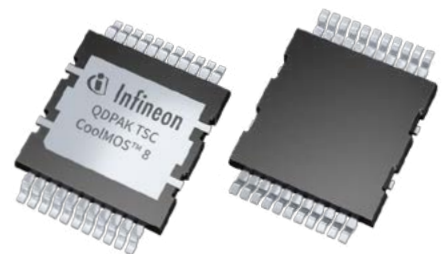


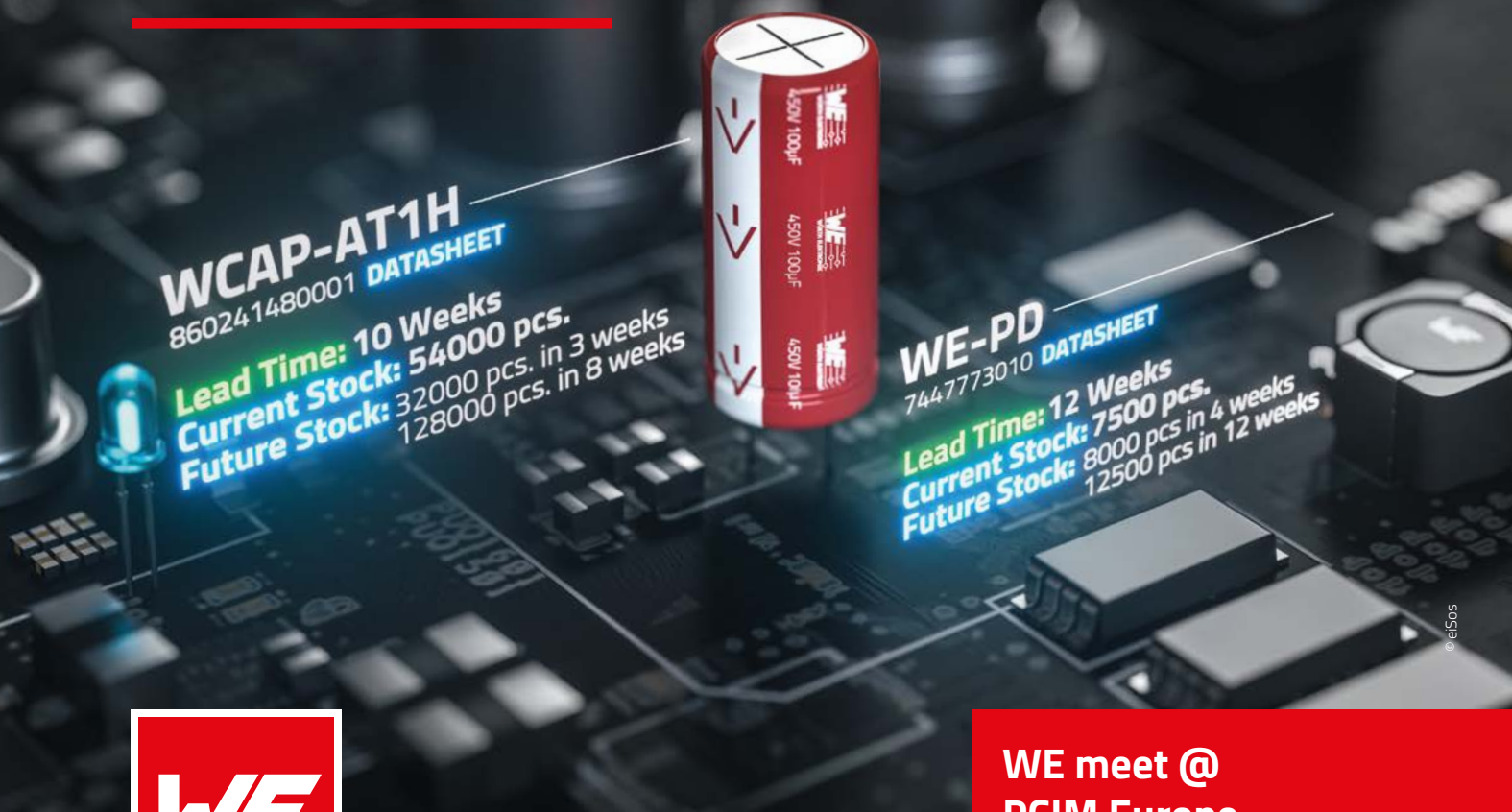


Revolutionizing Power Electronics With CoolMOS™ 8 Next-Generation Silicon MOSFET Technology



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Next-Generation Power Electronics



In the dynamic field of electronics, there is a continual pursuit of more efficient, powerful and compact components. Research and development efforts are underway to redefine the benchmarks for system integration in next-generation semiconductor solutions. These advancements aim to enhance power density and efficiency across a diverse range of power electronics applications.

This issue introduces Infineon's groundbreaking CoolMOS 8 technology, an advanced MOSFET innovation poised to revolutionize power electronics. CoolMOS 8 is designed to succeed the CoolMOS 7 series, enhancing power density and efficiency across a spectrum of applications from data centers to consumer electronics. One key advancement of CoolMOS 8 is its integration of a fast body diode across the entire series, simplifying part selection for designers and engineers.

Moreover, Sonu Daryanani is drawn to the cutting-edge developments in high-voltage power electronics made possible by gallium oxide, an ultra-wide-bandgap semiconductor. The article presents key takeaways from a webinar conducted by Professor Uttam Singiseti of the University of Buffalo, illuminating the potential of gallium oxide for upcoming applications in high-voltage devices.

Filippo Di Giovanni, a contributing writer at Power Electronics News, delves into the impact of quantum algorithms on optimizing power grid efficiency. Heraeus Electronics and AMX Automatrix are introducing large-area sintering for high-performance power module packaging. Heraeus's PE360 paste and AMX's equipment demonstrate the benefits of large-area sintering, including improved thermal resistance and reliability.

Giordana Francesca Brescia, a contributing writer at Power Electronics News, explores the transformative potential of smart grid technology in revolutionizing global energy efficiency. Brescia highlights the pivotal role of smart grids in addressing the substantial environmental impact of electricity production, positioning them as a crucial solution in the post-transportation sector for reducing greenhouse gas emissions. The article dissects the advanced architecture of smart grids, emphasizing their integration of digital technologies, IoT advancements and real-time data analysis capabilities.

Also in this issue, we report interviews with several major industry leaders on the latest advancements and applications of gallium nitride and silicon carbide technologies. GaN devices are based on AlGaN/GaN heterostructures, which allow the creation of a two-dimensional electron gas (2DEG) with high mobility to achieve high current density, a key element for power electronics. Automotive-certified SiC power components are a significant development that has the potential to transform the electric-vehicle industry and automotive power systems. Other topics are voltage-clamping components for solid-state circuit breakers; a new, more efficient superatomic semiconductor recently discovered by scientists at Columbia University in New York; and improving the power grid with ultra-wide-bandgap semiconductors.

I invite you all to visit us at Booth 170 in Hall 6 (6-170) during PCIM! We look forward to seeing you there.

Yours Sincerely,
Maurizio Di Paolo Emilio
Editor-in-Chief, Power Electronics News

The AspenCore Guide to Gallium Nitride

This 150+ page book on **Gallium Nitride (GaN)** power devices provides a comprehensive look at the technology, applications, market, and future of this emerging wide-bandgap material for power electronics.

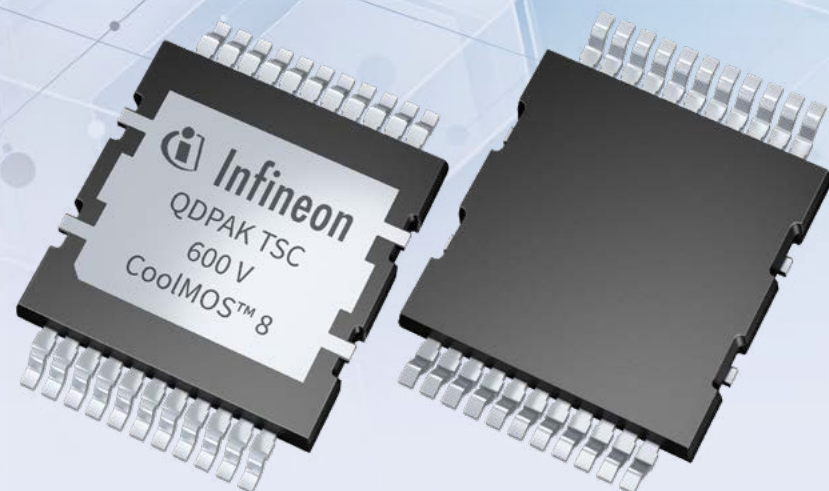


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Revolutionizing Power Electronics With Infineon 600 V CoolMOS™ 8 Next-Generation Silicon MOSFET Technology



How Infineon is setting new standards in system integration, efficiency and power density

By Stefan Preimel, product definition engineer for silicon MOSFETs at Infineon Technologies

In the rapidly evolving world of electronics, the quest for more efficient, powerful and compact components is never-ending. For next-generation silicon MOSFETs, significant research and development efforts are being undertaken to redefine the standards of system integration for improved power density and efficiency in a wide array of power electronics applications.

At Infineon, those efforts have come to fruition with the introduction of **CoolMOS™ 8**, an advanced MOSFET technology with an integrated fast body diode that is

poised to offer unparalleled benefits to designers and engineers. The technology enhances Infineon's existing portfolio of semiconductor wide-bandgap technologies and is set to have a far-reaching impact in sectors ranging from data centers and renewable energy to consumer electronics.

So let us look at the origins of CoolMOS™ 8 before focusing on its primary features and benefits. CoolMOS™ 8 is Infineon's next-generation silicon MOSFET technology, designed to supersede the current

series of CoolMOS™ 7 products for low- to high-power switch-mode power supplies (SMPS). It is intended to enhance the **CoolGaN™** and **CoolSiC™** families of wide-bandgap semiconductor technologies. This diverse portfolio will enable designers to address all types of power electronics applications. CoolMOS™ 8 is targeted at the consumer and industrial end markets; therefore, Infineon has intentionally not qualified devices in this series for use in automotive applications. Designers of these applications will still be able to rely on well-established CoolMOS™ 7 automotive-qualified devices.

The innovation comes with integrating a fast body diode in all devices across the CoolMOS™ 8 series, empowering designers to use a single MOSFET family for all main topologies in growing markets. The 600 V CoolMOS™ 8 portfolio will offer outstanding granularity, with devices initially being made available in through-hole, surface-mount and top-side cooling (TSC) packages. In addition, CoolMOS™ 8 MOSFETs have an even higher current-handling capacity compared with the nearest competing device and the world's smallest $R_{DS(on)} \times area$.

But what does this mean for designers and engineers? Ultimately, CoolMOS™ 8 will greatly simplify part selection for Infineon's customers by reducing the number of products by more than 50% compared with the available CoolMOS™ 7 series after a final rollout in the consumer and industrial segments. In the CoolMOS™ 7 series, devices with a fast body diode were identifiable by including "FD" in their name. All products in the CoolMOS™ 8 series will feature a fast body diode (regardless of $R_{DS(on)}$ value), meaning the previous naming convention will no longer be required.

PRIMARY FEATURES OF COOLMOS™ 8

Now that we've reviewed some product development background and rationale, let us look at some of the primary features of **CoolMOS™ 8**. These include best-in-class fast body diode performance for resonant topologies, advanced die-interconnect technology and innovative packaging options employing TSC.

CoolMOS™ 8 technology has a 10% lower E_{oss} and 50% lower C_{oss} compared with similar devices in the CoolMOS™ 7 series. For improved thermal performance, CoolMOS™ 8 devices also offer a minimum 14% lower thermal resistance than CoolMOS™ 7. This has been made possible through the use of Infineon's proprietary soldering technique (.XT), which improves thermal conductivity when attaching the silicon chip to the lead frame. These benefits lead to an improved efficiency of CoolMOS™ 8 compared with CoolMOS™ 7.

