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Next-Gen SiC MOSFETs Are Optimized For xEVs And Industrial Applications

Rohm Semiconductor is now sampling its fourth generation of 1200-V silicon carbide (SiC) MOSFETs, which exhibit much lower static drain-to-source on-state resistance ($R_{DS(ON)}$ or R_{ON}) due to an improved double-trench structure, and lower switching losses provided by a reduction in gate-drain capacitance. Along with these developments, the company is introducing package innovations that lower costs and reduce device footprint. These new devices target applications in EVs and industrial power electronics, which are moving toward higher voltage and higher frequency operation—enhancements that are enabled by SiC power devices. No part numbers have been announced yet, but some key data is available for these SiC MOSFETs.

Developed using trench gate technology, ROHM's fourth-generation (4G) SiC MOSFETs exhibit a 40% reduction in R_{ON} compared to third-generation devices of the same chip size. The benefits of this improvement are that the 4G SiC MOSFETs can operate with higher current density while minimizing conduction losses. In turn, these devices may be made smaller to meet the same system power requirements, reducing the cost of SiC components (Fig. 1).

The reduced R_{ON} is a result of a smaller unit cell pitch, an improved MOS interface, wafer backside grinding, and other performance enhancing design strategies. According to the company, these strategies have not compromised the short-circuit withstand time (SCWT). This is important, as typical reductions in R_{ON} lead to increases of saturation current, higher heat dissipation on a chip during a short-circuit event with commensurately faster junction temperature rise and shorter SCWT.

Another major advantage of the 4G SiC MOSFETs is their reduced C_{rss}, which has led to increased dv/dt speed and lower E_{on}/E_{off}. Moreover, the 4G devices exhibit a lower C_{rss}/C_{iss} ratio with lower E_{rr} and lower V_{GS} surge compared to 3G devices. Along with minimizing the risk of parasitic turn-on, the improved design and cell structure of the 4G SiC MOSFETs demonstrate a switching loss reduction around 50% compared to 3G devices (Fig. 2).

Improved chip design for greater power efficiency also requires optimal device packaging to maximize the switching performance and reduce the component footprint. With the 4G SiC MOSFETs, ROHM is offering discrete packages with added driver source connections, and an SDIP power module with compact size and flexible internal topologies.

For discrete products featuring separate Kelvin source pins, the source stray inductance on the main current path no longer influences the effective gate voltage applied to the chip. The result is significantly faster di/dt speed and lower switching losses, with minimal cost differences versus using the conventional packages.

The company is also providing a more-compact alternative to conventional power modules. The SDIP power module targets medium-power applications such as on-board chargers of electric vehicles, solar inverters, energy storage systems and UPSs. This module can integrate up to six SiC MOSFETs with topology options including the H-bridge, three-phase bridges and more. With a small footprint, insulated backside and easy assembly process, these packages can enable simplified circuit board designs that are smaller and less expensive than using multiple discrete devices or conventional modules (Fig. 3).

Since 2000, ROHM has been investing in R&D for SiC technologies, resulting in industry firsts for SiC MOS, full SiC module, and Trench SiC MOS in mass production, according to the vendor. The results of this legacy are the advanced 4G SiC MOSFETs. These newest devices are advantageous for many applications, as the growth in demand for SiC is driving down costs and leading to economies of scale in substrate/wafer process capacity.

A key component of this is the wafer diameter increase from 100 mm to 150 mm, and ROHM's investment in greater SiC capacity. This includes the acquisition of SiCrystal, a leading SiC substrate supplier, into ROHM Group Companies back in 2009. The acquisition helped to establish a vertically integrated SiC production system with consistent quality and supply assurance. ROHM is committed to the continued expansion in SiC material and device process capabilities to meet the rapidly growing market demand for SiC power devices.

These demands stem from major industry trends in automotive, and more recently in industrial applications. To enhance power system efficiency and power density, many applications have been incrementally increasing switching frequencies and overall system voltages. This trend has recently led to the demand for high-voltage power semiconductor switches capable of operating with ultra-low conduction and switching losses. For instance, previous generations of EVs used only a few hundred volt power systems, newer EV power systems are reaching up to 800-V battery voltage and moving toward higher switching frequencies to reduce passive component sizes.

This is also the case with datacenter, photovoltaic, and a wealth of other renewable energy and industrial applications. These new power conversion systems require a breakthrough in solid-state power switching devices to efficiently and reliably handle the high power, fast switching speed, and wide operating temperature ranges. According to Rohm, legacy IGBT technology struggles to offer the new threshold for efficiency required by these applications. With new mass market production capability and vast performance improvements, the latest generation of silicon carbide (SiC) MOSFET technology is well suited to meet the demanding requirements of today's high-voltage power electronic systems, says Rohm.

