Enabling a Sustainable Future with Silicon Carbide Power Electronics

Mighty Guides

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MOUSER ELECTRONICS

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Meet Our Experts

High-power technology is demanding more robust semiconductor materials than ever before, and silicon carbide (SiC) is here to answer the call. We interviewed nine experts on how SiC power electronics can benefit your designs and unlock new potential.

We hope you enjoy their insights!

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Introduction

Today's technological world depends more on high-power systems and applications than ever before. Power systems are a fundamental enabler of modern society, from the proliferation of electric vehicles (EVs) and development of energy infrastructure to the expansion of factory automation and increased consumption at data centers. However, as demands on power systems become stricter, conventional silicon electronics will not be able to meet future needs.

Instead, silicon carbide (SiC) power electronics are emerging as a robust new semiconductor material.

SiC is a wide-bandgap semiconductor material produced as a silicon and carbon compound. This compound exhibits several extremely impressive material properties, including increased breakdown voltages, temperature ranges, and electron mobility, as compared to conventional silicon. SiC-based power electronics have the potential to enable more efficient, power-dense, and performant power systems than those currently on the market.

As applications like EVs gain widespread adoption, SiC power electronics are finding more favor with power system designers. In this eBook, we will discuss the emerging SiC revolution, examples of how SiC can lead to a more sustainable future, and the ways in which onsemi can help designers leverage the power of SiC for future power system design.

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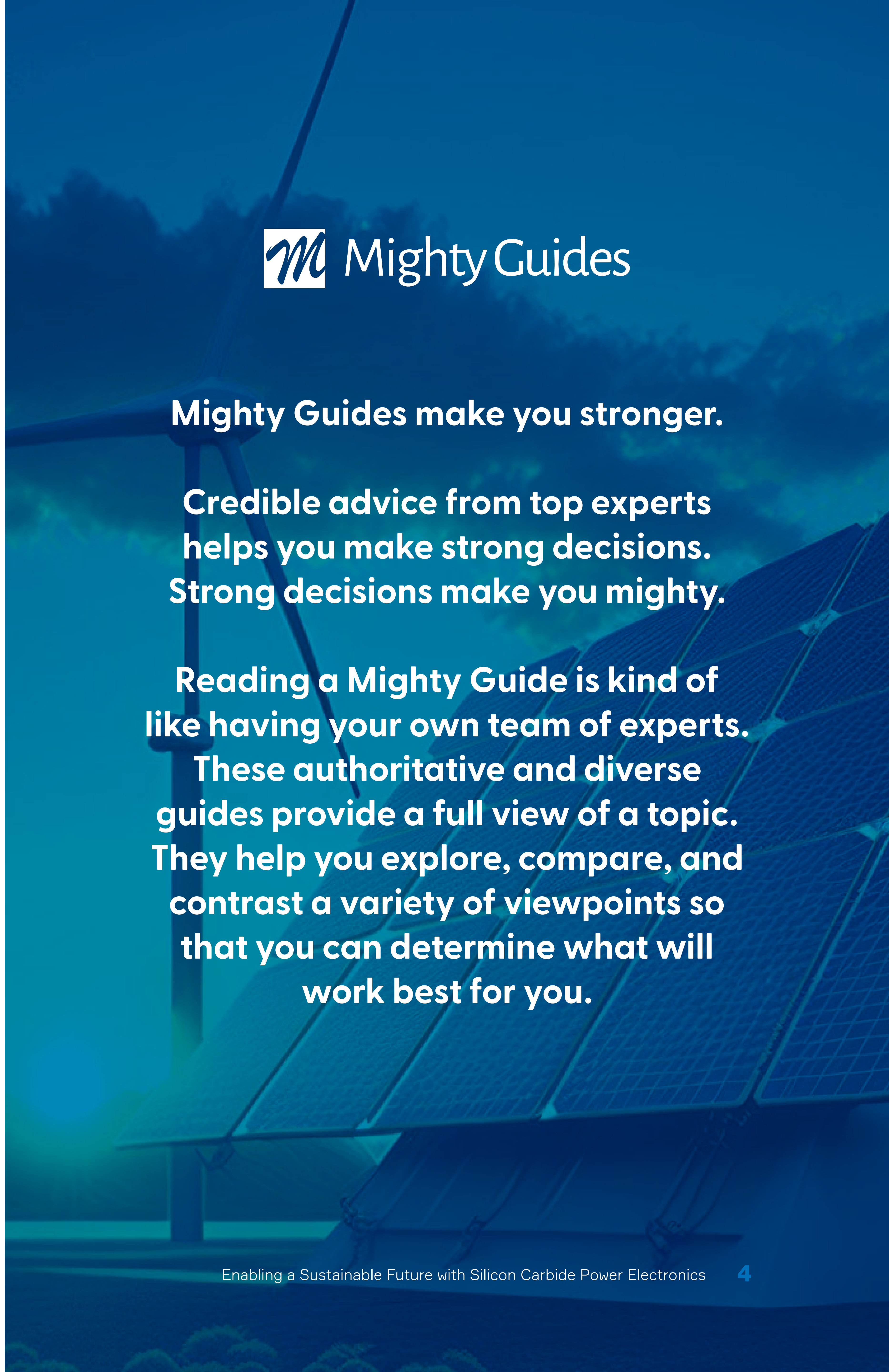


Foreword

By **Kris Casey**, Vice President Global Marketing, Power Solutions Group, onsemi

In today's rapidly evolving technological landscape, silicon carbide (SiC) power electronics represent a significant advancement in power system design. As the demand for efficiency, sustainability, and high performance grows, SiC stands out due to its exceptional material properties and advanced capabilities.