CoolMOS™ 8 MOSFETs also benefit from innovative ThinTOLL 8 × 8 packaging, which offers enhanced performance compared with ThinPAK 8 × 8 (with which it retains pin compatibility). This small-footprint package enables high power density and fully leverages the advanced interconnect technology to improve thermal performance. Despite its small form factor, the temperature-cycle-on-board failure rate of ThinTOLL closely matches that of TOLL-packaged devices, and it delivers almost identical factor performance.

This packaging evolution enables high-volume assembly and PCB design improvement as well as easier optical solder inspection at expensive assembly locations by facilitating a fully automatic handling of high-pin-count devices. CoolMOS™ 8 will undoubtedly enhance Infineon's unsurpassed reputation for reliability, which has resulted in only five field failures

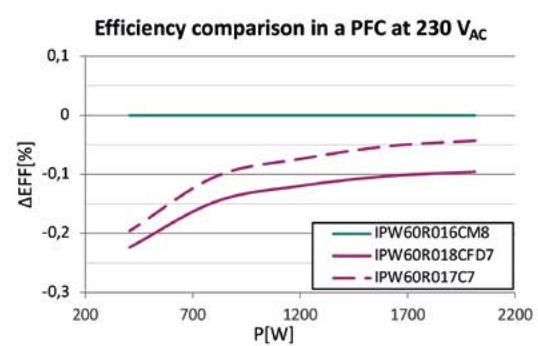
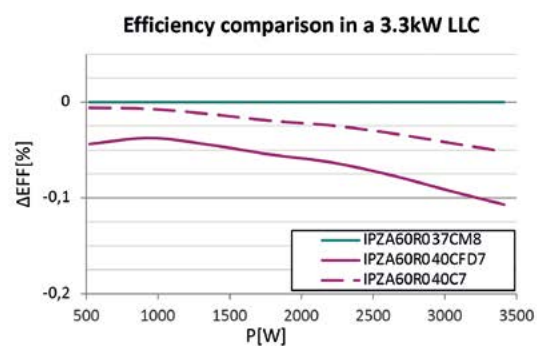
The new 600 V CoolMOS™ 8 SJ MOSFETs portfolio

R _{DS(on)} [mΩ]	SMD packages					THD packages			Applications
	QDPAK TSC	DDPAK	TOLL	ThinTOLL 8x8	DPAK	TO 247-3	TO 247-4	TO 220 FP NL	
600					IPD60R180CMB				<ul style="list-style-type: none"> Server Telecom SMPS Solar & ESS EV charging SSCB UPS Fridge compressor
180		IPD06R180CMB	IPF06R180CMB	IPFA06R180CMB	IPD06R180CMB			IPF06R180CMB	
37	IPW06R037CMB	IPD06R037CMB	IPF06R037CMB			IPW06R037CMB	IPZ06R037CMB	IPF06R037CMB	
16	IPW06R016CMB		IPF06R016CMB			IPW06R016CMB	IPZ06R016CMB	IPF06R016CMB	
7	IPW06R007CMB								

released STD samples From June 2024

More waves to come Please reach out to your regional contact if you are interested in further information on sample availability or roadmaps

Available 600 V CoolMOS™ 8 product offering (2024)



Relative efficiency comparison in (3.3 kW) LLC stage and (2.5 kW) PFC stage

from over 6.7 billion devices shipped over the last seven years.

BENEFITS FOR SYSTEM INTEGRATION

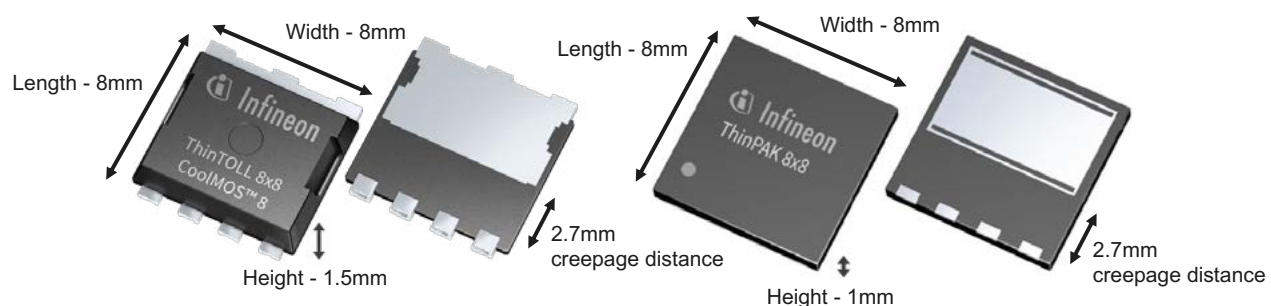
The benefits that CoolMOS™ 8 will bring for system integration are evidenced through its application in reference designs, which Infineon has based on devices from the series. For example, a 3.3-kW high-frequency and ultra-compact rectifier can offer 97.5% efficiency with a power density of 95 W/in.³, including 1U form factor. These high levels of operating efficiency and power density are achieved by co-deploying CoolMOS™ 8, CoolSiC™ and CoolGaN™ technologies in a single design, which leverages a novel integrated planar magnetic construction and offers complete digital control of the totem-pole power-factor-correction (PFC) and half-bridge GaN LLC DC/DC conversion stages.

A separate accompanying 2.7-kW evaluation board demonstrates a high-efficiency (>96%) power supply unit (PSU) built using bridgeless totem-pole PFC and LLC DC/DC converter stages. This high-power-density design is enabled through a combination of CoolSiC™ 650 V and CoolMOS™ 8 600 V switches. This PSU can

be digitally controlled with an XMC1404 controller (for the PFC stage) and an XMC4200 controller (for the LLC stage) to allow exploration of variable PFC switching frequencies to further reduce inductor size and/or power losses. Tests on this PSU showed improved efficiency performance (0.1%) at high load, resulting in fewer power losses and cooler components compared with a similar design constructed using CoolMOS™ 7 MOSFETs.

IDENTIFYING THE LEADING APPLICATIONS

CoolMOS™ 8 devices are ideal for various SMPS applications across the industrial and consumer sectors. Still, they are particularly well-suited for use in key end markets like data centers and renewable energy. In data center applications, CoolMOS™ 8 will allow designers to meet energy-efficiency and total-cost-of-ownership targets by providing the highest possible system-level power density, which can be attained using silicon components. In the renewable energy area, the availability of CoolMOS™ 8 devices employing TSC will help to reduce system size and solution costs.



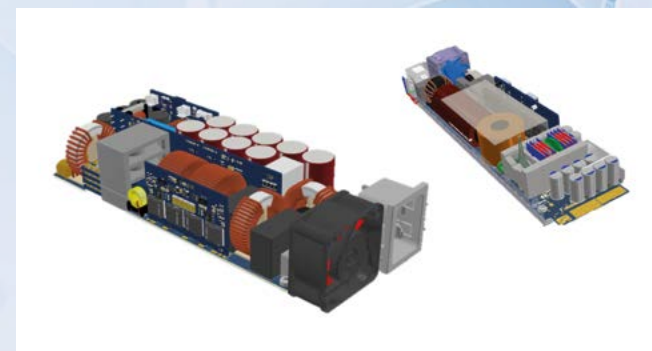
New ThinTOLL 8 × 8 vs. ThinPAK 8 × 8 dimension comparison

WHERE NEXT FOR ADVANCED MOSFET DESIGN?

CoolMOS™ 8 MOSFETs will soon be accompanied by a new generation of gate drivers, enabling them to deliver optimal $R_{DS(on)}$ performance in switching applications. These EiceDRIVER™ gate drivers will have unipolar driving capability and a package common-mode transient immunity over 600 V to help simplify system certification and compliance. The narrow height of these devices will make them ideal companions to QDPAK TSC packages, even allowing them to be located under a heatsink. Infineon is also planning the future release of CoolMOS™ 8 MOSFETs in several different packages within the next few years.

The introduction of the 600 V CoolMOS™ 8 next-generation silicon MOSFET technology is a significant development in power electronics. Key features like the integrated fast body diode, advanced die-interconnect technology and innovative packaging options underline Infineon's commitment to providing advanced solutions that address the evolving needs of designers and engineers. The technology also boasts superior thermal performance and reliability, evidenced by a remarkably low field-failure rate.

As CoolMOS™ 8 devices find their way into various SMPS applications, particularly in sectors like data centers and renewable energy, they enable more energy-efficient, compact and cost-effective designs. Looking ahead, the synergy between CoolMOS™ 8 MOSFETs and the upcoming generation of gate drivers illustrates Infineon's holistic approach to advancing MOSFET design and application. This journey reinforces Infineon's position at the forefront of semiconductor technology and lays the foundation for future developments.



Available demo board offerings (2.7-kW PSU and 3.3-kW HD/HF SMPS)

As 600 V CoolMOS™ 8 also has a very low $R_{DS(on)}$ value of 7 mΩ, it is suitable for the growing market of solid-state relay applications (S4), offering a cost-optimized alternative to CoolSiC™. Compared with mechanical relays, solid-state relays switch faster, don't have contact arching or bouncing, and therefore have a longer system lifetime. They are also shock- and vibration-resistant and operate quietly.

Furthermore, designers can optimize for system-level price-performance ratio by employing CoolMOS™ 8 in combination with CoolSiC™ devices. CoolMOS™ 8 will also enable cost-competitive designs for Type 2 wallboxes, light electric vehicles, wireless chargers, electric forklifts, electric bicycles and professional tool charging. In the broader consumer space, this technology will make it easier for end products to comply with electrostatic-discharge requirements and enable more flexible system designs. At the same time, TSC packages will help to further reduce assembly costs while increasing power density.

DDPAK and QDPAK package offerings for target applications



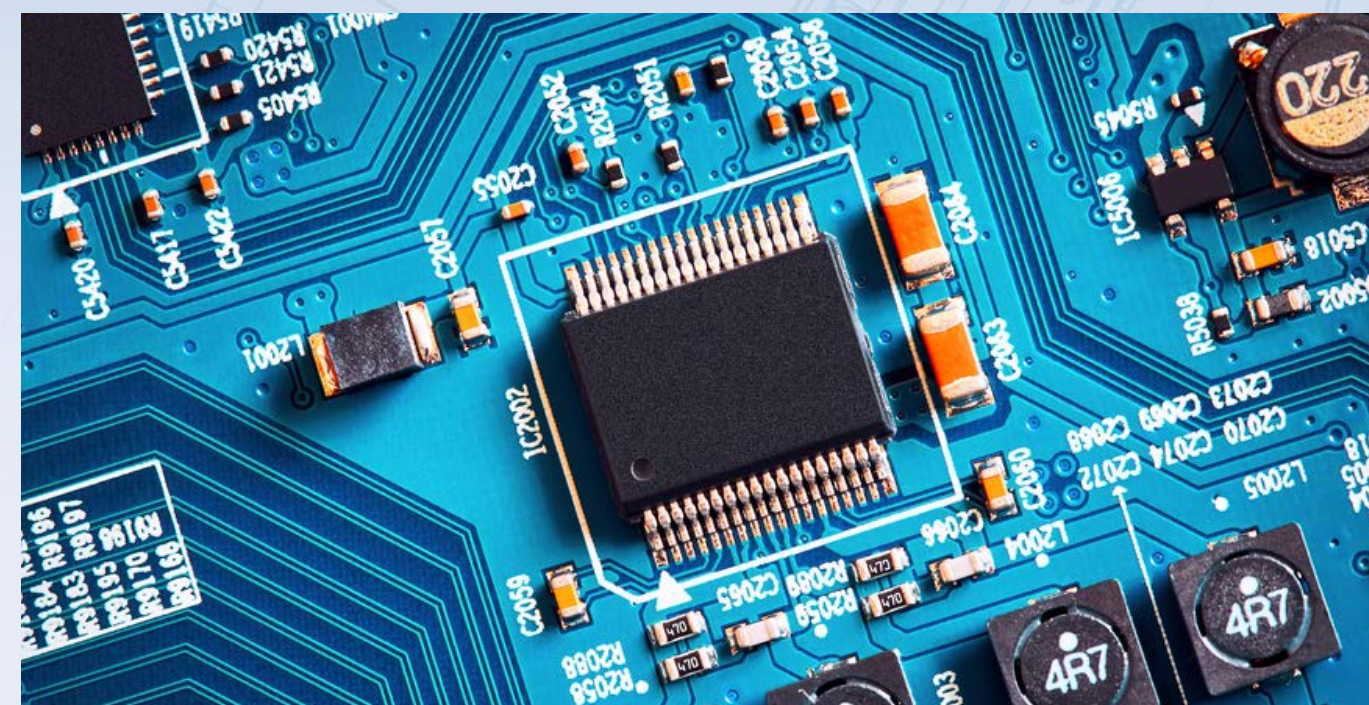
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Researchers Discover Superatomic Material Is Fastest, Most Efficient Semiconductor



A team of researchers at Columbia University discovered that a superatomic material, with the chemical formula $Re_6Se_8Cl_2$, is a semiconductor with unprecedented speed at room temperature.

