Traction, Charging and Sustainability – Addressing High-Voltage EV Challenges with SiC

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Sales of new electric vehicles in the US exceeded 5% of the total market for the first time in 2022[1], joining 18 other countries worldwide that have surpassed the same milestone. Although worth celebrating, as an indication that EVs are achieving a level of market acceptance that bodes well for their success in the future, their adoption must continue and accelerate. Changing to tailpipe-free vehicles is a pillar of governments' plans to meet climate pledges under the Paris Accord as well as improving air quality in major cities.

Standing in the way of progress, the usability of EVs is a key issue for many would-be buyers. Charging an EV at home can be impractical for those living in properties without off-street parking or allocated spaces. Moreover, while today's EVs offer plentiful driving range to handle average daily usage, longer trips would more likely require a stop to recharge. However, there is concern about the location and availability of suitable charging stations, and the duration of the stop. Whereas a liquid-fuel tank can be refilled in a couple of minutes, a discharged EV battery can need about 25 minutes to recharge to 80% of its full capacity.

Despite impressive technological progress, EV driving range and charging times are issues that still need better solutions to strengthen the case for EVs and drive faster market adoption to satisfy targets on emissions and sustainability.

Higher Voltage, Greater Efficiency

One response to these demands is seen in the adoption of increased battery voltages. Some prestige and high-performance models have voltages as high as 800 V. Increasing the voltage allows greater power transfer thereby enabling faster battery charging. Also, the higher operating voltage allows thinner and lighter cables to handle the power delivered into the charging and traction systems, and can help lower "I^2R" losses, contributing to longer driving range.

While greater passenger EVs use 400 V or 800 V, a new 1,250 V charging specification is coming to the fore to cut the charging times of long-haul trucks, including the high-capacity class 7 and 8 vehicles. Productivity is a major concern in commercial haulage and, to ensure the fastest possible charging times, the Megawatt Charging System (MCS) has been proposed, standardized as SAE J3271.

Currently under development, SAE J3271 specifies charging from 440 kW at 350 A and 1,250 V_{DC} without cooling, and up to 3.75 MW at 3000 A and 1,250 V_{DC} with active cooling. As a guide, charging at 1.6 MW for 30 minutes would deliver 400 miles of driving with a standard Class-8 tractor. The SAE J3271 specification standardizes aspects such as the plug design, communications protocols, and safety requirements to allow interoperability between vehicles, charging stations, charging networks, and the electric grid.

With the adoption of higher battery voltages, driving range could be extended by about 5-10%.

Technology for the Transition

Although easing progress towards faster charging and greater driving range, raising the system voltage places extra demands on important power-handling functions in EVs. These include the traction inverter, on-board charger (OBC), and HVAC systems.

As battery voltages are increased to 800 V and 1,250 V, silicon-carbide (SiC) technology is inherently better suited to these applications. SiC MOSFETs offer advantages including smaller feature sizes, lower parasitic capacitances, and lower on resistance in relation to their breakdown voltage rating (VBR) compared to silicon IGBTs or MOSFETs, which are the typical alternatives. The lower capacitances permit faster switching with lower losses, resulting in greater energy efficiency, while the lower on resistance allows to fewer transistors in parallel resulting in smaller module dimensions, lower weight, and a reduced bill of materials. SiC can also handle higher operating temperatures and devices have lower thermal impedance, which can help simplify the vehicle's cooling systems while preserving reliability.

SiC in Roadside Chargers

With the transition to higher battery voltages in modern EVs and trucks, it follows that roadside fast chargers must also be upgraded to charge at the increased voltage if the benefits of faster time to charge the vehicle are to be realized. Accordingly, SiC's advantages in terms of device size and efficiency make this technology an ideal fit for charging applications where high speed as well as reliability, flexibility and space savings are important advantages.

These chargers are also getting more intelligent to help manage smart infrastructures powered from renewable energy sources. In a world where grid-connected storage is considered essential to maintain stability, the value of a nation's fleet of EVs connected to the grid when not being used is inestimable as a storage solution. An EV with a 40 kW battery could satisfy the energy demand of an entire household. The EV can be recharged when possible, to be ready for when the owner next needs to travel. Vehicle-to-grid (V2G) communication is a specification that will enable smart charging systems to use the EV as a resource to help balance the flow of energy through the grid and keep pace with continuously changing supply and demand.

Trench-Assisted Planar-Gate Technology

While the performance advantages and favorable characteristics of SiC devices have been well documented, designing SiC MOSFETs for the real world involves compromises between performance, reliability, and manufacturability. Typically, the choices are between a planar or trench architecture.

Trench architectures can offer lower on resistance per die area and faster switching performance, although manufacturing yield can be low and gate oxide thickness is difficult to control leading to device failures in the field. On the other hand, planar devices benefit from superior gate ruggedness and short-circuit capability, as well as simpler manufacturing processes. Also, there is scope for future generations of the technology to deliver further improvements in die size and cell performance.

The GeneSiC MOSFET platforms stretch from 650 to 6,500 V, addressing a broad range of high-voltage, fast-charging systems. Patented trench-assisted planar-gate design combines the established strengths of planar technology with fast switching capability, extended operating lifetime, and high manufacturing yield. Table 1 compares the relative merits of the three architectures.