This eBook explores the impact of SiC on sustainability, its applications in electric vehicles and renewable energy, and the importance of selecting the right SiC partner. By understanding these aspects, readers can gain valuable insights into harnessing SiC technology for future power system designs.

Choosing a reliable SiC partner is crucial for achieving your product development and growth objectives. The ideal partner should have a cutting-edge technology roadmap and a proven track record of product performance. That partner is onsemi.

onsemi offers a dependable end-to-end supply chain that sets it apart in the market, guaranteeing high quality, flexibility, and capabilities. Combined with extensive application expertise and a diverse EliteSiC portfolio of specialized solutions, onsemi empowers you to navigate your design journey with greater confidence, reduced risk, and enhanced control.

Chapter 1

UNDERSTANDING THE SIC REVOLUTION

Within the changing power electronics landscape, SiC is emerging as a favorite material thanks to its exceptional properties. The first property of note is its high breakdown voltage.

Silicon carbide exhibits a 10x greater dielectric breakdown field strength than silicon. As a result, SiC power metal–oxide–semiconductor field-effect transistors (MOSFETs) can withstand greater voltages, making them more reliable and well-suited for high-voltage applications like EVs or data centers. Given SiC's greater breakdown voltage, a SiC-based transistor can exhibit the same blocking voltage as a silicon-based transistor while in a much smaller form factor because of a thinner drift layer. In other words, SiC transistors can lead to the downsizing of power systems, requiring smaller components and less board space.

An important result of this miniaturization is increased device efficiency. With thinner wafers, charge carriers must travel shorter distances across the device channel. SiC devices can be designed with lower on-channel resistance than their silicon counterparts, leading to fewer internal resistance (IR) losses and more efficient power systems.

SiC devices enable the design of smaller, lighter-weight, more power-dense, and

"For power electronics systems, three characteristics need to be considered: power density, efficiency, and reliability. Thanks to SiC's inherent material advantages, SiC semiconductors will always be superior to their silicon counterparts."

Bo Liu

ePowertrain Product Director, VReMT

> ***The fundamental advantages of SiC over Si are higher breakdown voltage and high thermal conductivity. Higher breakdown voltage allows a thinner drift layer and lower on-state resistance. This means conduction losses are less, and overall efficiency and power density are improved."***
>
> **Jayaram Subramanian**
>
> High Voltage Systems Engineer, Mercedes-Benz Research & Development North America, Inc.

more efficient power systems than those of silicon-based systems. Such design is extremely important in applications like EVs, for which decreased system weight directly translates into increased driving range. Additionally, more efficient power systems enable faster vehicle charging, greater utilization of stored energy, and extended driving ranges.

Beyond the exceptional material properties of SiC, recent manufacturing and device packaging advances are also catalyzing its adoption.

Modern advances in SiC wafer fabrication have created wafers with lower defect content, making SiC more affordable and reliable for end users. Additionally, new packaging is enabling SiC to gain widespread adoption. SiC boasts superior thermal conductivity (about 3 to 4.9 W/cm·K) compared to silicon (about 1.5 W/cm·K), necessitating packaging materials and techniques that can do the same. Recent innovations such as top-side and double-sided cooling packages enable SiC devices that can support greater temperatures and current densities than previously.

Despite the clear benefits of SiC over silicon, designers may encounter challenges when switching their designs from silicon to SiC. To actualize the benefits of SiC, designers must reconsider their designs and optimize them for SiC devices.

One difference between designing with SiC FETs and silicon FETs is the gate driver requirements. SiC devices require higher-voltage gate drivers to properly drive the transistors. Additionally, SiC devices are more power efficient and can operate at higher switching frequencies than silicon devices. This capability also requires changing the gate driver requirements to support higher frequencies and greater voltage ranges (e.g., 0–18V). Because of the higher switching frequencies, SiC also limits the size of surrounding passive components, reducing system weight and space.

Additionally, SiC devices may open up the opportunity for different system topologies. In silicon-based designs, the lack of reliable high-voltage devices often necessitates using multiple devices to share the overall power. These systems require complicated control algorithms and dedicated digital signal processors to effectively drive multiple devices. With SiC FETs, topologies can be simplified to use fewer devices, reducing cost, area, weight, and computational demand on the associated driving devices.

onsemi helps designers navigate the transition from silicon to SiC by

- Offering discrete SiC products that can be used up to 20kW
- Offering drop-in, highly integrated SiC power integrated modules (PIMs) for high-power applications
- Providing designers with detailed application notes and reference designs
- Providing engineers with detailed and accurate SPICE and PLECS models for reliable device simulations

“*In an electric vehicle, SiC’s advantages translate into power solutions that are smaller, lighter, and more efficient. Less energy is wasted, leading to a reduction in the number of expensive batteries required, an advantage that prices SiC into the automotive sector.*”