By Stefano Lovati, contributing writer for Power Electronics News

Semiconductors, which lie between conductors like metals and insulators like glass, are the foundation of all our contemporary electronics. Composed primarily of silicon, these semiconductors consist of memory modules, microprocessors and other chips that are included in nearly all electronic devices. Nevertheless, they are not flawless and have inherent constraints.

Heat loss occurs in all semiconductors because of the quantum speed bumps that are intrinsic to them.

When the atomic structure of any material vibrates, it creates phonons, which are quantum particles. In reaction, phonons cause the energy- and data-carrying particles, known as excitons or electron-hole pairs, to disperse in a matter of nanoseconds or femtoseconds. Data transmission rates are finite, and above certain limits, heat is lost.

A new, more efficient superatomic semiconductor was **recently discovered by scientists at Columbia University** in New York. This semiconductor was the

world's fastest, according to experiments, as it could transport quasiparticles at a speed twice that of electrons moving through silicon.

SUPERATOMIC SEMICONDUCTOR

The most efficient and fastest semiconductor to date, a superatomic material known as $\text{Re}_6\text{Se}_8\text{Cl}_2$, was described in *an article published in Science* by a group of Columbia University chemists headed by Ph.D. student Jack Tulyag and chemistry professor **Milan Delor**. As a superatomic material, its rhenium (Re), selenium (Se) and chlorine (Cl) atoms cluster together while behaving in certain ways similar to the original elements.

Delor is intrigued by the manipulation and control of energy transport via superatoms and other novel materials that have been developed at Columbia. The team achieves this by developing ultra-high-resolution imaging instruments capable of capturing particles in motion at extremely tiny and rapid speeds.

Excitons in this material exhibit a slower movement compared with electrons in silicon. However, it is important to note that excitons travel in perfectly straight paths, allowing them to cover greater distances at a faster rate. Unlike in conventional semiconductors, in the $\text{Re}_6\text{Se}_8\text{Cl}_2$ superatomic semiconductor, phonons don't cause the energy-carrying particles to scatter, thus avoiding the slowdown of the information transfer.

That happens because in $\text{Re}_6\text{Se}_8\text{Cl}_2$, energy particles and phonons bind together. The combination of these elements creates distinct quasiparticles called acoustic

exciton-polarons. These particles possess exceptional properties, as they can move without dispersing, which could lead to the development of speedier and more efficient technologies.

The quasiparticles traversed enormous distances while traveling at velocities twice as fast as electrons in silicon as they darted through $\text{Re}_6\text{Se}_8\text{Cl}_2$. This system allowed for the control of quasiparticles by light rather than electricity, which theoretically allowed devices to cycle at the femtosecond scale, which is six orders of magnitude faster than the nanosecond possible by contemporary gigahertz CPUs. You can even do all of this while the temperature is only room temperature.

"In terms of energy transport, $\text{Re}_6\text{Se}_8\text{Cl}_2$ stands out as the best semiconductor we've identified," Delor said.

Polarons in $\text{Re}_6\text{Se}_8\text{Cl}_2$ can do something no other material can: They can flow in a ballistic, or scatter-free, fashion. One day, devices built with this kind of ballistic behavior may be speedier and more efficient.

The team's investigations showed that acoustic exciton-polarons in $\text{Re}_6\text{Se}_8\text{Cl}_2$ traveled throughout multiple microns of the material in under a millisecond, which is double the speed of silicon electrons. The group believes that the exciton-polarons might traverse more than 25 μm simultaneously, considering that polarons have a duration of approximately 11 ns.

Processing rates in theoretical devices could approach femtoseconds (six orders of magnitude faster than the nanoseconds achieved in contemporary gigahertz

electronics) because these quasiparticles are controlled by light instead of an electrical current and gating.

'THE TORTOISE AND THE HARE'

To clarify this phenomenon, Delor uses Aesop's fable of the tortoise and the hare as an analogy (Figure 1). Fast-moving electrons are what make silicon so attractive. However, they disperse in all directions, just like the hurried hare, who does not manage to cover much territory. The excitons in $\text{Re}_6\text{Se}_8\text{Cl}_2$ are in stark contrast to this. They blend in with phonons that move at a comparable snail's pace, but they're still slow. These resultant quasiparticles move slowly but surely. When compared with silicon electrons, the superatom ultimately allows for faster mobility.

The remarkable speed with which electrons may traverse silicon makes it an attractive semiconductor; nevertheless, like the hare, they ultimately fail to cover a great distance in a short amount of time due to their excessive bouncing around. The relatively slow excitons in $\text{Re}_6\text{Se}_8\text{Cl}_2$ can meet and pair up with acoustic phonons that move at the same relative slowness because of their extremely sluggish speed. Similar to a tortoise, the produced quasiparticles are "heavy" and move at a leisurely but consistent pace. Because they are unbounded by other phonons, acoustic exciton-polarons in $\text{Re}_6\text{Se}_8\text{Cl}_2$ can outpace electrons in silicon.

CHALLENGES AND FUTURE APPLICATIONS

$\text{Re}_6\text{Se}_8\text{Cl}_2$ consists of atoms of rhenium, selenium and chlorine. However, rhenium is one of the scarcest elements on Earth, which contributes to its high cost. It is quite improbable that this type of superatom will ever be incorporated into common electronic devices.

However, this revelation has presented numerous opportunities. Delor suggests that there exists a complete set of superatomic and other 2D semiconductor materials that possess features conducive to the creation of acoustic polarons. The team is excited to discover further superatomic

materials using new theories and imaging techniques, which may surpass $\text{Re}_6\text{Se}_8\text{Cl}_2$ in performance and perhaps utilize more easily accessible chemical components.

$\text{Re}_6\text{Se}_8\text{Cl}_2$, like many of the new quantum materials studied at Columbia, can be easily separated into atom-thin sheets. This property opens the door to the possibility of combining them with related materials to discover even more interesting combinations with which to experiment.

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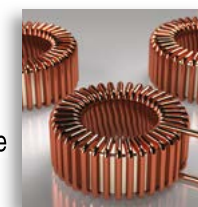
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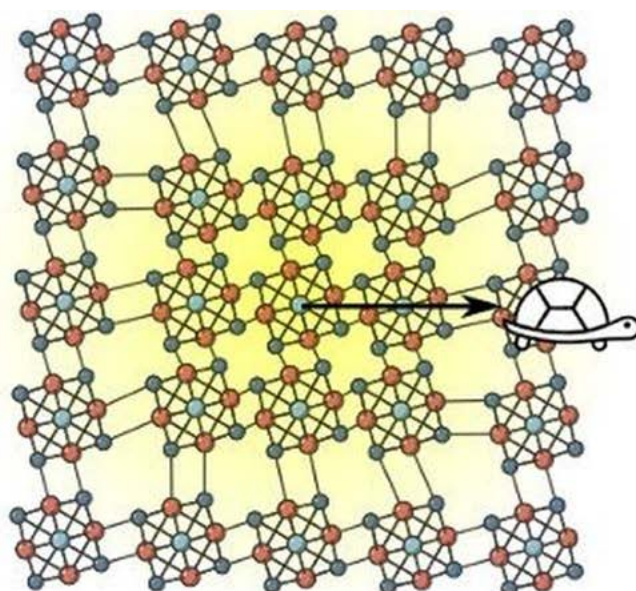
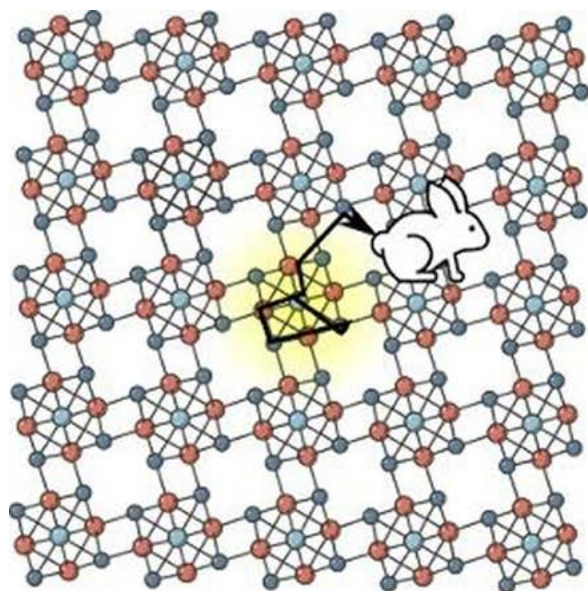


Figure 1: Acoustic exciton-polarons are like the slow-moving tortoise in Aesop's fable in comparison with the fast but still slow hare, which stands for an electron. (Source: Jack Tulyag, Columbia University)



