

## Wide Bandgap Goes Mainstream

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### How GaN and SiC Technologies are being Deployed across Legacy Silicon Applications in Mature Markets

While helping achieve CO<sub>2</sub> reductions, electrification is driving up demand for electricity. More loads are being connected to the grid at the same time as applications are demanding more power to accomplish more complex tasks or, for example, to charge batteries more quickly for vehicles, tools and other portable devices. Design, cost and legislative requirements combine to create a strong demand for greater efficiency across the board, whether its large appliances, computers or data center servers for AI processing or chargers for devices such as power tools, domestic robots, e-bikes and scooters, and mobile phones.

In response to these pressures, wide-bandgap semiconductors that enable power supplies and converters to become more efficient and handle more power within the same or smaller footprint have become essential to modern designs. Both silicon carbide (SiC) and gallium nitride (GaN) technologies are commercialized and are already in products that are on store-shelves and being used in homes, offices and factories worldwide.

So what has been gained? What has been learned? And what comes next?

#### SiC and GaN

In power transistors, both SiC and GaN deliver superior switching performance than legacy silicon. Faster transitions minimize power dissipation during turn-off and turn-on, resulting in greater efficiency and simplified thermal management. Faster transitions also permit increased switching frequency, thereby allowing the use of fewer and smaller passive components and associated savings in solution size and bill of materials. Smaller components and easier thermal management lead to a significant reduction in overall dimensions: greater power density equates to more power handling capability in a popular and established form factor, or the same power and usefulness in a smaller form factor where desired.

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It's also worth noting that fewer, smaller components add further to the improved environmental sustainability that more efficient SiC and GaN technologies deliver thanks to 'de-materialization' – the use of fewer materials and associated reductions in emissions from manufacturing and transport.

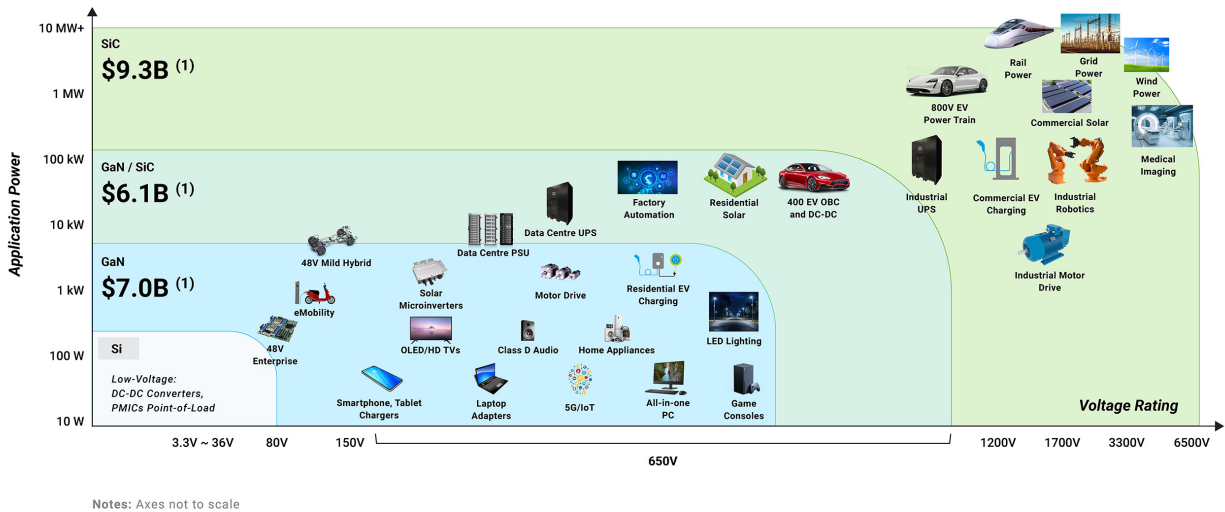


Figure 1: Applications for SiC and GaN technologies

While both display superior switching characteristics compared to silicon, each technology has individual strengths that can be used to delineate their applications. SiC has inherently higher thermal conductivity and a vertical device, which enables higher power density and dissipate heat more effectively. That's why SiC is preferred in applications where high-voltage operation and heat dissipation (from high power cycling) are priorities. These include electric vehicle inverters, industrial power supplies, some solar-power designs, rail traction, wind turbines, grid distribution and industrial and medical imaging.

GaN transistors can switch faster than SiC due to higher electron mobility and are therefore better suited to higher frequency applications in applications requiring voltages below around 650 V. As a result, GaN is more commonly used in soft-switching, high power density power applications including data center power supplies, electric vehicle charging, solar micro-inverters and fast charging travel adaptors.

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## SiC Device Innovations

Typically, SiC MOSFET device designers have chosen to use either a planar or trench gate architecture. Planar devices tend to offer superior gate ruggedness and short-circuit capability with simpler manufacturing processing. On the other hand, trench architectures can offer superior on-resistance  $R_{DS(ON)}$  x area and  $R_{DS(ON)}$  x gate charge ( $Q_G$ ) figures of merit.

