the truth. It's been a long and winding path for the innovation journey that Silicon Carbide has been on, with many, many years devoted to understanding the fundamental science alone. At Wolfspeed, we've been innovating and evolving the company for 35 years, ever since that first moment on the university's campus. It's been a slow burn, filled with curiosity and passion for a brighter, more sustainable future.

OUR HISTORY

In 1991, Cree Research Inc. released Silicon Carbide wafers that measured just one inch in diameter. We were officially out of the lab and into the wild, despite there not being a ton of commercial activity for the material or its products yet. But the compound semiconductor industry knew the positive impacts that the material could make, so Cree continually persevered to increase capacity and streamline processes to ramp production.

Cree Research Inc. became Cree, Inc. (Cree) as perseverance led to progress. Wafer diameters and volumes increased as the rapidly ramping LED business fueled cycles of crystal growth learning. In 2011, Cree, Inc. released the industry's first Silicon Carbide MOSFET, a key building block for more efficient power conversion systems that decreases the size, weight and bill of materials. 2017 saw the introduction of the Silicon Carbide 900V, 10mΩ MOSFET for electric vehicle (EV) drive trains, enabling a reduction of EV drive train inverter losses by 78%. In 2021, Wolfspeed, a Cree Company, announced the new Wolfspeed WolfPACK™ module family, which enables accelerated production of high growth mid-power technologies. To indicate our full

conversion from the research lab to a semiconductor powerhouse, we officially changed our name to Wolfspeed in 2021. Our manufacturing capabilities encompass the breadth of Silicon Carbide and its applications.

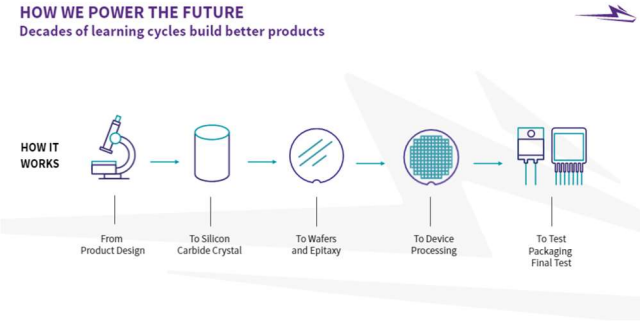

Fig. 1. Wolfspeed's vertical integration.

OUR MANUFACTURING TECHNOLOGY

Silicon Carbide has unique manufacturing challenges that must be overcome to reach world class semiconductor manufacturing standards. Early in the life of Cree, wafers were only processed with tweezers, and later vacuum wands. Transparent wafers that are almost as hard as diamond and up to twice the weight of silicon then provide unique automated wafer handling challenges. Equipment designed for silicon requires modifications to effectively process Silicon Carbide.

Cree had to invent solutions to these manufacturing challenges, but now that the mainstream silicon tool manufacturers are interested in this compound semiconductor, Wolfspeed can buy fab equipment designed to process Silicon Carbide. Standardized equipment is a necessity to reach full AMHS automation, and the Silicon Carbide industry has finally arrived. Wolfspeed has even adopted the "M12 SEMI standard" wafer ID scribe that enables OCR readers with a checksum. This is a major improvement to prevent wafer mix-ups over an operator with a magnifying glass.

Automation, however, goes beyond wafer handling in the fab. Silicon Carbide crystal growth, slicing and surface finishing has historically been a very manual and labor-intensive set of processes. Wolfspeed has been investing in automation solutions and "The JP" will be a highly automated materials factory, enabling production scale not previously seen in a Silicon Carbide wafer factory

Manufacturing technology goes beyond hardware. Software-based technologies including SPC, APC, FDC, FA, AI, ML, intelligent dispatching, predictive maintenance, and other improve yield, predictability, and throughput. While SPC can technically be managed by an engineer and a spreadsheet, automated systems enable data to be fed-forward, tools to be placed down, and data to be intelligently interpreted. Silicon Carbide is reaching cutting edge levels of manufacturing excellence and these digital transformations are enabling automotive readiness.

An area not to be forgotten when scaling is supply chain. Managing equipment and raw material lead times requires good business partners who scale concurrent with expansion plans, especially if the products are customized. Multiple sources ensure business continuity that customers expect, especially in automotive and defense industries. Partnering with equipment suppliers enables growth in technology that benefits all parties, and the industry as a whole.

OUR CAPACITY

With any changing landscape along the innovation path, however, there are other considerations to make. Analysts are predicting Silicon Carbide to reach over 20% of the power market by 2027, up from only 5% now[1] – that's a 4x increase in just five years. The world simply has not had Silicon Carbide manufacturing at such a large scale, and Wolfspeed is leading the way in capacity.

Wolfspeed's Durham, North Carolina headquarter campus remains the industry's largest Materials facility, producing 60% of the world's Silicon Carbide. It is currently undergoing an expansion that will support the accelerating demand for next generation semiconductors as the world sees the once-in-a-generation technology shift from silicon to Silicon Carbide.

