SiC modules for industry

Silicon carbide (SiC) is revolutionising the world of power electronics, offering advanced solutions for a wide range of applications, from automotive to renewable energy. WeEn Semiconductors, recognising the growing importance of this technology, is actively engaged in the development and production of SiC devices, with a particular focus on the rapidly expanding electric vehicle (EV) market.
In this article, we explore the potential of WeEn Semiconductors' SiC modules, their key applications and how they are shaping the future of power electronics in industry.

Automotive applications such as inverters, on-board chargers and charging stations are the main players in the SiC market. To optimise power conversion efficiency, SiC MOSFETs are expected to be increasingly used in such contexts. Indeed, market analyses reveal that the SiC segment is booming, with a projection that it will reach USD 5 billion by 2028. This growth will be particularly pronounced in sectors with power ratings above 80 kW and in high-end electric vehicles.

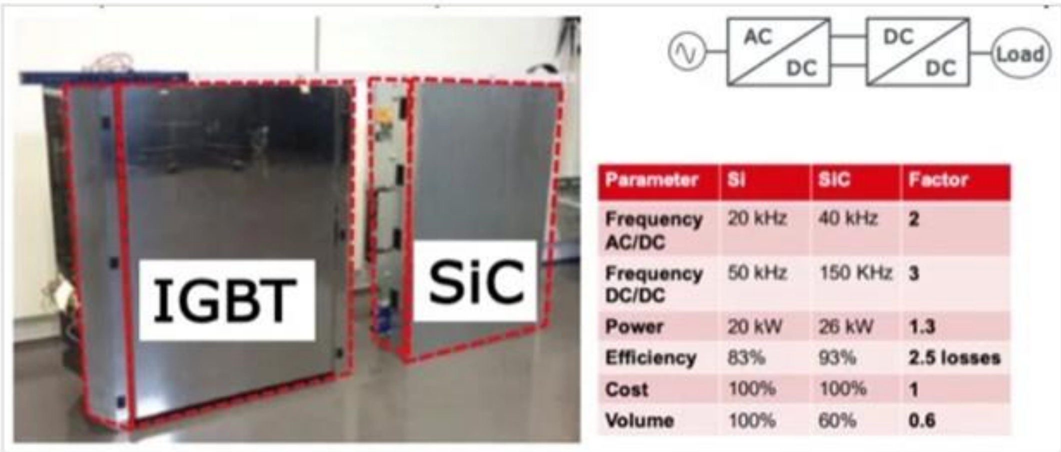
WeEn guarantees that its module production facilities meet automotive requirements by using industry-specific certified foundries during SiC production. In addition, to ensure product reliability and performance, the company has a reliability laboratory and a qualified in-house failure analysis centre.

However, WeEn Semiconductors does not only focus on automotive: the company also supplies certified SiC devices for non-automotive sectors, such as photovoltaic inverters, industrial power supplies, air conditioning systems and uninterruptible power supplies (UPS).

Advantages of SiC devices

SiC devices offer numerous advantages over silicon (Si), including the provision of higher voltage operation, wider temperature ranges and higher switching frequencies than existing

Si technology. The benefits of SiC also include significant efficiency gains through advances in miniaturisation, reduced cooling requirements and overall system cost reductions of up to 30 per cent compared to Si materials.



Parameter	Si	SiC	Factor
Frequency AC/DC	20 kHz	40 kHz	2
Frequency DC/DC	50 kHz	150 KHz	3
Power	20 kW	26 kW	1.3
Efficiency	83%	93%	2.5 losses
Cost	100%	100%	1
Volume	100%	60%	0.6

Comparison of two PS: IGBT PS vs. SiC PS

The high breakdown voltage, low RDSON, high thermal conductivity and high Tj(max) allow a SiC MOSFET to handle a much higher current and voltage than a Si MOSFET of similar size, hence a higher power density.

These advantages translate into lower power conversion losses, higher efficiency, simpler converter topologies and improved performance at high temperatures.

WeEn offers SiC MOSFETs with voltages of 1200V, competitive RDSON values and various package types. The resistance of these MOSFETs to short-circuit depends on Vgs and Vds. With the innovation of second-generation MOSFETs, a short-circuit withstand time of 3.5 microseconds is achieved at 18V and 800V, guaranteeing reliability without risk of failure. These SiC MOSFETs from WeEn are particularly suitable for inverters in electric vehicles, helping to improve vehicle efficiency and range.

In addition, WeEn's SiC MOSFETs use a clear designation for RDSON at 15V gate drive voltage; optimisation of the gate oxide ensures normal device operation at this drive voltage, facilitating integration into conventional designs.