Peter Gammon

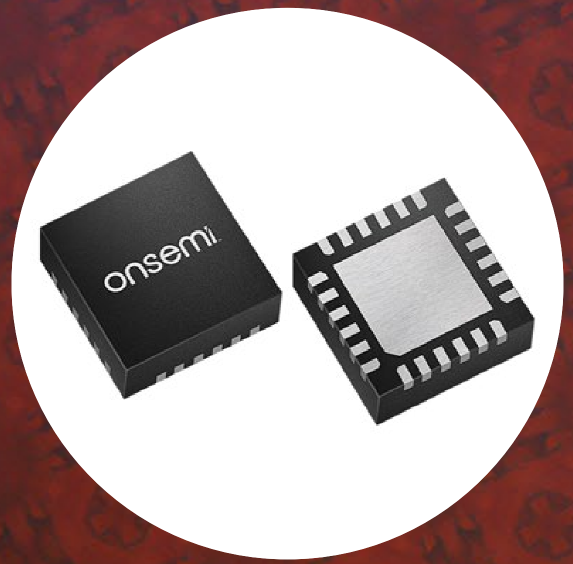
Professor of Power Electronic Devices, University of Warwick

"Designers can directly replace silicon devices with silicon carbide, but the benefits may not be significant. Additionally, they often fail to fully leverage the unique properties of silicon carbide. To maximize the value of SiC, a comprehensive redesign is necessary—from the chosen topology all the way down to gate driver power and frequency considerations."

Sara Kuzmanoska

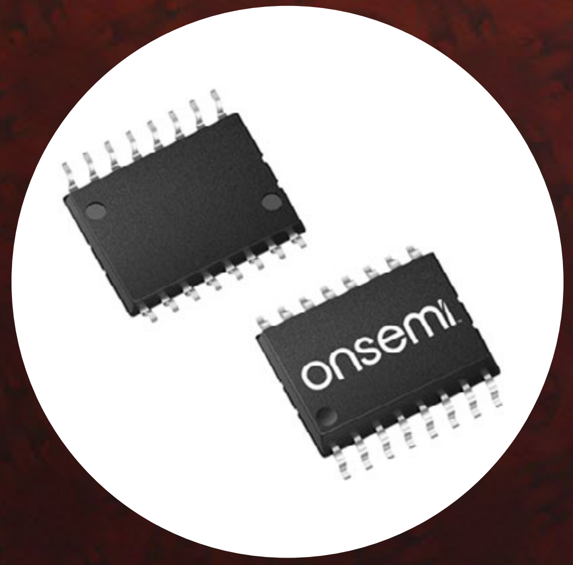
Staff Characterization Engineer, R&D SiC Technology, onsemi

Gate Drivers — Boosting Efficiency



Gate Driver

Learn More



Isolated Dual-Channel Gate Driver

Learn More

Key Points

- **Silicon carbide is gaining preference in power electronics because of its high breakdown voltage and ability to withstand higher voltages relative to silicon.**
- **The miniaturization enabled by SiC technology results in smaller, lighter, and more efficient power systems.**
- **Advances in SiC wafer fabrication and innovative packaging techniques have improved the affordability and reliability of SiC devices.**
- **onsemi supports the transition from silicon to SiC by offering a range of discrete SiC products, integrated modules, and extensive technical resources to assist designers in optimizing their applications.**

ACHIEVING A SUSTAINABLE FUTURE WITH SIC

One of today's most notable shifts in all industries worldwide is an increased push for sustainability. Fortunately, switching from silicon to SiC perfectly aligns with broader sustainability and decarbonization goals.

One way SiC helps achieve a sustainable future is by enabling more power-efficient systems. As previously discussed, SiC solutions lead to devices with lower conduction losses and decreased switching losses compared to those of silicon devices. With decreased device losses, power system designers can create more efficient solutions than those possible with silicon. When deployed at scale, this improved efficiency has a meaningful impact, especially in extremely high-power applications like data centers,

> ***"Efficiency and global warming will drive the use of silicon carbide. Silicon carbide focuses on increasing efficiency, decreasing material requirements, and miniaturizing the application. In applications like EVs and renewable energy, silicon carbide goes a long way in improving sustainability."***

Prasad Paruchuri

Technical Marketing Team Lead, Power Solutions Group, onsemi

Creating a more sustainable future requires innovative solutions that prioritize environmental impact reduction and resource efficiency. Prioritizing usage of materials like SiC, which can be recycled from aging components, can help close the loop for renewable resources."

Gaman Munukoti

Sr. Systems Engineer, KOSTAL Group

which already account for roughly 2% of global energy consumption.

Another way toward sustainability is through reducing size and material requirements. With miniaturized devices, decreased passive requirements, and the enablement of topologies with fewer devices, SiC systems require significantly fewer raw materials than their silicon counterparts. For example, SiC systems require less copper for interconnects and less magnetic material for inductors and transformers.

