SiC Delivers Next-Generation Efficiency and Sustainability

Last year Navitas Semiconductor, the industry leader in gallium nitride (GaN) power ICs completed the acquisition of silicon carbide (SiC) pioneer GeneSiC Semiconductor. Here Llew Vaughan-Edmunds, Senior Director, SiC Product Marketing at Navitas, takes a look at the benefits of SiC technology and the applications where these wide bandgap semiconductors are increasingly being deployed.

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Silicon carbide (SiC) is a critically important technology as high-power, high-speed applications test the limits of conventional silicon. Next-generation systems not only continue to push the boundaries of performance and capability, but also disrupt and replace systems that burn fossil fuels (e.g. transportation, electrical generation, HVAC), and move them towards clean, efficient, electrical energy. The mission to 'Electrify Our World™' keeps technologies and solutions evolving, while providing a more sustainable future. A recent report from market research firm Yole Développement, for example, predicts the SiC market will experience a compound annual growth rate of 34% from $1 billion in 2021 to over $6 billion by 2027. The importance of SiC has been further highlighted by various worldwide initiatives, including the CHIPS act in the US which will see some of the many billions of dollars used to fund new manufacturing capacity for this technology.

I. Benefits of SiC

Binding silicon and carbon with strong covalent bonds similar to those found in diamond, SiC is a robust semiconductor technology with a band-gap (the energy needed to free an electron from its orbit around the nucleus) of 3.26 eV - almost three times that of conventional silicon. As band-gap determines the electric field that a material can withstand (SiC has a ten times higher dielectric breakdown strength than silicon) and the speed at which it can operate, the wider band-gap of silicon carbide enables the development of semiconductors that can support higher frequencies and higher voltages than conventional silicon.

Properties SiC vs Si	Performance of SiC Devices	Impact on Power Circuits
Breakdown Field (10x)	Lower On-state Voltage Drop (2-3X)	Higher Efficiency in Circuits
Thinner Epitaxial Layers (10-20x)	Faster Switching Speeds (100-1000X)	Compact Circuits
Higher Thermal Conductivity (3.3-4.5 W/cmK vs 1.5 W/cmK)	Higher Chip Temperatures (250-300°C instead of 125°C)	Higher Pulsed Power, Higher Continuous Current Densities
Band-gap (3X) (10^{16}X Smaller n)	Lower leakage current, High Intrinsic Adiabatic Pulsed Current Level (3-10X)	High Temperature Operation, Higher Current Capability

Fig. 1: SiC devices offer superior properties to legacy silicon, including higher efficiency, faster switching speeds, and exceptional thermal dissipation.

In addition, the material's chemical properties provide for better thermal conductivity and thermal stability than silicon, making it ideal for delivering reliable performance in high-voltage and high-temperature applications.

While both GaN and SiC are wide band-gap semiconductor materials, SiC differs from GaN with respect to it's thermal properties and the speed of electrons through the semiconductor material. This 'electron mobility' reflects the types of applications where each can deliver the maximum benefit.

GaN's higher electron mobility, for example, coupled with a very low gate capacitance - makes it much more appropriate for high-performance, high-frequency designs. Navitas took an additional step by monolithically integrating the lateral GaN FET, GaN drive, plus logic and protection functions, to make the fastest, most optimized and protected GaN power IC in the industry.

For SiC, the combination of higher thermal conductivity, rugged design and a vertical structure, lends itself to applications where the ability to operate at higher voltages with larger power cycling capabilities is the key consideration.

II. SiC – Target Applications

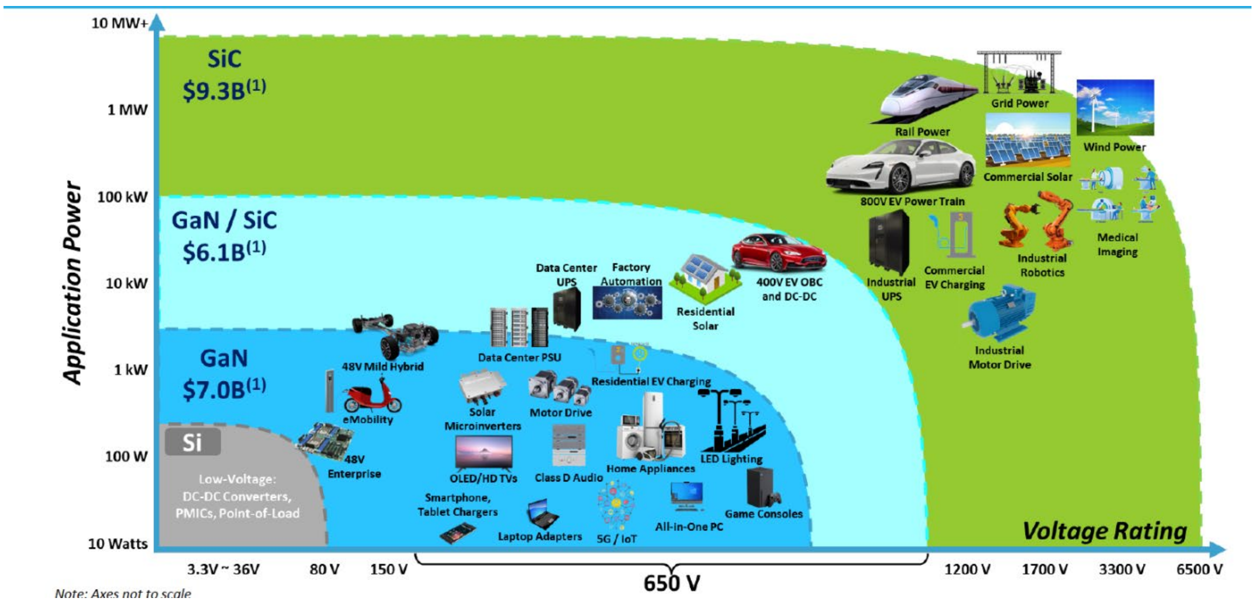

Fig. 2: SiC devices offer the highest performance and efficiency at higher voltages and power levels.