SiC, as a semiconductor, vastly outperforms silicon for power device applications in electrical breakdown, bandgap energy, electron saturation velocity, and thermal conductivity. This allows for SiC MOSFETs to innately operate at higher voltages, temperature and frequency, while conducting higher power levels. Additionally, SiC is an extremely hard and rugged material, with a mohs hardness of 13, compared to boron carbide and diamond, with mohs hardness ratings of 14 and 15, respectively.

Specifically, SiC devices are suitable for much higher breakdown voltage than their Si counterparts, by approximately 5 to 10 times. This factor is important, as high-voltage Si switches need to employ bipolar current conduction to lower their on-state resistance, which results in a slower and more energy-inefficient switching process. Moreover, this design necessity with Si transistors leads to a turn-on knee voltage to allow even the smallest current conduction, compromising the conduction loss performance.

SiC's inherent advantage over Si can be attributed to SiC's larger bandgap energy. A wide bandgap energy grants SiC nearly 10 times higher breakdown electric field than Si, making it capable of supporting the same voltage rating with 10 times thinner drift layers and nearly 100 times higher doping concentration. These factors reduce the on-state resistance by approximately 300 times per unit chip area. At voltage ratings of 650 V and higher, SiC MOSFETs exhibit much faster switching speeds than Si IGBTs due to the absence of minority carrier storage effect and tail current losses, enabling high-frequency operation and smaller system sizes.

SiC is also able to withstand harsh environmental conditions to greater temperature and mechanical strain than Si. This is partially due to SiC's much higher thermal conductivity than Si, in addition to its wider energy bandgap. Hence, SiC devices are able to maintain functionality and integrity to temperatures greater than 200˚C, where Si devices degrade significantly over 100˚C and are generally not rated beyond 150˚C. These features allow for SiC devices to be more reliable and rugged without requiring complex system design for thermal management and electrical protection.

The spider chart in Fig. 4 summarizes the key comparisons in material properties for silicon, SiC and GaN. Note that GaN, which is mainly offered in devices rated at 650-V and below, exceeds SiC in some areas, but has lower thermal conductivity than SiC, which is offered in devices rated at 650-V, 1200-V and higher. Naturally, improved performance for SiC comes at a price. SiC MOSFETs are more expensive than silicon IGBTs in terms of device cost. However, this cost can be justified and offset in automotive and other applications by the improved system performance that SiC MOSFET technology enables.

For more information, or to request samples of Rohm's 4G SiC MOSFETs, see https://www.rohm.com/one-on-one. Or for more information see "New 4th Generation SiC MOSFETs Featuring the Industry's Lowest ON Resistance" and "Solving the Challenges of Driving SiC MOSFETs".

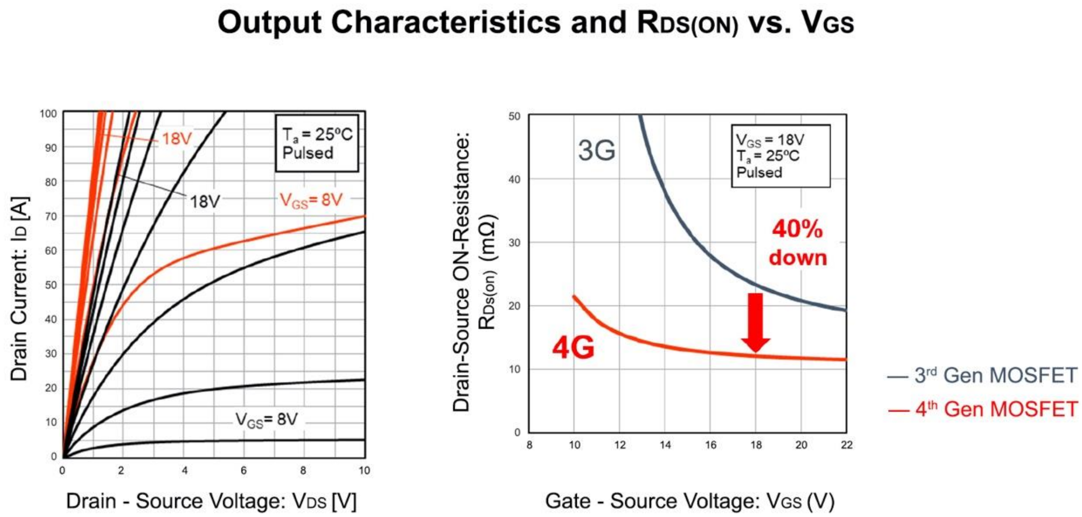

Fig. 1. A comparison of Rohm's 4th-generation 1200-V SiC MOSFETs with the company's existing third-generation n-channel devices reveals a 40% reduction in $R_{DS(ON)}$.