Revolutionizing Power Electronics

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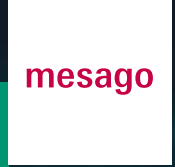
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- Renewable energy
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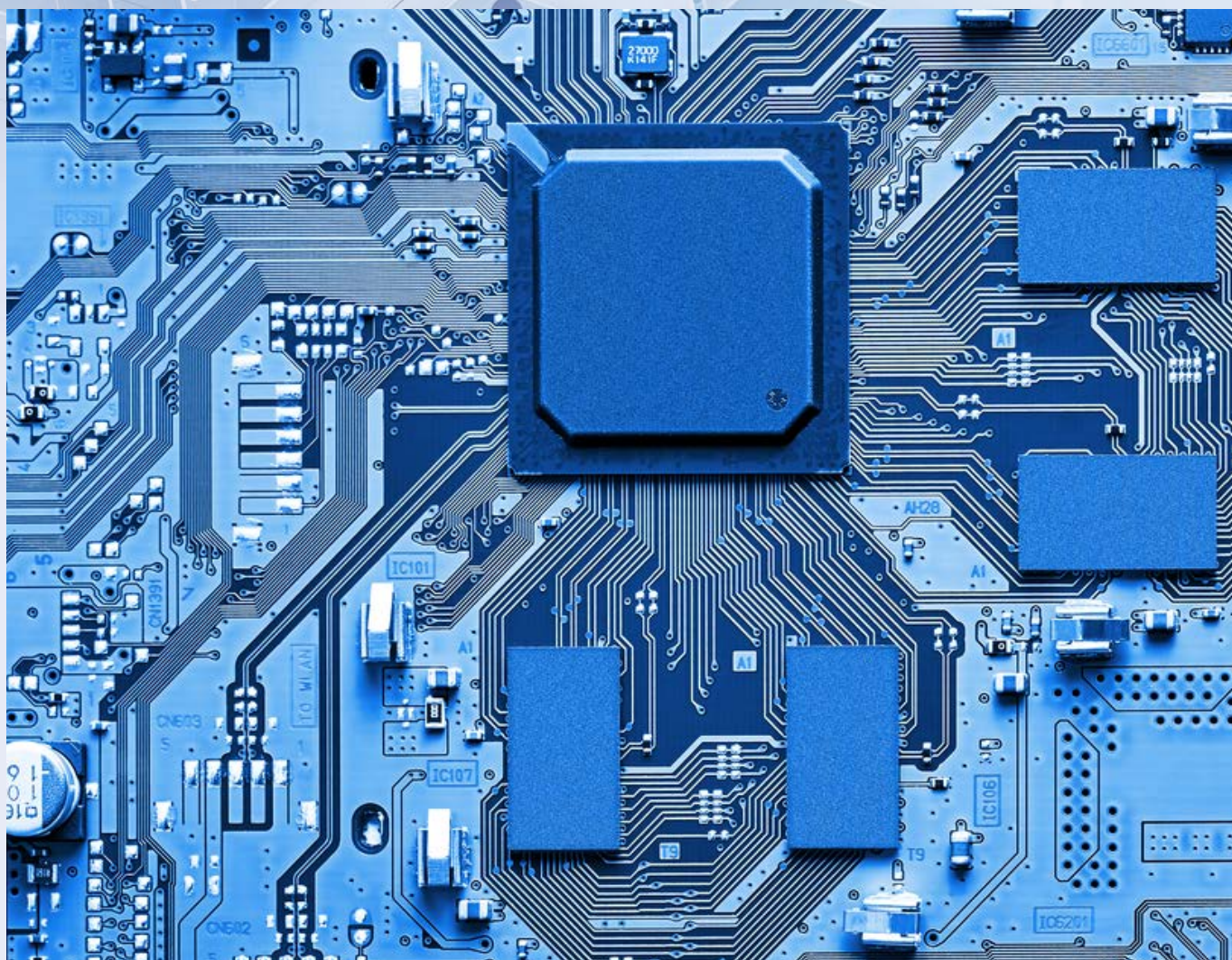
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Voltage-Clamping Components for Solid-State Circuit Breakers



By Stefano Lovati, contributing writer for Power Electronics News

Voltage-clamping components are indispensable for both solid-state circuit breakers (SSCBs) and hybrid circuit breakers (HCBs) to protect the solid-state switch from overvoltage damage and absorb the remnant energy in the system loop inductances.

This article compares various voltage-clamping components (e.g., metal-oxide varistors [MOVs],

transient-voltage-suppression [TVS] diodes, capacitor-based snubber circuits, etc.) in terms of operating voltage ranges, surge-current capability, energy-absorbing capability, cost and more. The presentation this article is based on can be found [here](#).

SSCBs AND HCBs

SSCBs offer the benefits of extremely rapid fault isolation and the ability to interrupt current without

producing arcs. They are gaining popularity due to advancements in power semiconductor devices, such as silicon carbide (SiC) MOSFETs, which greatly reduce conduction losses. HCBs, by the integration of a mechanical switch and a solid-state switch, offer the benefits of minimal conduction losses and relatively rapid current interruption.

The voltage-clamping component (Figure 1) is essential for both SSCBs and HCBs. It serves two purposes:

- ▶ To limit the peak voltage across the power semiconductor device and prevent overvoltage damage
- ▶ To dissipate the remaining energy in the system's parasitic inductances after the solid-state switches are turned off

The V_{pk}/V_{op} ratio is utilized to compare various voltage-clamping components and assess their performance.

MOVs

MOVs are the predominant voltage-clamping elements employed in SSCBs and HCBs. These components are constructed using various materials, such as zinc oxide and silicon oxide. At low applied voltage levels (below the clamping voltage), the MOVs exhibit high impedance properties. As the voltage increases to reach the clamping voltage, the impedance of the MOVs decreases fast, enabling the flow of current.

Market-available MOVs exhibit a range of package configurations, spanning from small surface-mount to large screw-mount. These MOVs also offer vast voltage ranges, with some devices capable of functioning at up to 3.5 kVDC. Additionally, they possess significant surge-current and energy-absorbing capabilities. MOVs can also conduct current and voltage in both directions and are very inexpensive when compared with alternative voltage-clamping devices like TVS diodes.

TVS DIODES

Transient-voltage-suppression (TVS) diodes are frequently employed as voltage-clamping components in SSCBs or HCBs. These diodes function similarly to avalanche diodes but can withstand high peak current and energy.

The TVS diodes can exhibit either unidirectional or bidirectional behavior and possess a rapid response time, similar to MOVs. In contrast with MOVs, TVS diodes have a restricted voltage range (less than 530 V for a single device) and a limited ability to handle high peak currents, as they are accessible only in small surface-mount and through-hole packaging devices. To attain a higher voltage rating or absorb a greater amount of energy, it is necessary to either join TVS diodes in series or in parallel.

One further disadvantage of the TVS diode is its relatively high cost in comparison with MOVs. The TVS diode can be several times more expensive than MOVs, even when they have identical energy-absorption and voltage needs.

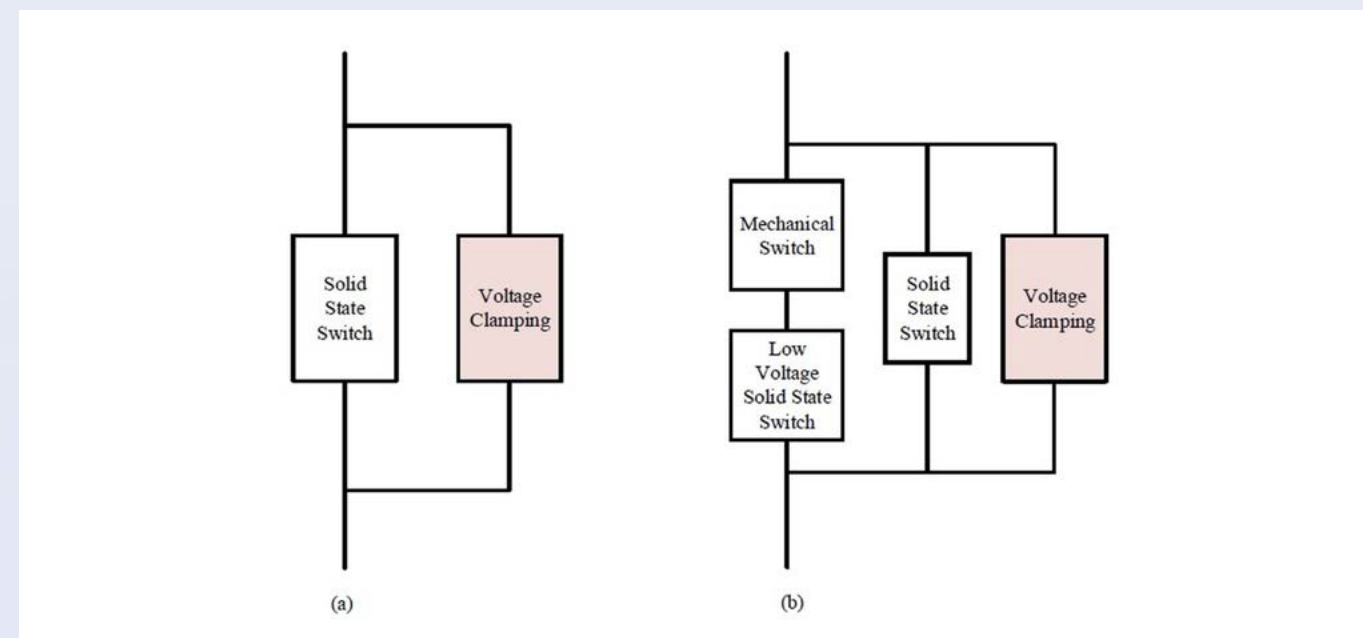


Figure 1: Both SSCBs and HCBs necessitate the incorporation of voltage-clamping components, which are required for their fundamental construction. The basic structure of an SSCB is shown on the left; the basic structure of an HCB is shown on the right. (Source: IEEE)

CAPACITOR-BASED VOLTAGE-CLAMPING CIRCUITS

The capacitor is a commonly utilized energy storage component in power electronics. It can also be employed in a voltage-clamping circuit to absorb any remaining energy stored in the parasitic inductances of the system. Capacitor-based snubber circuits are commonly employed in power electronics converters to restrict the rate of change of voltage during the turn-off of the solid-state device and mitigate voltage spikes.

In the case of SSCBs, the snubber circuit, which relies on capacitors, can effectively restrict the rate of change of voltage (dV/dt) during the turn-off process of the semiconductor switch. This capability is particularly important for SSCBs that utilize thyristors. Various types of snubber circuits exist, including those composed just of capacitors, the RC snubber and the RCD snubber, which incorporates a resistor, a diode and capacitors.

EXPERIMENTAL RESULTS

MOV devices have several benefits, including a broad range of operating voltages (up to 3.5 kVDC per device), high-surge-current and energy-absorption capacities, and a moderate cost compared with alternative voltage-clamping components.

Nevertheless, the ratio of peak clamping voltage to maximum operating voltage (V_{pk}/V_{op}) for this component is substantially elevated (>1.63) in comparison with that of the TVS diodes (>1.59). Several techniques are suggested to decrease the peak-voltage-to-output-voltage ratio (V_{pk}/V_{op}) of the MOV. These include

implementing an active adjustable switch in series with the MOV or connecting the MOV in a free-wheeling configuration with the solid-state device.

TVS diodes have a lower peak clamping voltage in comparison with MOVs. However, they have a restricted voltage range (less than 530 V for a single device) and a limited capacity for handling peak current (only small surface-mount and through-hole package devices are available). To attain a greater voltage rating or absorb a larger amount of energy, it is necessary to link more TVS diodes in either a series or parallel configuration.

One further disadvantage of the TVS diode is its significantly greater cost in comparison with MOVs. TVS diodes can be several times more expensive than MOVs, even when they have equal energy absorption and voltage needs. Capacitor-based snubber circuits can serve as voltage-clamping components for SSCBs. One advantageous characteristic of these circuits is their ability to control turn-off dV/dt , thereby reducing the energy stresses on the solid-state switches during fault-current interruption.

Various types of capacitor-based snubber circuits exist, such as the RC snubber and RCD snubber. An inherent concern with the capacitor-based snubber circuit is the occurrence of current oscillations following the shutdown of the solid-state device. To resolve this problem, the literature suggests using a snubber circuit consisting of a series connection of an MOV and a capacitor. This circuit effectively suppresses the oscillation by carefully selecting MOVs with the appropriate voltage level.

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Quantum Algorithms Will Optimize Power Grid Efficiency



By Filippo Di Giovanni, contributing writer for Power Electronics News

Quantum computing is emerging as one of the fastest-growing technology areas, thanks to phenomena occurring at the fundamental scale that only quantum mechanics can describe and explain, such as superposition, entanglement and interference. The processing power of quantum computers is phenomenal with respect to classical digital computers enabling execution of complicated calculations much more efficiently. Digital computers look unsuitable in addressing certain complex problems in mathematics, chemistry, weather forecasting, encryption, cybersecurity, grid management and transportation logistics.

WHAT IS A QUANTUM ALGORITHM?

A classical, non-quantum algorithm consists of a systematic approach to solving a given problem in the form of a limited sequence of instructions, with each instruction being executed by the hardware of a conventional computer. Similarly, a quantum algorithm is still a step-by-step procedure, but the steps are performed on a **quantum computer**. Even if classical algorithms can be performed on a quantum computer replicating quantum mechanics fundamentals and error correction and detection, quantum algorithms use some inherent features of quantum computation, such as **superposition** or entanglement.