Notably, SiC has an extremely large sustainability impact with respect to thermal management and cooling systems. Given that SiC is more efficient than silicon, SiC devices burn less power during operation and generate less heat. Therefore, SiC-based power systems rely less heavily on exotic cooling solutions that necessitate raw materials like

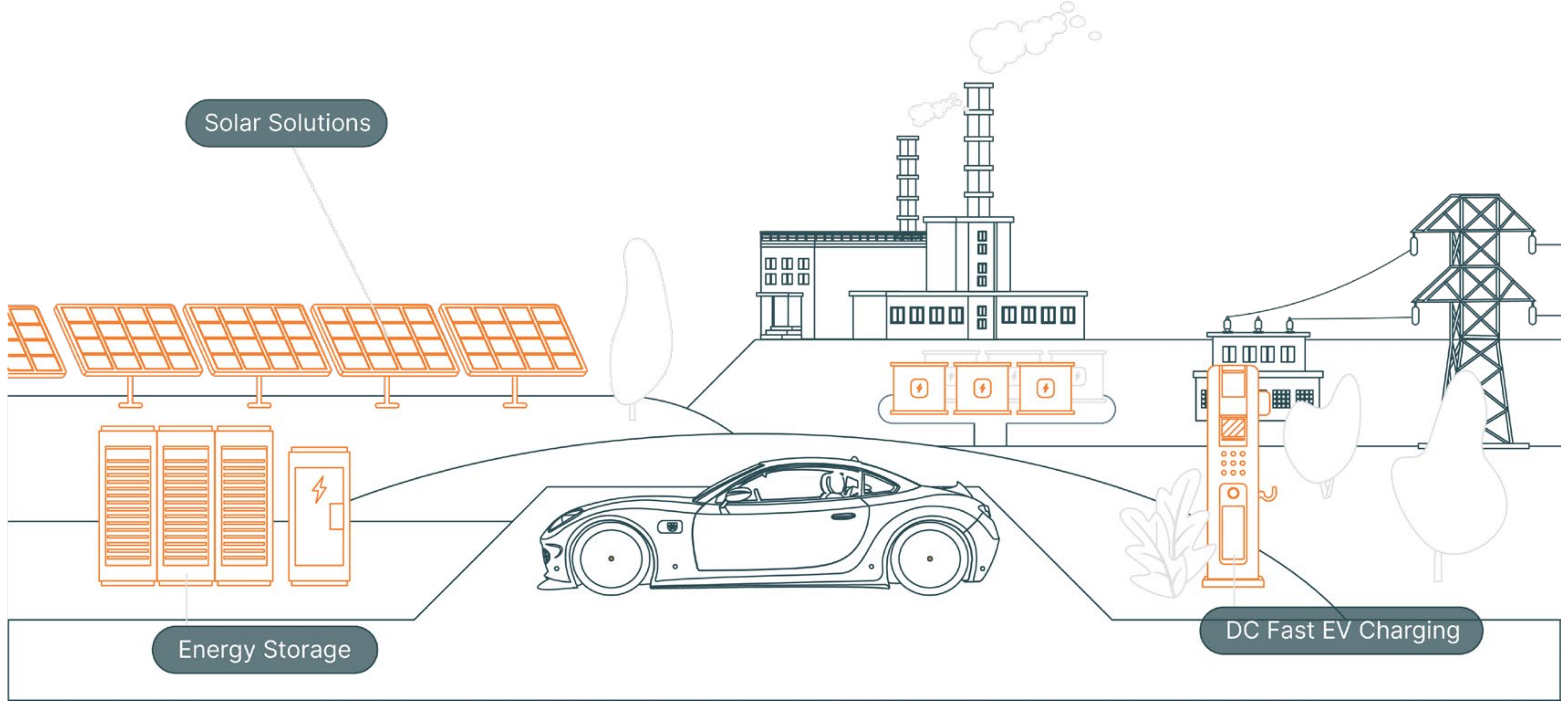


Fig. 1: SiC enables sustainable applications like EVs and renewable energy.

aluminum for heatsinks. The decreased need for cooling solutions also creates even more energy-efficient systems. Studies indicate that cooling accounts for roughly 40% of the energy consumed in data centers. By reducing the need for cooling, SiC reduces energy requirements for power systems, making them even more sustainable.

Finally, the improved durability of SiC results in fewer failures in the field and less time, material, and effort spent on repairs. With exceptional temperature tolerance and high breakdown voltages, SiC devices have a longer mean time between failure, making for more reliable and sustainable systems.

Beyond the devices themselves, SiC contributes to a more sustainable future by enabling new sustainable applications like EVs and renewable energy.

In EVs, designers use SiC to create more efficient and power-dense systems for applications including onboard charging, battery systems, and traction inverters. Additionally, SiC supports the current EV trend of transitioning from 400V to 800V architectures, which enables more efficient vehicle systems by decreasing power distribution losses at higher voltages. With the power density and efficiency benefits from SiC, designers can create EVs that charge faster, are more reliable, and have longer driving ranges.

In renewables, SiC devices are increasing the efficiency of technologies like solar panels and wind turbines. Designers strive to use high-voltage distribution systems to maximize solar and wind efficiency. Fewer IR drops are incurred during power transmission at high voltages, improving overall system efficiency. SiC devices help support this transition to higher-power renewable

“

SiC is an enabler for the entire electrification agenda and is being adopted in EV charging infrastructure, data centers, industrial machines, trains, and more. As the technology matures, other applications might come into scope, like haulage and shipping, wind and solar power converters, HVDC, and possibly even all-electric aircraft.”

Peter Gammon

Professor of Power Electronic Devices, University of Warwick

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Optimizing charging speeds and improving range are two of the most important factors for EVs. Implementing SiC semiconductors is a foundational way to meet these demands."

Gaman Munukoti

Sr. Systems Engineer, KOSTAL Group

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systems and, therefore, more efficient renewable energy generation and distribution.