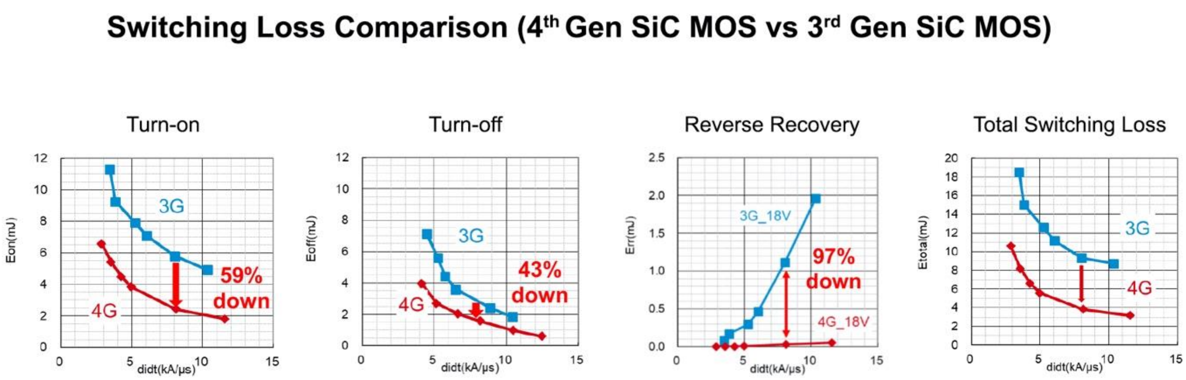

Fig. 2. In Rohm's 4G 1200-V SiC MOSFETs, the energy required to switch the device on and off has been significantly reduced and reverse recovery energy has been slashed, leading to dramatic reductions in total switching loss. With better switching loss performance, a device can operate at a higher frequency without exceeding the heat dissipation limits. This additional margin often opens up possibilities to reduce inductor and capacitor component sizes and leads to a more-compact power converter system.

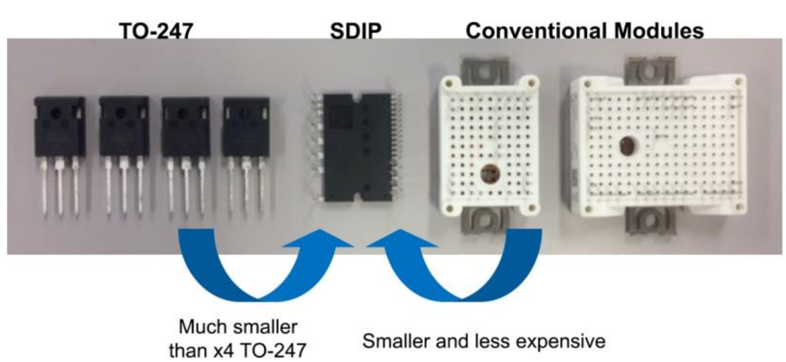

Fig. 3. Smaller and less costly than conventional ceramic power module packages, Rohm's SDIP power module can hold up to six SiC MOSFETs with topology options such as the H-bridge and three-phase bridges.

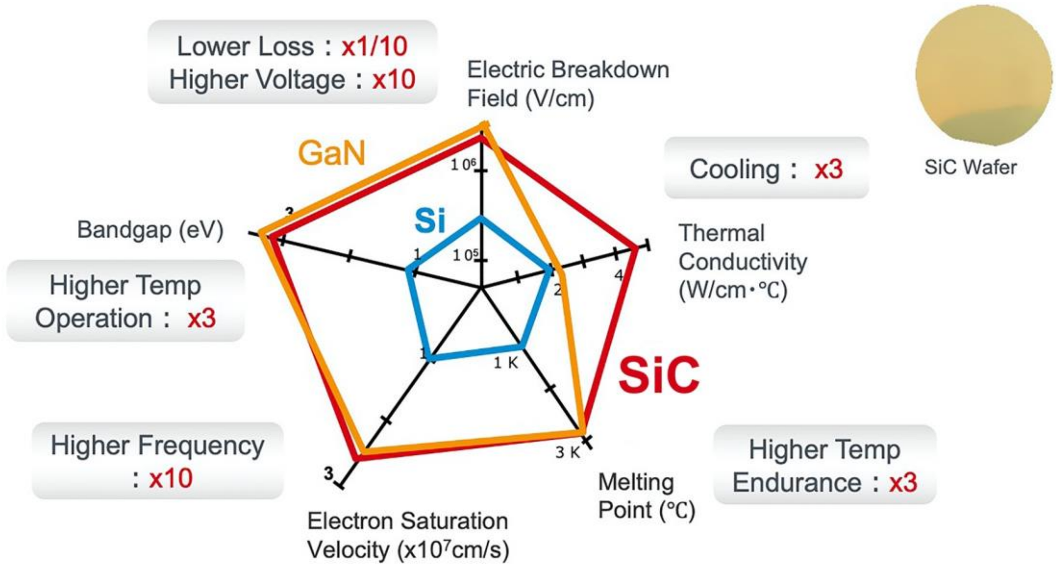

Fig. 4. Comparing material properties of SiC, GaN and silicon. The physical properties of silicon carbide account for the ability of SiC MOSFETs to operate at higher frequencies and with lower losses than silicon IGBTs.