Power lines and renewables (Source: Schneider Electric)

QUANTUM ALGORITHMS FOR ELECTRICAL GRID MANAGEMENT

Some researchers have already explored the potential of quantum computers in boosting power grid performance. The main problem arises from the fact that running and maintaining an existing grid is extremely expensive and time-consuming. The grid management issue is also compounded by the deployment of renewables, which are set to put extra stress on the distribution power lines. In fact, the world's electricity demand is set to surge, driven by economic growth, technological advancements and the imperative to transition to non-fossil energy sources. To put this into perspective, the expected global electricity demand could reach a value close to 35,300 terawatt-hours (TWh), from 22,000 TWh in 2017.

Power companies, many of which rely on narrow margins, often cannot afford to replace aged equipment, so they keep patching it up, making the grid more prone to power outages.

In response to the Paris Climate Agreement, countries worldwide have embarked upon implementing green energy policies aiming for 100% renewable-based power generation with net-zero emissions by 2050. Distributed energy resources, including photovoltaic and windmills—uncertain sources by definition—will therefore be integrated into power grids, and this may pose substantial challenges for system operators in terms of coordination and management. Power grids are already large distribution systems and will grow even further, so decisions become more complex, too. Events like cyberattacks, made possible by extensive data exchanged between stakeholders and entities, must also be considered. And ironically, attacks inspired by quantum algorithms may crack most of the cryptography algorithms in power system data communication based on various mathematical problems. In the end, operating such complex systems will require novel modeling strategies and trailblazing

computational techniques for various functions, such as control, optimization and forecasting.

Today's computers are ineffective in managing these big issues. Renowned companies including IBM, Google, D-Wave, Intel, Microsoft and various startups, namely IonQ and Rigetti, are competing to build the largest quantum computer.

CURRENT USE OF QUANTUM COMPUTING BY ELECTRIC UTILITIES

Electric utility companies are steadily moving toward employing quantum computing in various fields. Enel, an Italian multinational energy company and a major integrated player in the global energy, gas and renewable energy markets, partnered with **Data Reply**, an enterprise that offers advanced data analytics powered by AI, to solve combinatorial optimization problems based on the quadratic unconstrained binary optimization (QUBO) model. QUBO creates an optimal plan for assigning a large number of interventions with a finite number of crews. Optimizing the planning of maintenance work conducted by the teams operating in the area, from a computational point of view, means immediate availability and greater efficiency in the use of resources to achieve a significant reduction in costs.

U.K.-based **E.ON** has been working with IBM Quantum to implement quantum solutions for its critical workflow. According to E.ON, energy will no longer be transported unilaterally from the generating company to the user, but a future could include smaller companies and households that will feed energy into the grid—for example, via their own photovoltaic systems or electric cars. Quantum computing could be used to control these processes more efficiently and effectively in the future. At the same time, the increasing number of electric cars is leading to more complex charging processes, which quantum computing could help address.

THE PHASECRAFT CASE

In the race to make electrical grids more efficient, Phasecraft, a leading U.K. quantum algorithm startup, has won a U.K. government contract worth £1.2 million to optimize energy grids using quantum technology, as part of the Quantum Catalyst Fund, one of only six projects taken to the next stage of the competition. Following the successful completion of Phase 1, Phase 2 of this project will see Phasecraft work with the Department for Energy Security and Net Zero to prioritize and attempt to address such optimization problems with quantum solutions, with a special focus on operation costs. Building and maintaining grid connections is extremely expensive, costing up to £1.5

million per kilometer of line. The new contract comes after a successful year for the startup, which raised £13 million in Series A funding in August to reach practical quantum advantage—when quantum computers outperform classical computers for useful real-world applications.

What is remarkable is that the Quantum Catalyst Fund aims to accelerate the adoption of quantum technologies to transform public services. As Andrew Griffith, Minister of State for Science, Research and Innovation, remarked, “This further £45 million in funding underscores our commitment to support bright U.K. innovators who are pushing boundaries and seizing the potential of this technology to transform our public services.”

Phasecraft, founded in 2019 by quantum scientists, designs novel quantum algorithms to solve real-world problems on the imperfect quantum computers of today, aiming to accelerate the widespread adoption of quantum computing from decades to years away. Its algorithms are based on novel insights from theoretical physics and computer science, and Phasecraft's early focus is on applying these algorithmic improvements to modeling and simulation problems, such as the design and use of complex energy grids. Today, Phasecraft works in partnership with leading quantum hardware companies, including Google, IBM and Rigetti, as well as academic and industry leaders.

PRACTICAL PROBLEMS QUANTUM ALGORITHMS CAN ADDRESS

Optimization and load balancing

Quantum algorithms can efficiently solve complex optimization problems. In an optimization problem, we seek the best of many possible combinations. An example: “What is the most efficient route a traveling salesperson should follow to visit different cities?” Physics can help solve these sorts of problems because it boils down to an energy minimization problem. A fundamental rule of physics, including quantum physics, is that everything tends to reach a minimum-energy state (any object slides down slopes). Quantum annealing simply uses quantum physics to find low-energy states of a problem and therefore the optimal or near-optimal combination of elements. For smart grids, this means better load balancing, minimizing energy losses and optimizing power distribution.

Energy forecasting

Quantum algorithms, by enhancing the process of forecasting energy demand and supply, can help to achieve grid stability and efficient resource allocation.

Quantum machine-learning models can process large datasets and improve accuracy in predicting energy consumption patterns.

Grid resilience and security

Quantum cryptography offers accrued security protocols. Quantum-resistant algorithms are essential to protect smart-grid infrastructure against attacks from future quantum computers.

Grid simulation and modeling

Quantum simulators can produce an accurate model of power flow, fault analysis and stability assessments. These simulations enable grid operators to test scenarios, optimize grid parameters and strengthen overall reliability.

Power grid optimization

Quantum algorithms can work on large-scale combinatorial problems related to grid topology optimization, capacitor placement for stabilization purposes and fault detection with tremendous cost savings.

Energy market optimization

Quantum computing can make market-clearing algorithms more powerful, ensuring efficient energy trading and pricing. Real-time optimization of energy markets becomes feasible with quantum algorithms.

UNRESOLVED PROBLEMS OF QUANTUM COMPUTERS

Even though certain advantages have already been obtained with quantum computers, there are still some issues to be addressed before reaching quantum supremacy over classical computers. Quantum random-access memory is still not capable of effectively encoding information in a quantum state and ensuring the right execution speed of quantum algorithms. Many smart-grid applications rely on a large set of qubits to run quantum algorithms, and controlling those qubits may be a very tough job, as they are extremely sensitive to the surrounding environment, such as temperature and noise; therefore, special ad hoc infrastructure must be provided. Furthermore, maintaining a large number of qubits entangled could prove a critical feat because of decoherence occurrence.

The current quantum computers are not error-free as classical computers are, which may create extra challenges in sensitive power system applications. Therefore, designers must develop a universal fault-tolerant and error-correcting quantum computer for implementing arbitrary quantum algorithms with minimal effort.

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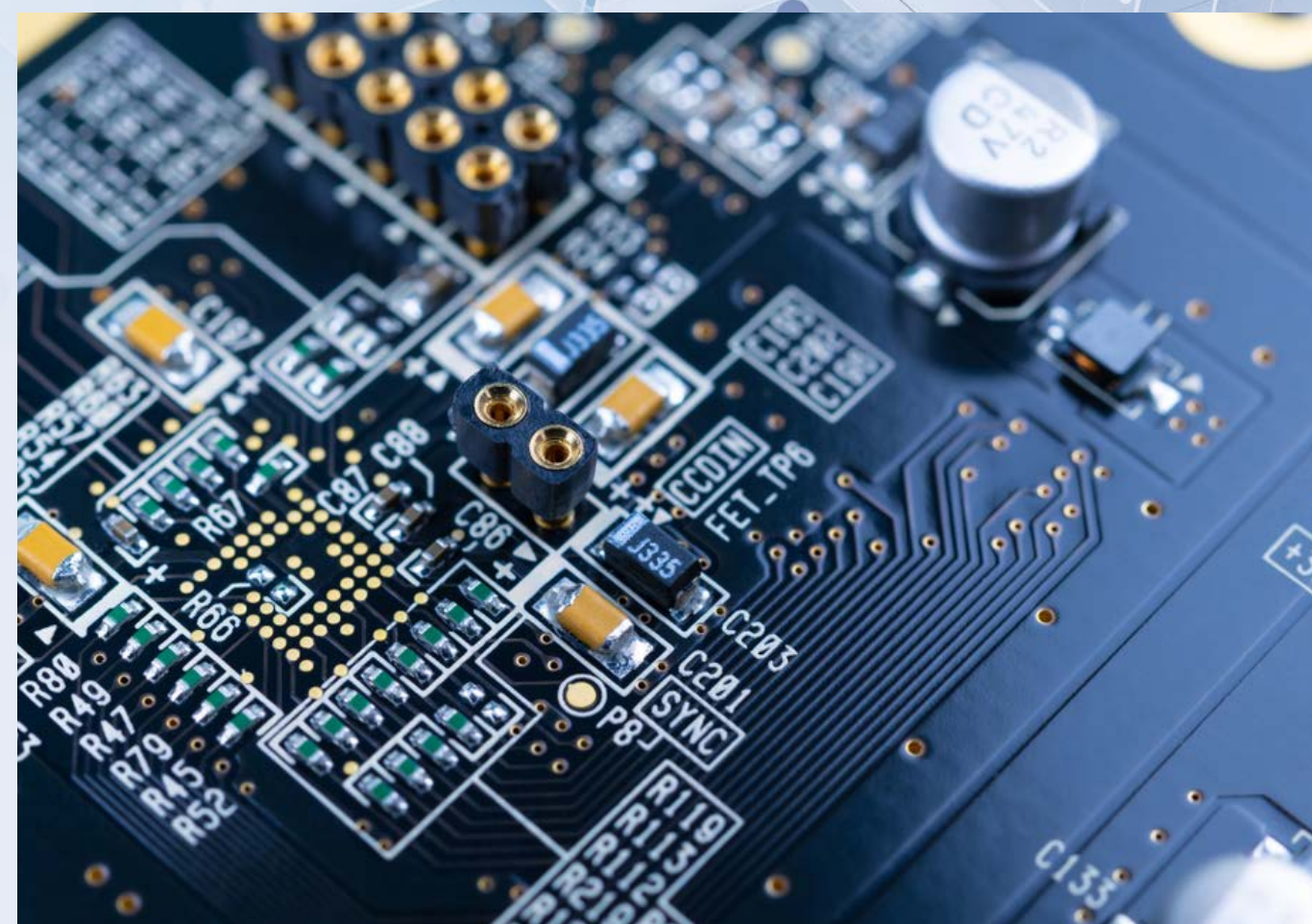
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Improving the Power Grid with Ultra-Wide-Bandgap Semiconductors



By Stefano Lovati, contributing writer for Power Electronics News

In February 2023, the United States Department of Energy (DOE) initiated an ULTRAFast program under the Advanced Research Projects Agency—Energy (ARPA-E). This program is specifically focused on developing semiconductor materials, devices and power module technology. The ULTRAFast program seeks to enhance the speed and efficiency of power semiconductor technologies, enabling faster switching and triggering at higher-current and -voltage levels. This will result in improved control and safety of the grid.

The **ULTRAFast** program aims to develop advanced technologies for faster-switching, higher-rated devices and power modules. These technologies will enable the implementation of innovative power management, protection and control systems for the grid and future green autonomous power distribution systems like electric vehicles and all-electric aviation.