SiC modules

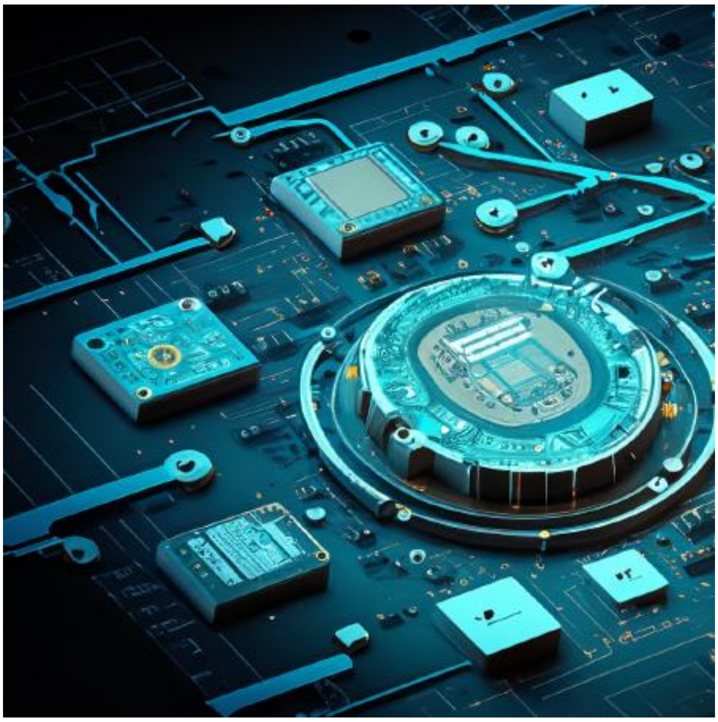
A silicon carbide power module is a power module that uses an SiC semiconductor as a switch. Silicon carbide power modules are used to transform electrical energy, obtained from the product between current and voltage, with high conversion efficiency.

Parallel connection of power modules to support higher current levels is a commonly used approach in practice, as each module is optimised for the effect of inductances and parasitic capacitances and can achieve better repeatability.

The optimal approach to creating parallel module architectures with SiC devices presents several challenges. Due to their high switching capacity, the layout of the module and gate drivers is of paramount importance to reduce parasitic capacitance and ensure uniform current sharing between modules. In terms of static current sharing, the device's RDSON and module connection resistors play a key role.

The positive temperature coefficient of RDSON in SiC MOSFETs subjected to strong gate drive facilitates parallelism, as the currents rebalance: the device that conducts more current heats up more and thus increases its RDS(on) compared to the cooler device. In this way, thermal runaway can be avoided. On the other hand, the negative temperature coefficient of the threshold voltage (VTH) causes the device with the higher junction temperature to switch on earlier, generating higher switching losses.

Challenges and solutions in the implementation of SiC devices



Due to the higher switching speeds, SiC devices are more sensitive to parasitic inductances in the package. These can resonate with the capabilities of the device, causing unwanted electromagnetic interference. During high-speed current transients (di/dt), large surges can be created on the device, which can degrade the reliability of the device or cause catastrophic failures.

Parallel devices are often used to achieve module current ratings. Imbalances in the parasitic inductances/capacities or in the static parameters of the device, such as the threshold voltage, can cause varying transient voltage overshoots between dies placed in parallel. Dies with higher overshoots will experience higher switching losses and thus higher temperatures. This may reduce the duration of the module.

To control overshoots, external gate resistors are commonly added, but these increase switching times and thus losses. Low-inductance wireless interconnection schemes have been proposed, e.g. with parallel plates interconnected to metal posts. Decoupling capacitors can be used to mitigate the impact of parasitic inductance. One approach involves placing the capacitors above the power device, creating a vertical power loop that maintains the module's horizontal footprint.

Parasitic capacities and partial discharges

Conventional power modules include a parasitic capacitance between the insulating ceramic substrate (such as direct bonded copper, or DBC) and the heat sink, which is generally located at ground potential. At higher voltage transients (dV/dt), this capacitance becomes a path for the common mode current (CM) to pass through the system ground. Filters and chokes can mitigate this, but add cost and complexity. With the use of multilayer ceramic substrates, a screen layer can be added, which brings the CM current back to the die while reducing high-frequency noise.

The high electric field created in these HV devices can overcome the breaking strength of the dielectric materials of the package. This can create partial discharges (PD), which can damage the insulating ceramic substrate. Reducing the electric field, and thus increasing the PD trigger voltage (PDIV), in the vicinity of the insulating substrate is crucial, as this is where PD occurs.