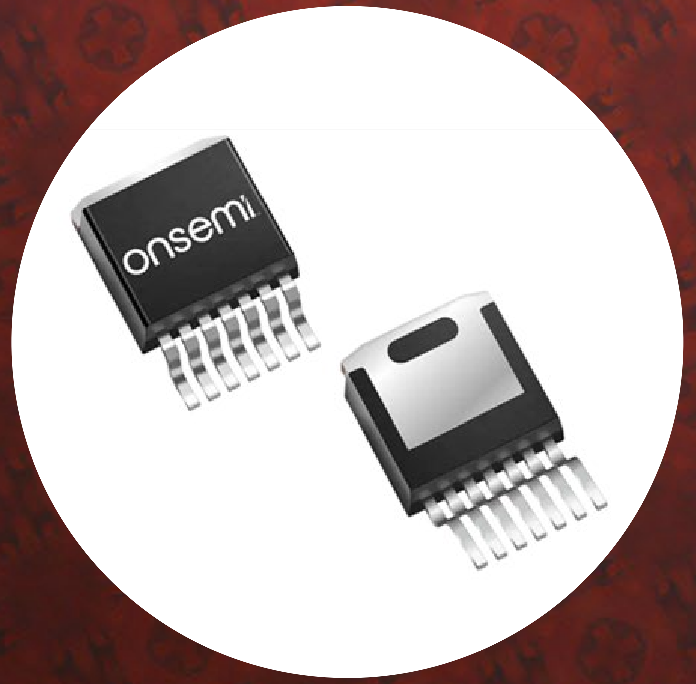
onsemi uniquely helps designers create a more sustainable future by

- Offering power-efficient and high-density SiC devices including discrete solutions and modules that can withstand the demands of EV and renewable energy applications
- Subjecting their SiC devices to extensive lifetime testing to ensure longevity and field reliability
- Being a vertically integrated company involved in all facets of production, from crystal growth to device packaging
- Providing a breadth of packaging options from standard to application-specific packages

"SiC in EV traction inverters offers better efficiency than alternatives like IGBT. EVs without SiC emit more CO2, need more electricity, and demand heavier batteries with more rare earth materials. For the environmentally focused consumer who also cares about the total cost of ownership, cars with SiC are the better choice."

Morten Feldstedt

Marketing Director EMEA, Power Solutions Group, onsemi



EliteSiC 1700V Silicon Carbide (SiC) MOSFET

Learn More

Key Points

- SiC enables a more sustainable future by enhancing device and system power efficiency.
- The energy efficiency and miniaturization of SiC devices reduce the demand for cooling systems and minimize the use of materials such as copper and aluminum.
- By facilitating a transition to high-voltage systems, SiC improves the efficiency of EVs and renewable energy applications.
- onsemi advances the adoption of SiC in sustainable technologies by providing power-efficient and durable devices, performing comprehensive lifetime tests, and maintaining a vertically integrated production process.

Chapter 3

CHOOSING THE RIGHT SIC PARTNER

Many different SiC offerings exist on the market today. Therefore, to get the most out of your SiC designs, you should choose a supplier who can be a trusted partner in your design process.

When choosing a partner, your first consideration is whether they offer high-quality SiC products.

High quality and reliability in SiC devices begin with producing defect-free SiC wafers. Defects can significantly impact device performance by increasing leakage currents, reducing breakdown voltage, and compromising thermal conductivity. Ultimately, the foundation of high-quality and reliable SiC devices lies in overcoming the material and process challenges associated with producing pristine SiC wafers that maintain the superior electrical, thermal, and mechanical properties of SiC. Overcoming these challenges involves meticulous control over the manufacturing process, from substrate creation to epitaxial growth.

Following wafer production, the development of devices with an optimal oxide material is necessary. The oxide layer serves as the gate dielectric in MOS devices, playing a crucial role in controlling device conductivity. Therefore, optimizing the oxide material and its

"When choosing SiC products, on-state resistance, gate charge, reverse recovery charge, and reverse recovery time are important parameters to consider for the application."

Jayaram Subramanian

High Voltage Systems Engineer,
Mercedes-Benz Research & Development North America, Inc.

> ***"When choosing high-quality SiC, you must truly understand what all the stakeholders of your design need. A design, to a large extent, is the result of the conditions of its making, so a complete understanding of a manufacturer's capability is paramount."***

Joshua Raimond

Principal Design Engineer, Commonwealth Fusion Systems

interface with SiC is crucial to unleashing the full potential of SiC devices in high-power applications.

As a designer, you can often identify a high-quality SiC device by examining the device's specifications on the datasheet, where performance parameters and device tolerances can indicate SiC quality.

Beyond device quality, choosing a SiC partner who ensures a high level of supply chain reliability is important. The ideal partner should have a robust manufacturing process, a proven track record of meeting demand, and strong logistical capabilities to ensure the timely delivery of products. For example, partnering with a company that demonstrates transparency, has a comprehensive risk management strategy, and maintains strategic stockpiles or multiple sourcing options can safeguard against unexpected supply chain interruptions.

Finally, a good SiC partner will support your design efforts through resources such as application notes and virtual prototyping tools and models.

A comprehensive suite of resources—including detailed datasheets, design guides, and simulation software—enables designers to accurately predict device behavior under various conditions, reducing development time and costs. Virtual prototyping tools, in particular, allow for the testing of different scenarios and configurations without the need for physical prototypes, accelerating the iteration process. Additionally, application notes provide valuable insights into best practices, troubleshooting, and innovative applications of SiC technology in real-world scenarios. A partner offering strong technical support and educational resources facilitates a smoother design process and helps designers overcome the steep learning curve associated with adopting new technologies.