THE GRID NEEDS INNOVATION

The national electric system encounters numerous obstacles, such as deteriorating infrastructure, a rise in extreme weather occurrences and the emergence

of cyber and physical dangers. These issues lead to power interruptions that incur a financial loss of more than \$150 billion annually for the U.S. Furthermore, the U.S. is experiencing a significant surge in the need for electricity due to its ambitious goal of achieving net-zero emissions by the year 2050.

To accomplish the objective of reducing carbon emissions, it is necessary to electrify many sectors, such as transportation, industrial processes and urban infrastructure. This implies that the power systems in the U.S. must expand by 60% by 2030 and more than triple by 2050 to meet the increasing demand. The ULTRAFAST initiative aims to deliver technological advancements in power electronics that will enhance the security and dependability of the grid (Figure 1) while simultaneously enabling it to satisfy increased electricity requirements in support of decarbonization objectives.

The grid's ability to adapt to new demands has traditionally been restricted by its regulatory capacities. Currently, power flows at high- and medium-voltage levels are primarily directed through substations that utilize traditional electromechanical equipment, low-frequency transformers and slow protective devices. The response speeds of these components can vary throughout multiple line cycles. This constraint hampers the grid's capacity to regulate, assimilate, redirect and segregate power currents, hence presenting substantial dangers and susceptibilities, including the occurrence of cascading power outages.

Due to its cost-effectiveness, ease of manufacture and well-established manufacturing processes, silicon has been the preferred semiconductor material for power devices. Nevertheless, silicon devices are



Figure 1: The grid power systems need innovation to meet decarbonization goals.

approaching their maximum capacity in terms of their ability to block voltage, operate at high temperatures and switch frequencies. This is due to the inherent material qualities of silicon, which are constrained by a short bandgap and critical electrical field.

The primary goal of ULTRAFAST is to enhance the performance thresholds of silicon, wide-bandgap (WBG) and ultra-wide-bandgap (UWBG) semiconductor devices. The advancement of WBG semiconductors, such as silicon carbide and gallium nitride, as well as UWBG semiconductors, including aluminum gallium nitride, diamond, gallium oxide and boron nitride, presents exciting prospects for the development of more efficient devices.

Conventional semiconductors made of silicon are approaching their maximum capabilities in terms of speed and durability. However, semiconductors made of diamond have the potential to bring about a significant transformation in power grids.

ADVANTAGES OF DIAMOND-BASED SEMICONDUCTORS

Diamond-based semiconductors possess unparalleled speed capabilities, making them highly advantageous. Diamond's remarkable electron mobility allows for quicker switching rates, which in turn enables fast data transmission and processing inside the power grid. The increased velocity not only enhances the grid's ability to respond quickly but also allows for real-time monitoring and control, optimizing the distribution of energy and reducing losses.

Moreover, the exceptional thermal conductivity of diamonds guarantees the effective dispersion of heat, hence minimizing the likelihood of overheating and augmenting total energy efficiency. Diamond-based semiconductors enhance the sustainability and cost-effectiveness of the power grid infrastructure by reducing energy waste and increasing throughput.

Diamond-based semiconductors possess remarkable durability and chemical stability, distinguishing them from silicon. Diamonds are resistant to damage caused by radiation and have a great tolerance for temperature changes, allowing them to function without interruption under extremely difficult conditions. This resilience leads to decreased periods of inactivity, decreased expenses for upkeep and heightened dependability of the power grid, which are crucial elements for contemporary power infrastructure.

The utilization of diamond-based semiconductors (Figure 2) has substantial ramifications for power electronics. Diamond-based devices offer significant

	Si	4H-SiC MOSFET	GaN HEMT	Diamond
Bandgap eV	1.12	3.26	3.39	5.47
Ecrit MV/cm	0.23	2.2	3.3	7.7 - 20
Intrinsic carrier density ni (/cm ³)	1x 10 ¹⁰	8x 10 ⁻⁹	2x 10 ⁻¹⁰	1x 10 ⁻²⁰
RT Electron Mobility in Device cm ² /V-s	1400	<100	1500-3000	~ 1100
RT Bulk Hole Mobility (cm ² /V-S)	480	120	< 200	~ 2000
Thermal Conductivity λ W/cm-K	1.5	4-5	1.3-1.7/4*	22 - 24
Typical Substrate diameter (inches)	8 - 17.7	6 - 8	6 - 8 (GaN on Si)	< 1
			* GaN on SiC substrates	

Figure 2: A comparison of some of the basic electrical properties of diamond, silicon, SiC MOSFET and GaN HEMT devices

breakthroughs in power management applications, encompassing a wide range of components, such as high-voltage switches, inverters, rectifiers and voltage regulators.

THE DIAMOND PCSS PROJECT

Among the institutions that were awarded is the [University of Illinois](#), which has been selected to receive \$3.5 million in funding from the U.S. [DOE ARPA-E](#).

The University of Illinois at Urbana—Champaign is now working on the development of diamond semiconductor switching devices that have the potential to bring about significant advancements in power grid protection. The device under consideration consists of UWBG materials that are activated by light. It successfully addresses the constraints in voltage and current that are typically encountered in traditional photoconductive devices. If the gadget proves to be successful, it will serve as an essential element in power electronics that operate at higher temperatures, are more efficient and offer greater reliability.

The research team, headed by associate professor Can Bayram, concentrates on utilizing diamond as an innovative material for semiconductor devices. According to Bayram's explanation, diamonds are essentially composed of carbon, which is not inherently expensive. Consequently, the production of lab-grown diamonds significantly reduces their cost, making them less expensive.

Bayram says that photoconductive semiconductor switches provide rapid bypass capability with little integration, aiming to mitigate power outages that impact an average of half a million Americans daily and result in an annual cost of \$150 billion for American families. However, the conventional photoconductive

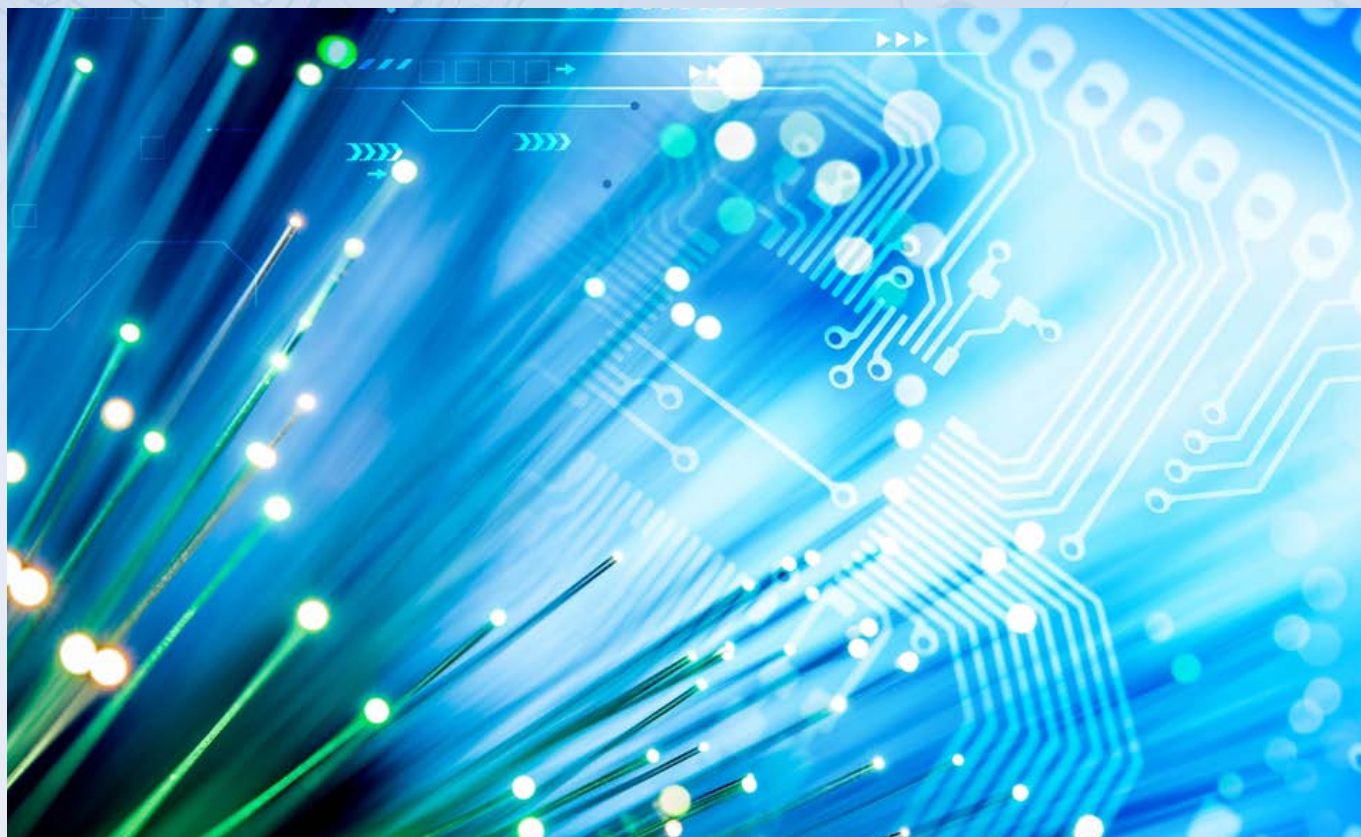
semiconductor switch (PCSS), which was created in 1970, is incapable of achieving the necessary voltage/current levels at the needed voltage/current slew rates.

Diamond is a UWBG material with exceptional breakdown strength, superior carrier mobility and excellent thermal conductivity. Diamond, in comparison with other WBG and UWBG semiconductors, offers the potential for faster switching and higher-rated device and power module technologies, which can revolutionize power management.

The PCSS was first created in 1970. Bayram's team has modernized the design and materials, which were groundbreaking at the time. In addition to utilizing diamond as a primary material, they also modified the device's construction by integrating a concealed metallic conductive channel, which facilitates the flow of larger electric currents. The devices are activated by ultraviolet light sources, a technology that was first developed in the Laboratory for Optical Physics and Engineering.

The research team's objective is to develop a device that may serve as a crucial element in power electronics that operate at higher temperatures while also being more efficient and dependable.

Prospects for power grids in the future are becoming more closely linked with diamond-based semiconductors. With ongoing research and development, we can expect a significant change in the grid infrastructure, characterized by increased speed and durability, driven by the exceptional qualities of diamonds. By adopting this cutting-edge technology, we are laying the foundation for a future in which energy is more sustainable, dependable and optimized.



High-Voltage Gallium Oxide Devices Show Promise



By Sonu Daryanani, contributing writer for Power Electronics News

Ultra-wide-bandgap (UWBG) semiconductors have superior intrinsic material properties compared with silicon and WBG materials like silicon carbide and gallium nitride. Amongst the different **UWBG materials**, gallium oxide is showing increasing promise for future use in high-voltage power electronics. This article summarizes some of the intrinsic properties of this material and showcases some recent high-voltage device advances. It is based on a **PSMA webinar** given by Uttam Singiseti, a professor of electrical engineering at the University of Buffalo.

INTRINSIC MATERIAL PROPERTIES OF GALLIUM OXIDE

The beta phase of gallium oxide ($\beta\text{-Ga}_2\text{O}_3$) has emerged as a key candidate for evaluation as the choice of UWBG material. Several factors play

into this. Table 1 lists some of the basic material properties of silicon, SiC, GaN and $\beta\text{-Ga}_2\text{O}_3$.

The higher bandgap and electric field strength are two advantages of $\beta\text{-Ga}_2\text{O}_3$. This allows for more efficient device scaling in high-voltage power devices and can consequently result in improved metrics for both conduction and switching losses.

