Advancing semiconductor design through wide-bandgap engineering

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The global demand for energy and compute is rising exponentially, largely driven by data-intensive AI workloads, electrified transport and the exponential growth of data centre infrastructure. This presents new challenges for power electronics engineers tasked with the design, development, testing and improvement of systems that control the critical flow and transformation of power.

There are a lot of important conversations happening about how to secure energy, keep the lights on, and continue to meet these computational demands. An area within this that is often overlooked, are the big developments happening at the tiny, semiconductor-level – with silicon chips having been an essential building block for all the technology and power infrastructure we take for granted today.

The need for new building blocks

The silicon chips that have powered this digital growth now face constraints in speed, efficiency and sustainability. Meeting the demand for ever-greater compute density while reducing power consumption requires a rethink at the material and system-level. Chip designers are now turning to wide-bandgap (WBG) and compound semiconductors that promise higher performance and lower emissions – a quiet revolution redefining how power is generated, converted and delivered - from grid infrastructure and EV charging systems to renewable converters and industrial drives

Silicon-based semiconductors have clear performance limitations in today's AI and data-led world. As power, thermal and switching demands soar, silicon's narrow band-gap restricts the ability for chips to operate efficiently at high voltages, frequencies and temperatures. To sustain the trajectory of performance and efficiency, chip designers are increasingly turning to compound materials.

At the same time, the opportunity is enormous. The UK government's National Semiconductor Strategy highlights compound semiconductors as critical to industrial competitiveness and energy resilience. The future of compute and the systems that it powers, will depend on how effectively we can navigate the limitations of silicon and adopt materials that enable both speed and sustainability.

While there will always be a role for silicon to play, but there is a clear demand for a new class of devices based on WBG chips that are physically able to deal with modern power requirements.

Power at the core of the next generation of devices

Devices powered by WBG semiconductors are capable of sustaining higher voltages, switching at higher frequencies and using materials that are more resistant to high temperatures. These characteristics translate directly into lower energy losses, reduced dependence on liquid or direct-to-chip cooling systems, and higher power density and performance at the device-level.

In data centres especially, WBG devices support power-supply units and conversion modules that handle heavier loads while consuming less power and producing less heat - a critical advantage as the UK faces grid-connection constraints and cooling bottlenecks. But their impact extends far beyond the server rack. In electric-vehicle inverters, renewable-energy converters and industrial automation systems, WBG semiconductors enable smaller components and more efficient power control.

Semiconductors perform multiple core functions to this end: processing and memory (CPUs, GPUs, DRAM), networking (photonic and optical interconnects for high-speed data transfer) and power management (voltage regulation, DC-DC conversion). WBG devices enhance each of these layers - improving efficiency, reducing heat and ultimately cutting total power usage effectiveness (PUE).

To understand how these device-level improvements are achieved, we need to look a little deeper at the specific materials and compounds that make such performance gains possible.

Inside the materials that make it possible

The two compounds underpinning this performance leap are primarily Gallium Nitride (GaN) and Silicon Carbide (SiC). Their wide-band gaps enable higher electric-field strengths, faster switching and greater thermal resilience than silicon. Though these materials have existed for decades, their relevance is accelerating quickly as power and performance demands grow.

As ever, with opportunity comes new challenges. China accounts for roughly 98 % of gallium production, creating supply-chain and geopolitical dependencies. GaN and SiC devices have tended to carry higher upfront costs but their lifecycle economics tell a different story: higher efficiency and lower cooling requirements translate to reduced operating costs and extended component life.

In the UK, a recent Power Semiconductors Landscape Report highlights domestic capability and the opportunity to scale compound semiconductor production. This type of national and regional capability is important, but alongside this we should consider how to develop a decentralised and accessible global value chain, that provides companies with access to GaN and SiC at an affordable price.

Meanwhile, innovations taking place at the back end including assembly and packaging of chips into wafers, is helping to reduce heat generation at the source. Rather than relying on energy-intensive direct-liquid cooling, advanced chip-stacking and substrate design enable ambient-temperature operation - achieving stability and efficiency through architecture rather than auxiliary systems. The result is lower energy use, lower water consumption and a significant cut in total system cost.

These same properties that improve data centre and compute efficiency are also transforming how power is controlled, converted and delivered across conversion and energy storage systems.

Powering the hydrogen and clean-energy transition

WBG semiconductors are central to the clean-energy transition. In renewable energy conversion, storage and hydrogen systems, GaN and SiC deliver compact, efficient and robust power electronics.

In green-hydrogen production for example, where renewable electricity powers electrolysers to split water molecules, GaN/SiC devices increase efficiency by minimising switching and conduction losses. Their higher switching frequencies allow smaller, more affordable power modules, reducing balance-of-plant cost and physical footprint. In fuel-cell vehicles and hydrogen refuelling stations, the ability to handle high voltages and temperatures improves conversion performance and system reliability.

A recent report from the Compound Semiconductor Applications (CSA) Catapult identifies compound semiconductors as “critical enablers across the hydrogen and energy value chain,” highlighting their importance in high-efficiency power conversion for electrolysis, grid integration, and energy storage. Meanwhile, the UK’s £11 million REWIRE Innovation & Knowledge Centre, led by the University of Bristol and funded through UK Research and Innovation (UKRI), is advancing wide- and ultra-WBG semiconductor technologies for high-voltage, low-energy-loss applications spanning electric vehicles, renewable-energy converters and data-centre systems

As these innovations scale across sectors, they signal a wider transformation. One where material science, system design and sustainability converge to define the next era of global compute and energy.

Looking ahead

The story of semiconductors has always been one of constant reinvention and right now, that story is entering its next chapter. Wide band-gap materials like GaN and SiC are changing we think about power itself. The push toward data centre efficiency, green transport and renewable infrastructure all depend on the same principle: doing more with less. The companies and research centres driving this change are building a foundation for an economy that can grow without overheating the planet.

There is a mindset shift taking place across the semiconductor value chain and adjacent sectors, and the next generation of chips are set to make our world more sustainable - one watt at a time.