EliteSiC

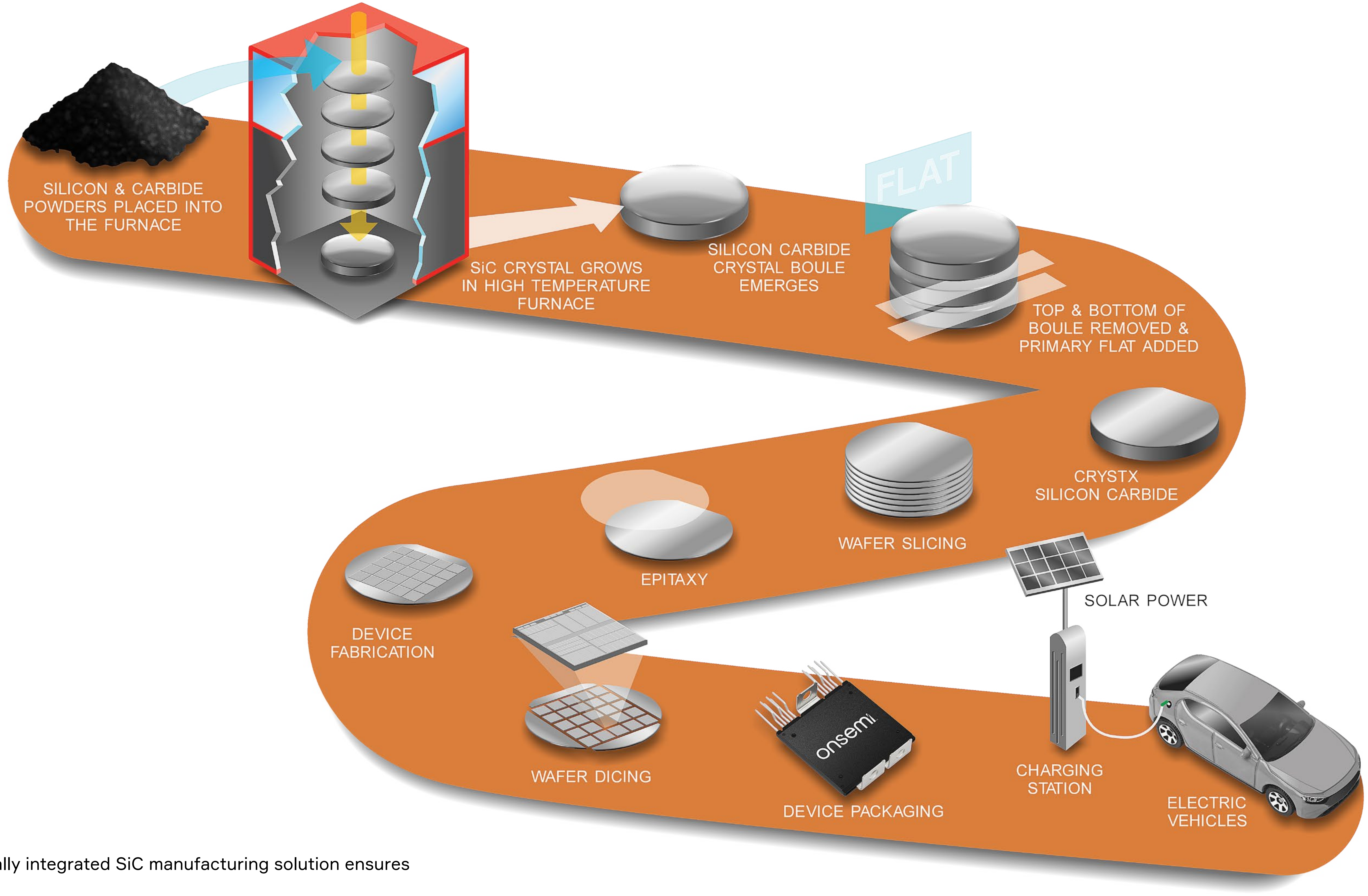


Fig. 2: From substrates to assembly to packaging, a vertically integrated SiC manufacturing solution ensures the customers to have a reliable supply of SiC.

onsemi is a trusted SiC partner because they

- Are a vertically integrated company, allowing them to control the quality of their SiC devices at every stage of the development process
- Are investing heavily in supply chain management, including in new manufacturing and packaging facilities, to ensure a robust and reliable SiC supply chain and control the quality at every stage (from substrate to systems)
- Are providing physically based, scalable SPICE and PLECS models, which are therefore more accurate than the industry-standard curve-fitting models
- Are developing performance optimized package technologies to meet customer's system requirements
- Offer decades of experience in power semiconductors

"Currently, during the development phase, it is better to choose the supplier who has mass production experience, strong knowledge regarding the die manufacture and test, and also the packaging and application experience to support final system design."

