How Silicon Carbide Semiconductors Are Conquering E-mobility

Bosch has tailored its semiconductor development to the demands of the automotive industry.

POWER ELECTRONICS ARE AT THE HEART OF many electronic systems in battery-electric vehicles. Here, semiconductors manage the energy and ensure that it is utilized as efficiently as possible. MOSFETs (metal-oxide-semiconductor field-effect transistors) made of silicon carbide (SiC) are renowned for taking electromobility to new levels of efficiency. While semiconductor technology is already widely used in some areas, its application is still in its early stages in certain automotive applications.

Silicon carbide semiconductors in on-board chargers ensure more efficient charging and lighter systems.

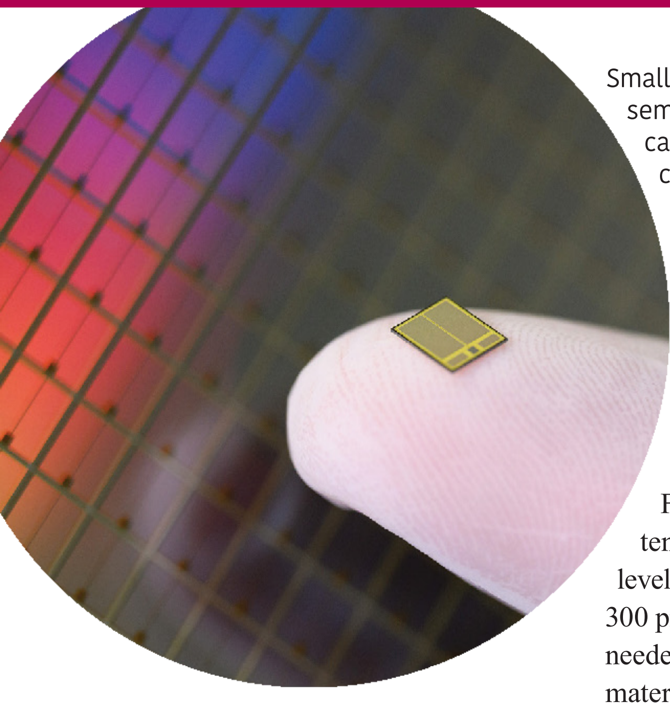
The semiconductor manufacturer and automotive expert Bosch has an optimistic outlook on the future of silicon carbide.

Silicon carbide belongs to a class of materials known as wide bandgap semiconductors. This wider bandgap offers several advantages over silicon: thanks to the higher breakdown field strength, these special semiconductors can block higher voltages with lower on-state resistances, making them ideal for the high-voltage range. In addition, the improved temperature stability ensures that the semiconductor retains its performance even at temperatures of up to almost 400 degrees Fahrenheit. Another key advantage of SiC is its higher charge carrier mobility, which enables significantly higher switching frequencies compared to conventional silicon-based solutions. Together, these benefits lead to improved overall efficiency.

Why SiC is worthwhile

The main benefits of silicon carbide vary depending on which vehicle components the chips are used in. In electric vehicles, SiC primarily enhances power electronics, especially the inverter, the

Bosch is systematically expanding its manufacturing capacity for silicon carbide chips over the next few years.



Small chip with a big impact: semiconductors made of silicon carbide have clear advantages over conventional semiconductors in many applications.

DC/DC converter, and the on-board charger. The use of SiC in the inverter enables higher efficiency, which increases the driving range.

SiC MOSFETs have higher switching transients than Si-IGBTs, allowing for quicker switching speeds. By increasing the switching speed, the overall switching loss is reduced by around 50 percent. Additionally, SiC technology enables higher switching frequencies, reaching up to 24 kHz.

The capability significantly benefits DC/DC converters and on-board chargers by enabling more compact and lightweight systems with improved efficiency. Inverters equipped with SiC semiconductors enhance the overall efficiency of electric drives, reducing electrical consumption (kWh per 100 km) in conjunction with other improvements in the overall system. This increases the range of electric vehicles or, in other words, allows the battery capacity to be optimized based on the vehicle class and application to save costs.

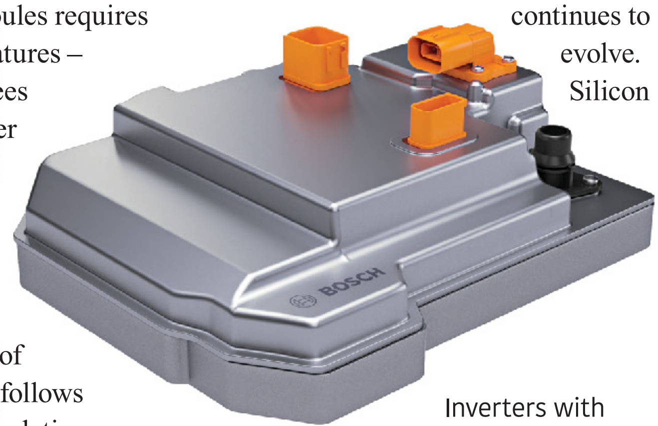
SiC chips are conquering the market

Despite their numerous advantages, not all electric cars currently contain silicon carbide chips. One reason is that SiC semiconductors are more expensive than comparable silicon components. The production of silicon carbide boules requires very high temperatures – around 3,600 degrees Fahrenheit – and over ten mask or structure levels with more than 300 process steps are needed before the raw material turns into a chip. As a result, the use of silicon carbide generally follows a careful cost-benefit calculation.