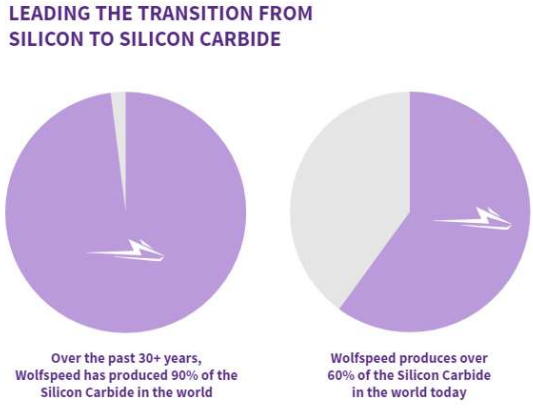

Fig. 2. Global Silicon Carbide production.

Our innovation path led us to another key decision: build the world's largest fabrication facility. To meet the increasing demand for groundbreaking technology that supports the growing EV, 4G/5G mobile and industrial markets, Wolfspeed opened the world's first 200 mm Silicon Carbide fab in Marcy, New York – our Mohawk Valley Fab (MVF). The brand new, fully automated Power wafer fab will also be automotive-qualified.

Fig. 3. Wolfspeed's Mohawk Valley Fab clean room. Heather Ainsworth for Wolfspeed, used with permission.

Capacity used to consist of laboratory tools in an office building, and later to a headquarters that had been retrofitted as the technology evolved, so it was time for a more manufacturing-focused approach. Our MVF was thoughtfully designed with maximum efficiency in mind. It is fully automated, featuring manufacturing technology improvements that materially affect the fab's achievable wafer supply that has never been seen before in Silicon Carbide. Below are just some of the features utilized to enable Wolfspeed to meet the world's demand.

- SMIF pods, rather than open cassettes
- AMHS with tool-to-tool lot delivery, rather than operators
- Robots, rather than tweezers or vacuum wands
- Fully factory-automated system versus paper travelers with pens, inks and staples

During our session, we will discuss the fab's cutting-edge technology more in depth, along with some of the bumps in the road experienced along the way.

With the ability to produce more chips per wafer at our MVF, it was time to take the next turn in the road. In September 2022, Wolfspeed announced that we are constructing the world's largest Silicon Carbide manufacturing facility in Siler City, North Carolina. This state-of-the-art facility, known as The John Palmour Manufacturing Canter for Silicon Carbide ("The JP"), will yield a 10-fold increase in Wolfspeed's Silicon Carbide wafer production. The first phase alone will be big enough to fit both the New Orleans Superdome and the Sears Tower, with room

to spare. The 445-acre site is scheduled to be completed in 2030.

Fig. 4. Wolfspeed's future John Palmour Manufacturing Center for Silicon Carbide in Siler City, N.C.

Additionally, Wolfspeed announced our plans to construct the world's largest and most advanced Silicon Carbide device manufacturing facility in Saarland, Germany on February 1, 2023. This 200 mm semiconductor fab will utilize innovative manufacturing processes to produce next-generation Silicon Carbide devices. ZF Friedrichshafen (ZF) intends to make a significant investment in Wolfspeed to support the project's construction, and it is being planned as part of the Important Project of Common European Interest (IPCEI) for Microelectronics and Communication Technologies. It is dependent upon state aid approval from the European Commission.

To complement the planned Germany Fab, Wolfspeed is also partnering with ZF to establish a joint research and development center in Germany to further advance global Silicon Carbide system and device technology. The facility will focus on innovation for Silicon Carbide systems and devices to meet specific requirements in all mobility segments including consumer, commercial, agricultural, and industrial vehicles as well as in the industrial and renewable markets. The collaboration will drive improvements such as higher efficiency, increased power density and higher performances for electrification solutions.


Fig. 5. Wolfspeed's planned fab in Saarland, Germany.

CONCLUSIONS

From researching the material in laboratories, to producing our first small wafers, to now producing eight-inch wafers, Wolfspeed and the semiconductor industry are ushering in a new era of energy efficiency that supports a more sustainable future for all. From research to reality, it's been a long road. However, much like every other adventure, the path of innovation reminds you to enjoy the journey along the way.

ACKNOWLEDGEMENTS

The authors would like to thank the people that helped Silicon Carbide grow from a laboratory science project to a modern semiconductor industry technology leader, including customers, suppliers and friendly competition.

REFERENCES

[1] YOLE

[2] INTERNATIONAL ENERGY AGENCY

ACRONYMS

APC: Advanced Process Control
AI: Artificial Intelligence
AMHS: Automated Material Handling System
EV: Electric Vehicle
FA: Factory Automation
FDC: Fault Detection and Classification
LED: Light Emitting Diode
ML: Machine Learning
OCR: Object Character Recognition
SEMI: Semiconductor Equipment and Materials International
SMIF: Standard Mechanical Interface
SPC: Statistical Process Control