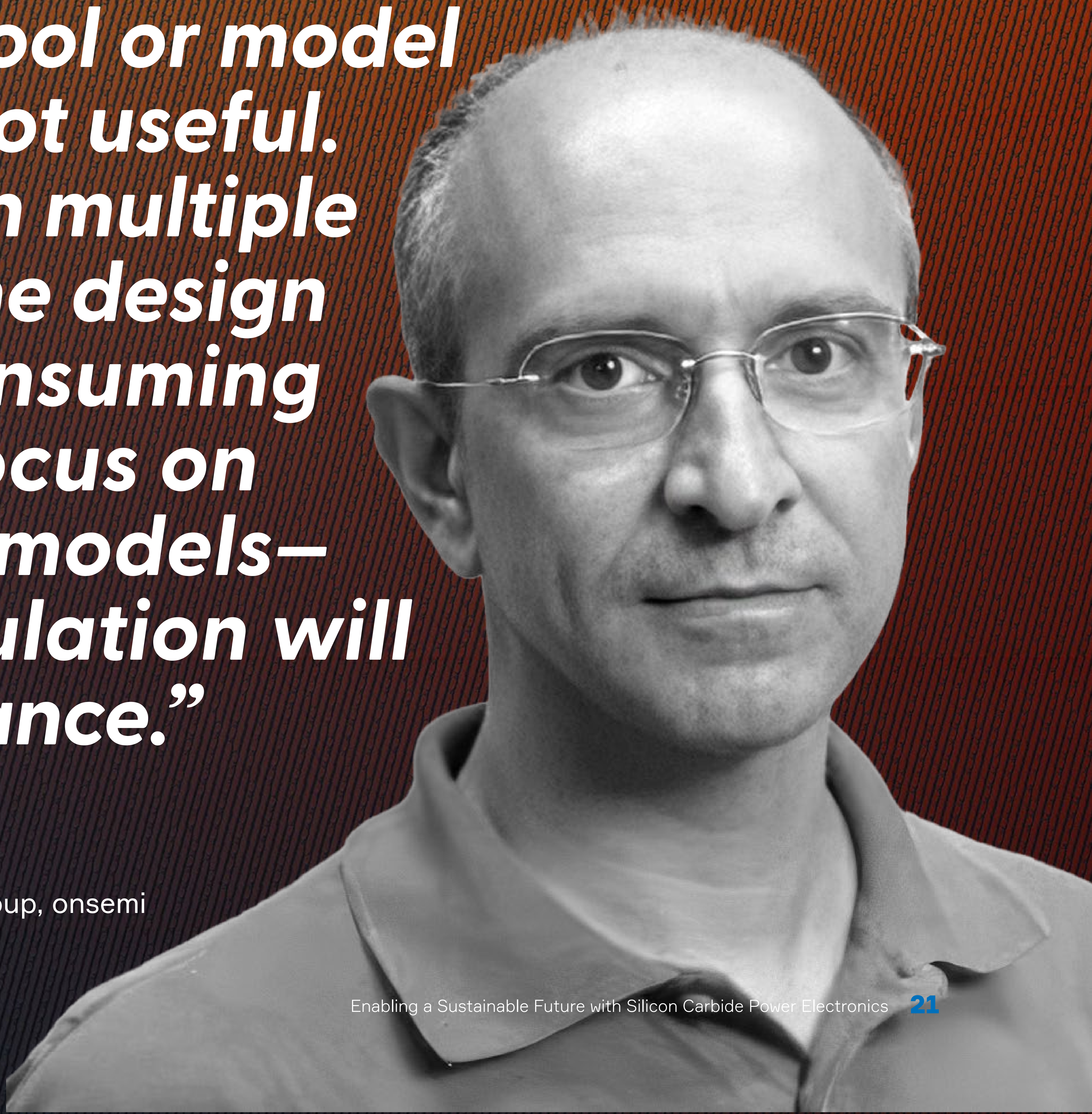
Bo Liu

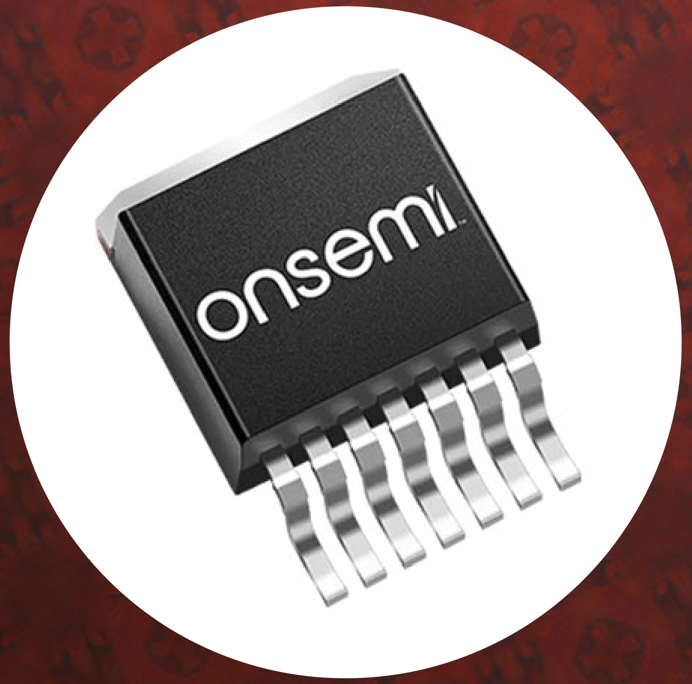
ePowertrain Product Director, VReMT

"If you have a virtual prototyping tool or model that gives you a large error, it's not useful. Inaccurate simulation can result in multiple design revisions before getting the design right, which is costly and time-consuming for customers. That's why we focus on accuracy when creating device models—so you can be sure that your simulation will match real-world performance."