Navitas' patented trench-assisted planar-gate approach permits a combination of fast and cool operation with extended reliability, while also achieving high manufacturing yield by allowing simpler processing. These devices also have low  $R_{DS(ON)}$  at high temperatures and low energy losses at high speeds, boosting performance, robustness and quality.

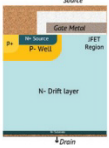

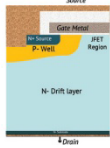
	 <p><b>Planar</b></p>	 <p><b>Trench</b></p>	 <p><b>GeneSiC</b></p>
<b>Manufacturability</b>	<ul style="list-style-type: none"> <li>» Repeatable</li> <li>» High yield</li> <li>» Low cost</li> </ul>	<ul style="list-style-type: none"> <li>» Inconsistent trench etch</li> <li>» Lower yields</li> <li>» High cost</li> </ul>	<ul style="list-style-type: none"> <li>» Repeatable</li> <li>» High yield</li> <li>» Low cost</li> </ul>
<b>Performance</b>	<ul style="list-style-type: none"> <li>» High <math>R_{DS(ON)}</math> / area</li> <li>» Slow switching</li> <li>» High <math>R_{DS(ON)}</math> / <math>\Delta</math> temp</li> </ul>	<ul style="list-style-type: none"> <li>» Lower <math>R_{DS(ON)}</math> / area</li> <li>» Faster switching</li> <li>» High <math>R_{DS(ON)}</math> / <math>\Delta</math> temp</li> </ul>	<ul style="list-style-type: none"> <li>» Lower <math>R_{DS(ON)}</math> / area</li> <li>» Fastest switching</li> <li>» Lowest <math>R_{DS(ON)}</math> / <math>\Delta</math> temp</li> </ul>
<b>Reliability</b>	<ul style="list-style-type: none"> <li>» Rugged gate oxide (stable <math>V_{TH}</math>)</li> </ul>	<ul style="list-style-type: none"> <li>» Failures due to non-uniform gate oxide</li> <li>» Lower short-circuit capability</li> </ul>	<ul style="list-style-type: none"> <li>» Highest 100% tested avalanche</li> <li>» Long short-circuit withstand time</li> <li>» Rugged gate oxide (stable <math>V_{TH}</math>)</li> </ul>

Figure 2: Comparison of conventional and trench-assisted planar architectures

The issue of  $R_{DS(ON)}$  and temperature is particularly important. In datasheets,  $R_{DS(ON)}$  is typically rated at 25 °C, but depending on temperature coefficient, this can significantly increase at elevated temperatures. In real-life applications, the ambient temperature in a system can be up to 80 °C, with device power cycling further elevating junction temperature.

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Navitas' trench-assisted planar-gate SiC MOSFETs are designed with a very low  $R_{DS(ON)}$  temperature coefficient and have been shown to operate with a 25 °C cooler case temperature than competing devices in experimental conditions. In practice, this 25 °C equates to a three-fold increase in the device lifetime.

## SiC Applications

In a domestic scenario, SiC devices can bring a valuable efficiency gain in solar inverters used to convert DC power from a string of solar panels into grid-quality AC to be used immediately, stored for later, or supplied to the grid for a feed-in tariff. A small system may be rated for 4.6 kW AC. The electricity produced can be used immediately in the home, returned to the grid, or stored locally for later use.



*Figure 3: Company's such as KATEK use GeneSiC MOSFETs in their 4.6 kW 'coolcept' inverter topology to enable very high peak efficiency results of 98.6%*

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Navitas GeneSiC SiC MOSFETs have been chosen for a consumer-oriented 4.6 kW solar inverter, built with 16 MOSFETs, each rated at 1200 V and with 75 mΩ  $R_{DS(ON)}$  and connected as a two-level H-bridge. This topology is inherently bidirectional, which eases integration with a domestic energy storage system. Because the SiC devices have significantly lower reverse recovery charge ( $Q_{rr}$ ) than silicon MOSFETs, the inverter can operate efficiently in reverse. SiC's superior thermal performance ensures excellent reliability, while the technology also enables the inverter to operate at a relatively high switching frequency, permitting smaller passive components. This, in turn, allows the enclosure to have much smaller size and lower weight than conventional silicon-based inverters currently on the market.

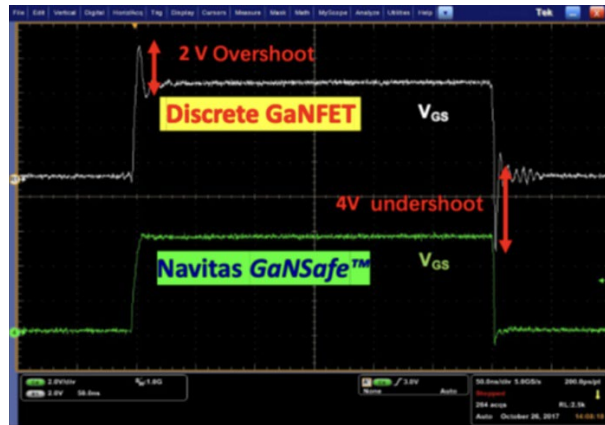
## GaN Devices and Applications

While SiC devices are typically selected for high-power, high-voltage applications, GaN technology is a strong choice in applications up to about 650 V.