Symbol	Parameter	Conditions	Notes	Values			Unit
Absolute maximum rating							
V_{DS}	drain-source voltage	T_j = 25 °C		1200			V
I_D	drain current	V_{GS} = 15 V; T_h = 75 °C; T_j = 175 °C		63.5			A
P_{tot}	total power dissipation	T_h = 75 °C; T_j = 175 °C		189			W
T_j	junction temperature			-40 to 150			°C
Symbol	**Parameter**	**Conditions**	**Notes**	**Min**	**Typ**	**Max**	**Unit**
Static characteristics							
$R_{DS(on)}$	drain-source on-state resistance	V_{GS} = 15 V; I_D = 50 A; T_j = 25 °C		-	20	35	mΩ
Dynamic characteristics							
$Q_{G(tot)}$	total gate charge	I_D = 50 A; V_{DS} = 800 V; V_{GS} = 0 V/18 V; T_j = 25 °C		-	214	-	nC
Q_{GD}	gate-drain charge			-	45	-	nC
Source-drain diode							
Q_r	recovered charge	I_{SD} = 50 A; V_{GS} = -4 V; di/dt = 6000 A/µs; V_R = 800 V; T_j = 25 °C		-	tbd	-	nC

Figure 1: Reference data of the N-channel silicon carbide MOSFET module WMSC020H12B1P (Source: WeEn)

Advantages of SiC modules

Increased efficiency: one of the main characteristics of SiC modules is their superior energy efficiency. SiC semiconductors can operate at higher temperatures and voltages than conventional silicon-based components, resulting in lower conduction and switching losses. This improvement in efficiency results in less power dissipation and, consequently, greater energy savings;

Reduced size and weight: SiC modules offer higher power density due to their improved thermal performance. This allows designers to build more compact and lightweight power electronics systems, making them ideal for space-constrained applications such as electric vehicles and inverters for renewable energy;

Higher switching speeds: SiC semiconductors can switch on and off much faster than silicon

devices, enabling higher frequency operation and tighter control of power electronics systems. This feature improves the overall performance and responsiveness of electronic devices;
Increased reliability: high temperature tolerance and resistance to harsh environmental conditions make SiC modules exceptionally reliable, ensuring consistent performance over long periods.

Applications of SiC modules

Silicon carbide (SiC) modules have emerged as an innovative technology in several areas, revolutionising the landscape in several key areas. In the electric vehicle (EV) sector, SiC modules represent a breakthrough, as they bring significant improvements in efficiency while reducing size and weight. This translates into a longer driving range and faster charging times for electric vehicles, improving their overall performance.

In addition, SiC-based power electronics enable electric vehicles to achieve greater acceleration and optimise regenerative braking efficiency, further cementing their position as the future of sustainable transport. In addition to electric vehicles, SiC modules play a key role in renewable energy systems, significantly increasing the efficiency of solar inverters, wind turbine converters and energy storage systems.

Their high efficiency ensures that a higher share of energy from renewable sources is converted into usable electricity, reducing system costs and facilitating the transition to clean energy. In industry, SiC modules find applications in high-frequency power supplies, motor drives and welding equipment, due to their higher switching speeds and robustness, making them ideal for the most demanding production environments. Furthermore, SiC modules are making inroads into the aerospace and defence sectors, where reliability, size and weight are crucial. These modules are used in power converters, radar systems and electric propulsion systems for drones and aircraft, ushering in a new era of innovation in these critical sectors.

The WeEn module

The WMSC020H12B1P is a module incorporating a silicon carbide (SiC) N-channel MOSFET.

Overall, this module appears to be designed for applications requiring high efficiency, low losses and reliable power switching, typical of areas such as power electronics, motor control, renewable energy systems and others. The combination of silicon carbide technology and half-bridge configuration makes it suitable for high-performance power conversion applications.

Some important technological solutions used in this module are as follows:

Technology: the module uses PressFit pin technology. PressFit technology is a solderless connection method in which pins are pressed into a plated through-hole on the PCB (Printed Circuit Board), providing a reliable, gas-tight connection;
MOSFET type: The module integrates a WeEn 1200V Gen2 SiC MOSFET. Silicon carbide MOSFETs are known for their high temperature tolerance, low switching losses and high-

frequency capabilities.

Topology: the module is configured with a half-bridge topology, in which two power transistors (usually a high side and a low side) are used to control the power flow to the load. This configuration is commonly used in power electronics applications.

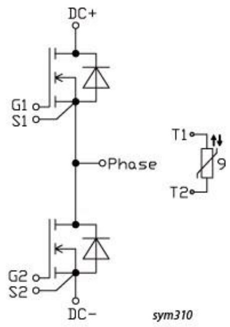
Simplified outline	Graphic symbol
	

Figure 2: Silicon carbide N-channel MOSFET module WMSC020H12B1P schematic (Source: WeEn)

WMSC020H12B1P module features

The main technical features of the module are as follows:

Low RDS(on): The module offers low resistance in the on state, RDS(on), for more efficient power delivery;

Low switching losses: SiC MOSFETs generally have lower switching losses than conventional silicon MOSFETs, making them suitable for high-frequency switching applications;

Low Qg and Crss values: low gate charge (Qg) and reverse transfer capacitance (Crss) are desirable characteristics in power MOSFETs, as they help reduce switching losses and improve efficiency;

Low-inductance design: a low-inductance design helps reduce voltage spikes and electromagnetic interference in the circuit;

Auxiliary inverters: this module can be used in auxiliary inverter circuits, commonly found in various power electronics applications;

DC/DC converter: the module can also be used in DC/DC converter applications, where it can efficiently switch and regulate DC voltage levels.