Material	Si	SiC	GaN	$\beta\text{-Ga}_2\text{O}_3$
Bandgap	1.1	3.3	3.4	4.8
Relative Dielectric constant ϵ	11.7	9.7	9.5	10
Electric Field strength (MV/cm) E_{cr}	0.3	2.5	3.3	8
Electron Mobility (cm^2/Vs) μ	1400	800	1200	200
Thermal Conductivity (W/cm.K)	1.5	2.7	1.3	0.24
Intrinsic carrier conc. ($/\text{cm}^3$)	$1.5\text{e}10$	$0.8\text{e}-8$	$1.9\text{e}-10$	$1.8\text{e}-22$
P-doping (holes)	Yes	Yes	Yes	Yes
Substrates	Yes	Yes	No	Yes
BFoM (e. μ . Ecr^3) w.r.t. Si	1	274	926	2314

Table 1: Some basic properties of silicon, SiC, GaN and $\beta\text{-Ga}_2\text{O}_3$ (Source: Singiseti, U., 2024)

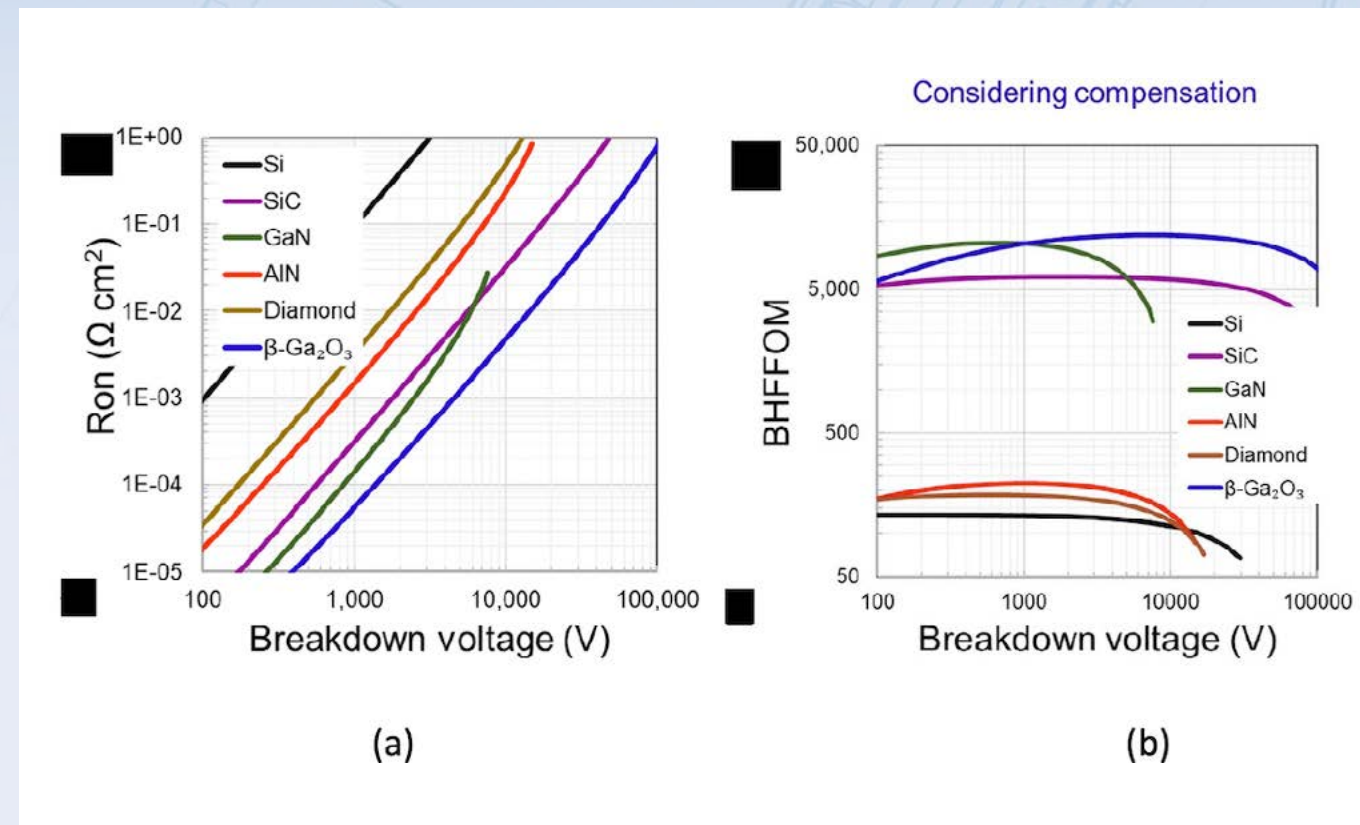


Figure 1: A comparison of the modified BFOM metrics, considering dopant activation and background impurities: (a) shows the conduction loss metric, while (b) shows the switching loss metric. (Source: Zhang, Y., & Speck, J., 2020)

The ideal Baliga figure of merit (BFOM) shown in Table 1 is commonly used to describe the tradeoff between the on-state resistive loss and the breakdown field. This, however, does not include two important factors:

- Incomplete ionization from dopants
- Background impurities in the substrates

The availability of shallow dopants is a key enabler in achieving performance close to the theoretical BFOM limits. UWBG materials, however, can suffer from a lack of such dopants. In the case of aluminum nitride (AlN) and diamond, high-dopant-ionization energies make it difficult to effectively achieve high levels of activated dopants, especially at room temperature. This leads to low electrical conductivity. Fortunately, $\beta\text{-Ga}_2\text{O}_3$ has shallow, n-type donor dopants (tin, silicon).

The impurity states within the bandgap can further compensate for dopant densities and degrade device performance. Impurity levels can be orders of magnitude higher in UWBG materials compared with silicon. AlN and diamond both suffer from this effect, with background concentrations that can range into the $1\text{e}16/\text{cm}^3$ range. In WBG materials, GaN also suffers from relatively poor background concentrations of above $1\text{e}15/\text{cm}^3$. $\beta\text{-Ga}_2\text{O}_3$ again has an advantage

here, with progress in epitaxy and substrate growth resulting in background charge concentrations of below $1\text{e}15/\text{cm}^3$. A good example of the importance of low background doping and a high bandgap is a silicon IGBT rated to 6.5 kV that would need a minimum blocking-voltage thickness of 220 μm and a background impurity below $4\text{e}13/\text{cm}^3$, which is hard to achieve and would in any way result in a very high $R_{\text{DS(on)}}$, while $\beta\text{-Ga}_2\text{O}_3$ would need only an 8- μm -thick blocking layer with a net doping concentration of $3\text{e}16/\text{cm}^3$!

The modified BFOM comparisons taking these above effects into account are shown in Figure 1. These plots show the advantage of $\beta\text{-Ga}_2\text{O}_3$ over other materials, especially at voltage ratings above 1 kV.

SUBSTRATE GROWTH

High-quality substrates of $\beta\text{-Ga}_2\text{O}_3$ at relatively low costs are possible with melt growth, similar to silicon. This is a key advantage compared with WBG materials like SiC, which need to use costly sublimation methods. An example of a company that is manufacturing 100-mm $\beta\text{-Ga}_2\text{O}_3$ substrates is **Novel Crystal Technology**, based in Japan.

$\beta\text{-Ga}_2\text{O}_3$ HIGH-VOLTAGE DEVICES

Let's now look at some of the work done by Singiseti's group and others in the creation of $\beta\text{-Ga}_2\text{O}_3$ high-voltage power devices. Several atomic-layer-

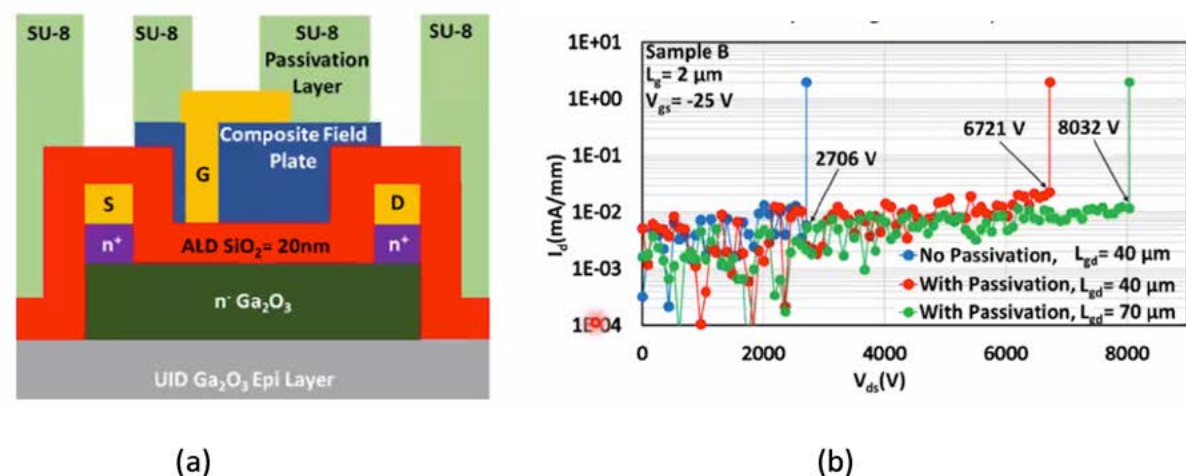


Figure 2: Cross-section view and BV curves of a $\beta\text{-Ga}_2\text{O}_3$ MOSFET (Source: Sharma, S., & Singiseti, U., 2020)

deposited (ALD) dielectrics have been used as a gate dielectric to create lateral n-channel MOSFET devices. Silicon dioxide (SiO_2) is a promising candidate, with a large conduction band offset and low interface states at room temperature. Initial MOSFETs created exhibited a breakdown outside the channel region. Failure analysis pointed to high fields in the air above the gate-field-plate (GFP) region. The use of a composite field-plate dielectric (comprising PECVD and ALD SiO_2), a recessed MBE-grown channel and a high-field-strength epoxy polymer (SU-8) passivating film above the GFP resulted in MOSFETs with the highest reported breakdown voltage (BV) of over 8 kV in lateral MOSFETs.² This work showed that field management techniques are critical. A cross-section schematic and BV curves of this device are shown in Figure 2.

These devices still suffered from relatively poor $R_{\text{DS(on)}}$. It was found that vacuum annealing post-RIE etch created damage recovery and improved $R_{\text{DS(on)}}$, without affecting the BV.

MESFET devices with a Schottky gate have shown promise. The 4.4-kV MOSFETs with a power FOM ($\text{PFOM} = \text{BV}^2 \div R_{\text{DS(on)}}$) exceeding 100 MV/cm^2 and specific $R_{\text{DS(on)}} \approx 20 \Omega\text{-mm}^2$ have been demonstrated using a silicon nitride passivation dielectric.³ While this PFOM was much better than the theoretically achievable number with silicon, it's still well short of $\beta\text{-Ga}_2\text{O}_3$'s theoretical limits. The use of improved epitaxial growth techniques and a FINFET MESFET structure have demonstrated electron mobilities of $184 \text{ cm}^2/\text{V}\cdot\text{s}$. This 4.4-kV device, which uses 25 fin widths of 1.2 to 1.5 μm , achieved a record PFOM of 0.95 GW/cm^2 .⁴

HIGH-TEMPERATURE OPERATION

As shown in Table 1, $\beta\text{-Ga}_2\text{O}_3$ suffers from poor thermal conductivity. This can put a burden on cooling requirements in high-power applications. Some intrinsic advantages, however, help $\beta\text{-Ga}_2\text{O}_3$ perform well at high temperatures. The extremely low intrinsic carrier density and a combination of other factors enable a low thermal degradation coefficient to be achieved. In comparison with GaN, where the $R_{\text{DS(on)}}$ at 125°C can be over $2\times$ that at 25°C , the $R_{\text{DS(on)}}$ for $\beta\text{-Ga}_2\text{O}_3$ moves little with temperature.