Didier Balocco

Technical Marketing Engineer, Power Solutions Group, onsemi





EliteSiC 1200V Silicon Carbide (SiC) MOSFET

Learn More

Key Points

- **A key aspect of high-quality SiC devices is the production of defect-free SiC wafers, which are essential for maintaining superior electrical, thermal, and mechanical properties.**
- **The performance and reliability of SiC devices also depend on the quality of the oxide layer used as the gate dielectric.**
- **Selecting a SiC supplier involves ensuring supply chain reliability, as evidenced by robust manufacturing processes and a proven ability to meet product demands on time.**
- **onsemi distinguishes itself as a SiC partner through its vertical integration, which enhances control over every stage of SiC device development and is coupled with significant investments in supply chain management.**

Learn More About Our Experts

Didier Balocco

Technical Marketing Engineer,
Power Solutions Group,
onsemi

Didier Balocco, a Technical Marketing Engineer at onsemi, holds a PhD in Power Electronics from the University of Bordeaux. Didier spent almost 15 years at AEG Power Solutions where he spearheaded research activities and managed projects related to power electronics. In 2018, he brought his many decades of experience to onsemi, where he continues to be a prolific author and key figure in the power electronics industry.

Morten Feldstedt

Marketing Director EMEA,
Power Solutions Group,
onsemi

Morten Feldstedt leads the European marketing team for the Power Solutions Group at onsemi. He has a background in electronics design, was educated at Danfoss, and worked for Lenze, both strong power electronics companies. He also served as Sales and Applications Director at Fairchild Semiconductors and later as Marketing Director. When joining onsemi, he moved into the business unit, where he enjoys contributing to power semiconductor innovations.

Peter Gammon

Professor of Power Electronic Devices,
University of Warwick

Peter Gammon, Professor of Power Electronic Devices at the University of Warwick, is a leading figure in the development of silicon carbide (SiC) power devices. Demonstrating his expertise, Peter has authored 100+ papers and founded PGC Consultancy, where he specializes in SiC industry insights, device design, and market analysis. Peter's contributions extend beyond academia; he's a sought-after speaker and collaborator, facilitating innovation in semiconductors for electric vehicles, space tech, and industrial machines.

Learn More About Our Experts

Sara Kuzmanoska
Staff Characterization Engineer,
R&D SiC Technology,
onsemi

Sara Kochoska, a Characterization Engineer in R&D SiC Technology, has spent more than 7 years at onsemi and currently leads a dynamic team exploring cutting-edge applications of SiC. In 2017, Sara earned a master's degree in Automotive Electronics from THI Ingolstadt, Germany, and has authored numerous impactful papers on SiC topics. As an advocate for innovation, Sara is continuing to push the boundaries of SiC technology.

Bo Liu
ePowertrain Product Director,
VReMT

With over 18 years in power electronics, Bo is a seasoned leader in technical innovation and project management. From CHINT Electric to Siemens, his expertise spans high voltage systems, inverters, and hardware architecture. Currently, as Product Director at VReMT, he drives product definition and strategy, leading the introduction of cutting-edge inverter platforms. Bo has a degree in Electronic Information Engineering from Harbin Engineering University.

All views presented in this ebook are Bo's own and not representative of his company.

Gaman Munukoti
Sr. Systems Engineer,
KOSTAL Group

Gaman Munukoti, a seasoned Senior Systems Engineer at KOSTAL Group, brings over five years of automotive industry experience to his role. Specializing in automotive electrical engineering, embedded systems, and power electronics, Gaman is known for his passion for clean energy and innovative thinking. He holds a master's degree in Electrical and Electronics Engineering from the University of Cincinnati and is affiliated with prestigious organizations, including IEEE, FSAE, and ACM.

Learn More About Our Experts

Prasad Paruchuri

Technical Marketing Team Lead,
Power Solutions Group,
onsemi

Prasad Paruchuri drives innovative EliteSiC family products for industrial applications at onsemi. His 25+ years of semiconductor experience (15 at STMicroelectronics and 10 at onsemi) extend from application development and system architecting to technical marketing and strategy development. Prior to that, Prasad worked as Design Engineer at ASTEC Power (Emerson Electric). In his spare time, he watches basketball with friends and family and discusses politics for improving the environment and developing communities.

Joshua Raimond

Principal Design Engineer,
Commonwealth Fusion Systems

Joshua Raimond is a Principal Design Engineer and founder of cog design—an engineering design consultancy. An expert in clean sheet engine design and powertrain systems, Joshua brings a wealth of expertise to his role. Recent achievements, including his SiC mirror design for a tokamak and clean sheet design of a first-stage rocket engine, highlight his drive for engineering excellence and his dedication to innovation.

Jayaram Subramanian

High Voltage Systems Engineer,
Mercedes-Benz Research & Development
North America, Inc.

Jayaram Subramanian, a High Voltage Systems Engineer, holds a PhD in Electrical Engineering from West Virginia University. He's known for pioneering research in linear generators, combined heat and power, and electrification systems. Alongside his technical pursuits, Jayaram dedicates himself to mentorship through volunteer work and enjoys teaching. He has authored several journal articles and presented at conferences in IEEE and SAE, embodying a multifaceted commitment to engineering innovation and education.