Figure 2 illustrates some key applications in their respective power and voltage ranges. The power technology is then overlayed to show the preferred and optimal type, be it conventional silicon or next-generation wide band-gap GaN and SiC technologies. As the figure shows, in some applications such as data centers and electric vehicle (EV) DC-DC conversion, designers are increasingly looking to mix GaN and SiC devices into their systems to optimize performance and efficiency. However, it is at the higher power and higher voltage ratings that SiC really comes into its own.

One of the key drivers for the growth of SiC will come from the automotive industry as manufacturers and Tier 1s look to improve the efficiency and reduce the size, weight and cost of electric and hybrid powertrains and other key vehicle functions.

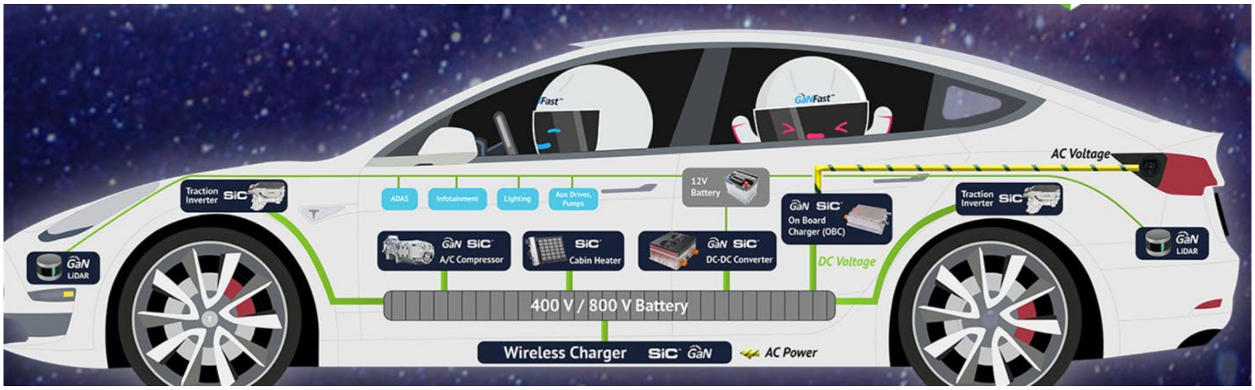

Fig. 3: SiC in EVs provides smaller, lighter, and more efficient systems, resulting in longer mileage range or smaller batteries.

SiC-based designs deliver better efficiency, faster switching and higher power densities than silicon alternatives in areas such as onboard chargers (OBC), DC-DC conversion, traction control and HVAC systems. Choosing SiC enables the choice of smaller batteries and smaller motors, reduces the size of passive components and contributes to the overall reductions in dimensions, weight, and cooling that, for an EV or hybrid, mean extended driving range, better fuel efficiency and lower cost.

Improving the efficiency of renewable energy and the electricity grid is another area where SiC is playing an important role. Here the technology is increasingly employed in converters for wind energy systems, high-power off-board EV chargers, high-voltage sensing and protection equipment, and auxiliary power supplies, as well as commercial solar energy systems and micro-grid applications.

Take, for example, solar string inverters that aggregate the power from multiple DC-optimized groups of solar panels (‘strings’), and multiple strings of panels then connect to a single inverter where electricity is converted from DC to AC. SiC MOSFETs and diodes in the inverter and boost stages can deliver a significant efficiency gain over legacy silicon power devices, while providing the fast-switching frequencies that help to reduce system size, weight, and cost.

SiC is also making its presence felt in the transportation sector. Here designers of everything from trains and buses to delivery vehicles and aircraft are turning to the technology to improve the efficiency and reduce the size of power systems used to provide traction power and power for other on-board systems. SiC-based transportation power units are more efficient and operate with less audible noise than silicon-based equivalents and, again, can be smaller and lighter with corresponding advantages in terms of space utilization and fuel efficiency.

Among the industrial applications in which SiC is finding a home is motor control for robotics and industrial automation. Here designers are, among other things, reducing switching and conduction losses by taking the first step to replace the anti-parallel silicon diodes used for motor current commutation with SiC merged pin Schottky (MPS™) diodes. The alternative approach, and most efficient solution, is to replace all the power silicon IGBTs and diodes with SiC MOSFETs. This evolution is particularly important as it is estimated that motors contribute to over 53% of the world's energy usage and that the majority are simple AC motors that are only 60% efficient.

Improving efficiency and reducing both the energy and the size of the motor drive needed for a given task by combining SiC with variable speed designs will, therefore, make a major difference to global energy consumption, operating costs and emissions.

III. SiC Evolution

Historically the cost of manufacturing SiC technologies has been greater than comparable silicon devices due, in large part, to a much more complex and costly substrate growth process, accounting for approximately 50% of the final die cost. However, the good news is that the price delta is now shrinking as SiC production continues its ramp into high volume, yield improvement, dedicated manufacturing methods come online, and SiC substrate costs dropping quickly.

As well as reducing costs, this evolution also means that the range of SiC devices on the market, including MOSFETs and MPS™ diodes is growing fast. SiC MOSFET and diode devices capable of handling from 650 V up to 3.3 kV are now available. Navitas, through its GeneSiC technology, is extending those capabilities up to 6.5kV.

Additional Information

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