Unlike silicon or SiC MOSFETs, GaN HEMTs have no body diode and therefore completely eliminate any reverse-recovery issues. On the other hand, the HEMT gate structure is known to be sensitive. The device can be damaged if exposed to excessive gate-source voltage ( $V_{GS}$ ) overshoot or undershoot, or when exposed to negative  $V_{GS}$  spikes generated at low-side turn-off in high-power bridge circuits. There is also a high risk of unwanted turn-on that allows shoot-through currents to pass and, in buck circuits, the transistors can be vulnerable to drain-current surges.

Proper control of the gate is therefore vital for reliability as well as performance. Navitas GaNFast, GaNSense, and GaNSafe ICs ensure the proper control by integrating a carefully designed gate driver in the package with the GaN HEMT. The driver uses optimized dead-time algorithms to prevent shoot-through and the circuit layout ensures zero gate-source loop inductance. The devices can be switched safely at frequencies up to 2 MHz.

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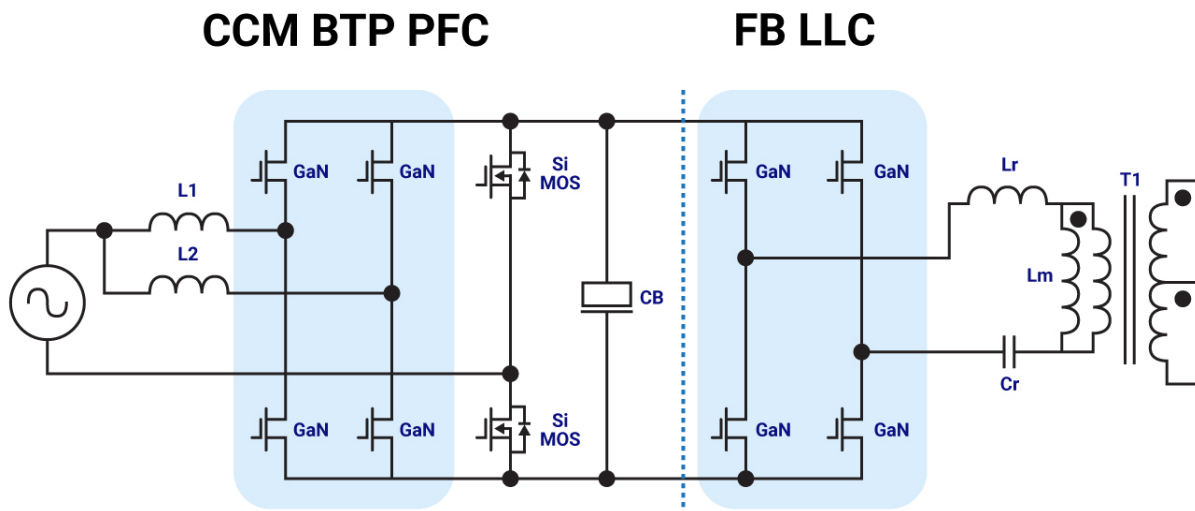
*Figure 4: The GaNSafe gate driver eliminates the dangers of  $V_{GS}$  overshoot*

Alongside the gate driver, the GaNSafe ICs also integrate protection and control circuitry to help save bill-of-materials costs, a Miller clamp that relieves any need for complex negative gate-voltage circuitry, and extra features for control and protection. These include  $dV/dt$  control at turn-on/turn-off, short-circuit protection with response time of 300 ns, under-voltage protection and thermal protection. There is also electrostatic discharge (ESD) protection up to 2 kV, which is typically not provided with discrete GaN transistors.

Navitas has created several reference designs based on its GaN and SiC technologies, including a 4.5 kW data center AI PSU in the industry-standard CRPS185 form factor. Optimized for high-performance computing (HPC) applications including power for AI processing, this reference design exceeds 80Plus Titanium, the most stringent applicable eco-design standard. The PSU integrates boost PFC and an LLC resonant converter, and has a 48 V-output, enabling 137W/inch<sup>3</sup> with over 97% efficiency, making it the highest power density AI PSU on the planet!

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*Figure 4: 4.5 kW AI CRPS185 power supply reference design*

## Conclusion

Wide-bandgap devices are already widely adopted in applications across numerous markets, where high efficiency is required and where reliability at high voltages and high temperatures are expected. These range from data center power supplies, EV traction and OBCs systems, solar inverters, to domestic equipment such as chargers and appliance power supplies. Several generations of SiC and GaN devices have already been commercialized and development continues, aiming to deliver even more robust and reliable devices into the hands of power-systems designers.

The technology and markets for wide-bandgap power devices will continue to mature, particularly with GaN HEMTs, as devices have been in the marketplace for a shorter period than SiC MOSFETs. One notable observation is that the different gate designs can perform better with certain applications, such as motor controllers and power supplies. Recognizing this, Navitas continues to develop devices that incorporate properties that are finely tuned for their target applications.

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