Inverters based on silicon carbide technology are therefore currently found primarily in high-performance vehicles, where the benefits of SiC semiconductors are most obvious. "In smaller electric vehicles, which often use 400-volt batteries, silicon-based IGBT modules are still common in inverters. However, in vehicles which are based on 800-volt technology, the advantages of silicon carbide in the inverter clearly outweigh the disadvantages," explains Anne Bedacht, Head of Product Management for Power Semiconductors at Bosch.

The Bosch power module with silicon carbide semiconductors offers high power density.

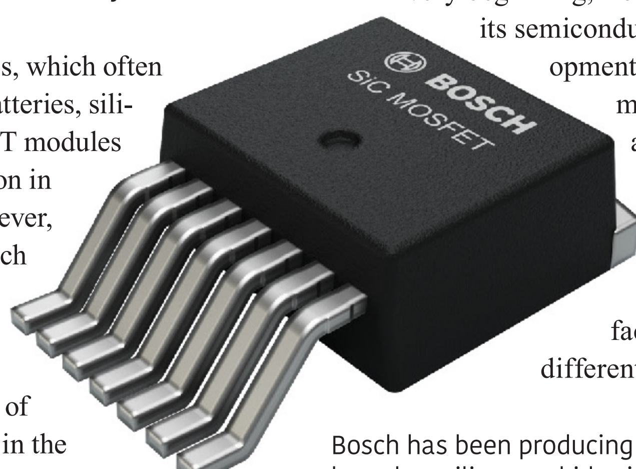
For her, efficient e-mobility is therefore closely linked to SiC: "If you look at the progress made in both SiC and electric vehicles over the last ten to fifteen years, it's undeniable and continues to evolve. Silicon carbide chips have been conquering the market for several years, starting with the most profitable applications. As production scales up, the cost of these chips will eventually decrease – making their use increasingly worthwhile across more vehicle components and models."



Inverters with silicon carbide semiconductors show their advantages particularly in the high-voltage range.

Designed for electric driving

Bosch was an early adopter of SiC technology. The company began developing the first SiC semiconductors in 2001 and had the first MOSFET prototype available by 2011. From the very beginning, Bosch tailored its semiconductor development to the demands of the automotive industry. "Semiconductors in vehicles face entirely different conditions



Bosch has been producing MOSFETs based on silicon carbide since 2001.

Bosch's wafer fab in Roseville, California: starting in 2026, the first silicon carbide chips will be produced in the United States on 200-millimeter wafers.

compared to stationary applications," explains Bedacht. "For example, the temperature fluctuations that a car is exposed to put significant strain on the electronics. In addition, we must deal with higher quality requirements. A car is in use for many years, and the semiconductor's lifespan must keep pace. Our chip designs reflect these demands."

One example is the design of the gate oxide in the trench MOSFET. Bosch has developed its own manufacturing process for SiC chips, adapting Bosch's own trench etching technique. This process, commonly referred to in the industry as the "Bosch process", was originally developed in 1994 for MEMS sensors. It enables high-precision vertical structures to be etched into the wafer material. Unlike the conventional planar structure, the gate is vertical. The insulating oxide not only covers the surface of the chip but also protrudes into it. "This structure ensures higher power density while guaranteeing a long service life. This is important because the component will be exposed to high voltage for many cumulative hours in the vehicle over the years," the semiconductor expert reports.

The future is all about SiC for Bosch

Bosch has positioned itself broadly in the automotive industry and offers SiC MOSFETS in multiple forms. The company sells bare dies and discretes directly to OEMs, to tier 1 and 2 suppliers and to distributors, while also implementing them in its own modules and components. From Bosch's point of view, the two sales channels are by no means contradictory, as Bedacht explains: "On the contrary, both customer groups benefit from our broad experience in the automotive industry. Many customers have long relied on their own designs and systems for greater differentiation, and we aim to support these OEMs and tiers just as much as those who use complete modules and components that include our SiC semiconductors."

Anne Bedacht, product manager for silicon carbide semiconductors at Bosch.

For Bosch, the future is clearly centered around SiC. The company is systematically expanding its production capacities – both at its existing production facility in Reutlingen, where mass production of SiC chips began in 2021, and at the new wafer fab in Roseville, California, which is currently being converted to silicon carbide. In Reutlingen, Bosch is already producing samples of its first silicon carbide chips on 200-millimeter wafers for customer trials. The delivery volume is expected to increase more than tenfold in the coming years.* With the new fab in Roseville, Bosch will reinforce its global portfolio of SiC chips. Starting in 2026, the first silicon carbide chips will be produced in the United States on 200-millimeter wafers. "The automotive industry is a key player in driving the technology forward," summarizes Bedacht. "With high production volumes, we will achieve economies of scale, which will reduce costs over time and extend the benefits of silicon carbide to other applications."

The IPCEI ME/CT project is supported by the German Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Parliament, by the Ministry for Economic Affairs, Labor and Tourism of Baden-Wuerttemberg based on a decision of the State Parliament of Baden-Wuerttemberg, the Free State of Saxony on the basis of the budget adopted by the Saxon State Parliament, the Bavarian State Ministry for Economic Affairs, Regional Development and Energy, and funded by the European Union — NextGenerationEU.