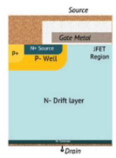
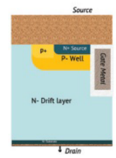
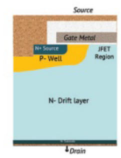
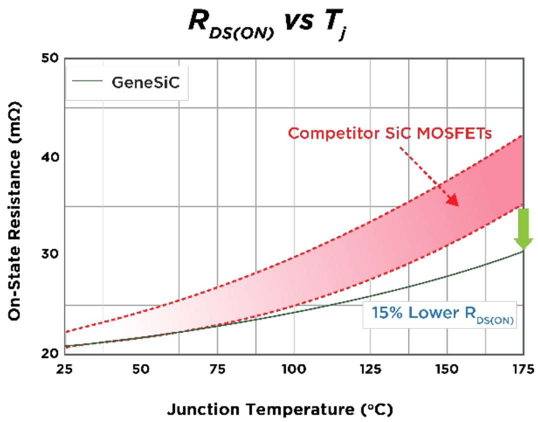
	Planar	Trench	GeneSiC
			
Manufacturability	» Repeatable » High yield » Low cost	» Inconsistent trench etch » Lower yields » High cost	» Repeatable » High yield » Low cost
Performance	» High $R_{DS(ON)}$ / area » Slow switching » High $R_{DS(ON)}$ / Δ temp	» Lower $R_{DS(ON)}$ / area » Faster switching » High $R_{DS(ON)}$ / Δ temp	» Lower $R_{DS(ON)}$ / area » Fastest switching » Lowest $R_{DS(ON)}$ / Δ temp
Reliability	» Rugged gate oxide (stable V_{TH})	» Failures due to non-uniform gate oxide » Lower short-circuit capability	» Highest 100% tested avalanche » Long short-circuit withstand time » Rugged gate oxide (stable V_{TH})

Table 1: Planar, trench, and trench-assisted planar comparison.

With low $R_{DS(ON)}$ at high temperatures and low energy losses at high speeds, these trench-assisted planar devices outperform alternatives including trench-gate structures. Their very low $R_{DS(ON)}$ temperature coefficient is particularly important. In datasheets, $R_{DS(ON)}$ is typically stated at 25°C but conventional devices can suffer from a significant increase in resistance at elevated temperature. GeneSiC MOSFETs have been shown to operate with up to 15% lower $R_{DS(ON)}$ over the rated temperature range (figure 1a). This reduces energy losses, leading to increased system efficiency, while the reduction in device self-heating can lower the case temperature by as much as 25°C compared to equivalent alternative SiC devices operated with the same gate drive and ambient conditions (figure 1b). The 25°C cooler operation translates into three times longer device lifetime.



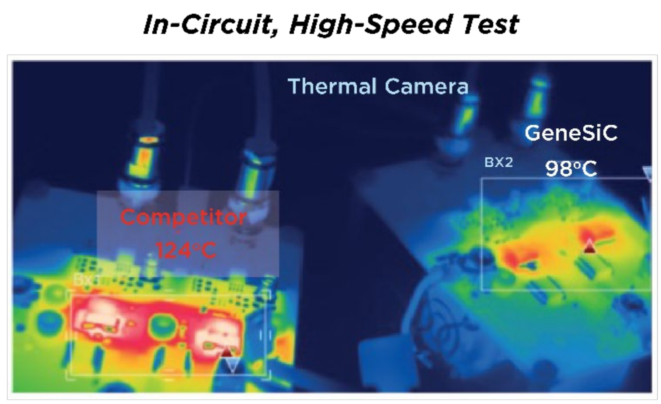


Figure 1a. Lower $R_{DS(ON)}$ temperature coefficient of GeneSiC MOSFETs.

Figure 1b. Operating temperature reduced by 25°C.

Future Trends: More Power, More SiC

The future must contain more fast-charging locations, if EV adoption is to continue growing. However, installing more fast chargers can demand a significant financial commitment to upgrade the supplying utility infrastructure, and could slow the rate of progress. A fast and relatively low-cost approach involves upgrading ordinary level 2 charging points by integrating an energy storage system to boost the charger output[2]. The storage is charged continuously from the same low-voltage infrastructure used to supply the level 2 charger, and then discharged at a fast rate into the EV battery when connected.

The electrification of heavy goods vehicles is also a critical element of the transition to climate-neutral mobility. The US has committed to ensuring that all new trucks sold will be zero-emission vehicles by 2040[3]. It is reckoned that replacing 100,000 40-ton trucks with electric equivalents on long-haul routes could save 10 million tons of CO2 each year[4]. One aspect that could help this transition is that specific long-haul routes can be targeted to change first, prioritizing those that allow vehicles to cover long distances at a constant speed, with MCS chargers placed in specific locations along the route. This approach, which could establish a minimum viable infrastructure as a platform for further progress, is expected to give fleet operators and vehicle manufacturers confidence to make their own investment in zero-emission haulage[5].

Off-highway applications such as agricultural vehicles and construction vehicles are expected to transition to electric powertrains more slowly. Arguably, such vehicles cover much less distance than passenger cars and long-haul trucks, although leading brands are answering the call to make every possible effort to reduce emissions by developing ruggedized diesel-electric drivetrains as well as electric pumps and generators[6].

Finally, hydrogen fuel cell technology is expected to have a role in future e-mobility and can leverage the energy efficiency, ruggedness, compactness, and reliability of SiC power semiconductors in the production of hydrogen by electrolysis as well as in the electric powertrains of hydrogen fuel-cell vehicles.

Conclusion

Automotive OEMs have demonstrated that both passenger and commercial (bus, truck) EVs can be practical, reliable, convenient, and cost-effective. However, further improvements in charging times are critical to reduce range anxiety and accelerate adoption. The latest 800 V and 1,250 V systems require 1,700 V or 3,300 V SiC FETs and diodes, which must be efficient, robust, and reliable to meet critical needs for the migration to faster charging.

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