The SBD was operated to 600 K and exhibited a much smaller, tenfold increase in the reverse leakage current from 300 K to 500 K at 500 V, compared with at least a hundredfold increase of the same in vertical GaN and SiC SBDs at similar ratings. The MESFETs were operational to the measured 500°C . These examples demonstrate the potential use for $\beta\text{-Ga}_2\text{O}_3$ devices in high-temperature, high-voltage operation.

Work has also been done to improve the packaging for thermal resistance reduction. A double-side-packaged large area ($4.6 \times 4.6 \text{ mm}$) $\beta\text{-Ga}_2\text{O}_3$ vertical SBD device rated for 15 A was used⁷ with silver sintering on both sides of the die. The top anode junction-ambient thermal resistance was measured to be 0.5 K/W , which is lower than that of similarly rated SiC SBDs. This and other work that involves thinning down the substrate below $100 \mu\text{m}$ highlights that the low thermal conductivity need not be a showstopper in high-voltage, high-power applications.

USE OF HETEROJUNCTIONS/ SUPERJUNCTIONS TO CREATE BIPOLAR DEVICES

The p-doping of $\beta\text{-Ga}_2\text{O}_3$ is difficult due to the lack of shallow acceptors and strong self-trapping of holes. Heterojunction and superjunction devices using n-doped $\beta\text{-Ga}_2\text{O}_3$ with p-doped nickel oxide have been

successfully demonstrated as diodes and MOSFETs. High-quality interfaces have been successfully created between these two materials and good device performance that creates the advantages of the p-n junction, including avalanche and surge capability, which can be a vital robustness criterion in many power system applications.



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The Smart Grid: A Revolutionary Approach to Global Energy Efficiency



New technologies are revolutionizing the way we produce, distribute and consume energy. Today, the energy transition features smart grids, which represent one of the most promising innovations in the field of electricity management, capable of significantly revolutionizing the global distribution of electricity. They are advanced systems that combine the power of information technology with traditional network infrastructure, enabling more intelligent and efficient management of energy resources. The integration of advanced technologies like the IoT further enhances their performance, paving the way for a more intelligent, flexible and efficient energy system.

By Giordana Francesca Brescia, contributing writer for Power Electronics News

After the transport sector, electricity production is the second-largest cause of greenhouse gas

emissions worldwide. Smart grids are intelligent systems of interconnected electrical networks that

integrate digital technologies, advanced sensors and two-way communications to optimize energy production, distribution and consumption. They differ from traditional electricity networks in their ability to collect and analyze data in real time, allowing for more dynamic and efficient management of energy resources. Their ability to improve efficiency and revolutionize power conversion systems makes them critical to the sustainable future of electricity.

The general architecture of smart grids includes sensors distributed along the network, advanced measurement units, reliable communication systems and a centralized control system. All of these elements work synergistically to improve grid control, enabling faster responses to changes in demand and supply disruptions. The proper design of reliable and innovative smart grids solves several problems associated with traditional networks, such as interruptions, security problems or high carbon emissions.

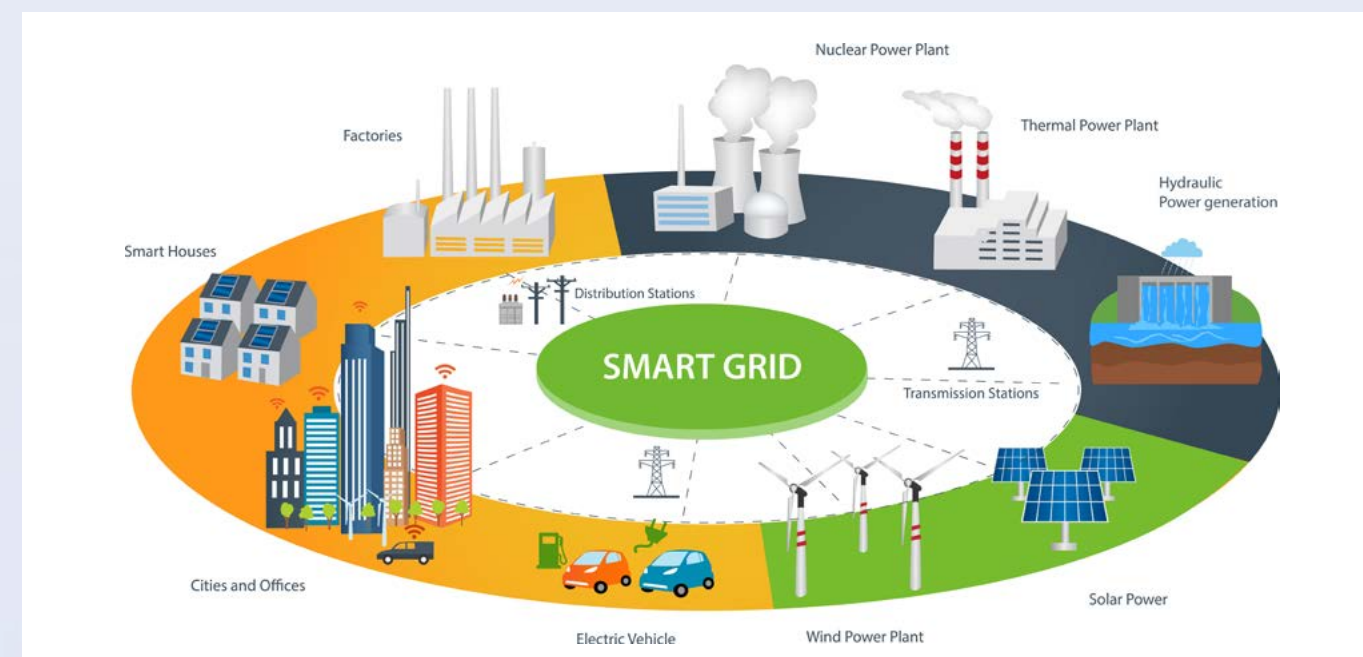
ENERGY EFFICIENCY IN SMART GRIDS

Smart grid technology is an integral part of the digital transformation of the energy sector and promises to modernize the world's traditional electricity system through digital intelligence techniques that help utility providers transition to clean energy and reduce carbon emissions. Among the main objectives of smart grids are to improve the overall efficiency of electricity systems and optimize energy production with the latest technologies, and these are achieved through a series of key features and operational methodologies.

First, smart grids make it easier to integrate renewable energy sources, such as solar and wind, into the electricity grid. Thanks to the ability to monitor and control energy production from these intrinsically variable sources over time, smart grids allow for the better management of production fluctuations while ensuring a continuous supply of energy.

Furthermore, smart grids enable active demand management, allowing production to be adapted to fluctuations in demand. Users can thus receive real-time information on energy costs and make informed choices about electricity use based on availability and current prices. These systems involve the generation of energy, its transmission and distribution, and the conversion between different energy forms.

In the context of generation, smart grids enable more intelligent and dynamic management of resources, can monitor the performance of generation plants, predict necessary maintenance and optimize production based on market conditions and grid needs. Regarding transmission and distribution, smart grids improve the safety and reliability of infrastructure and can automatically detect and respond to faults, reducing downtime and increasing overall system resilience. In power conversion operations, smart grids facilitate the integration of advanced technologies, such as smart distribution grids and energy storage devices. Smart grids also play a fundamental role in conversion systems by helping to optimize the flow of power, reducing losses and improving the overall efficiency of conversion systems.



Schematic diagram of a smart grid and a traditional energy network

Climate change and the ongoing energy crisis are intersecting on our networks, which are proving to be increasingly obsolete and unsustainable. We therefore need to rethink the energy network. Within the traditional grid, electricity providers have little information about how consumers use electricity. The one-way flow of a traditional grid is directed from centralized sources (such as coal, nuclear and gas) to points of consumption (homes, businesses and data centers) and is based solely on demand; i.e., when there is an increase in demand for electricity, operators send more to the network.

In traditional energy networks, power plants produce electricity and then distribute it to consumers. The system is largely passive and unresponsive, with little real-time information on usage and demand. Digital electricity grids, on the other hand, are much more reactive and flexible and allow us to effectively integrate renewable energy into our energy supply. They offer a radically different method based on the integration of distributed energy resources, resulting in a real-time, interactive, two-way flow of information and electricity between consumers and utilities, thus enabling an automated and advanced energy supply, together with a valuable tool for controlling electricity use and costs. The integration of distributed energy sources promotes a more sustainable and resilient network architecture, as well as more efficient energy routing, as the use of distributed resources promotes local energy production and reduces transmission losses.

Advanced techniques like intelligent optimization algorithms balance the intermittent nature of renewable energy sources and ensure the stability of the energy infrastructure. Distributed generation systems can feed excess electricity back into the grid and reduce dependence on traditional fossil-fuel power plants. Smart grids are made up of several integrated components, each of which plays a well-defined role:

- ▶ Smart meters
- ▶ Sensors and automation devices
- ▶ Communication networks
- ▶ Software and analysis tools

Metering infrastructure is one of the most important components in smart grid technology. The meters measure energy consumption in real time, providing detailed information on consumption patterns to both the consumer and the energy supplier. These devices are installed throughout the network to

monitor voltage, current and load capacity and can automatically adjust parameters to avoid overloads and prolonged blackouts.

Communication networks simplify the transmission of data between various components, including sensors, automated devices and control centers. Transmission systems can be wired or wireless and use a variety of communication protocols and technologies, such as Wi-Fi, Zigbee and 4G/5G. However, smart networks produce enormous amounts of data. To correctly manage, analyze and interpret this data, utilities rely on advanced software and analytics tools that can help suppliers predict demand trends through a clear understanding of consumption patterns, identify potential problems and optimize the distribution network.

Using sensors, data analytics and AI algorithms, utilities can monitor grid components in real time and optimize smart grid technology. By implementing data-collection capabilities at the edge, including smart meters, smart-home technologies, electric-vehicle chargers, solar and wind farms and more, usage and condition data can be shared across the entire supply chain value.

IIOT ENABLES SMART GRIDS

By definition, the internet of things is a set of internet-enabled devices capable of collecting information and data and transmitting this information between devices and other people in real time. The IIoT contributes to the transition toward smart energy, supporting the technology and communication necessary to make energy networks intelligent and offering specific advantages and solutions for multiple applications and use cases that can be implemented in networks. The IIoT can indeed enable energy solutions that strengthen smart grids by generating a highly automated, responsive and self-healing network with interfaces between all parts of the network. Smart grids today represent the main application of IIoT technology in the energy sector by exploiting interconnected devices that share information with each other using common frameworks. Smart sensors, advanced measurement devices and control equipment communicate with each other, enabling a highly responsive and adaptable power grid.

Smart metering works by providing a two-way communication line between devices and the end utility to collect, disseminate and analyze user energy consumption data. With advanced metering, the information that has been recorded and communicated by the smart meter can be

implemented by automated processes in real time. Information from network monitoring can be used to optimize operational strategies, identify areas with high energy losses and reduce system inefficiencies. IIoT technologies like smart meters can help provide real-time alerts of meter or network damage or outages, install software updates, help save energy, monitor and control power quality, change prices and real-time offers based on data insights, monitor solar parks and improve their efficiency while keeping CO₂ emissions low.

The IIoT in the smart grid improves predictive analysis by collecting performance data based on variables (time of year, weather conditions, performance of individual panels, etc.). This simplifies maintenance by connecting monitors to individual solar panels that provide real-time feedback on performance and structural deficiencies. All of these aspects allow you to get more from each panel by optimizing design factors like the inclination angle and the direction of the panel.

Another key application of the IIoT in smart grids is in battery-monitoring systems. Batteries are increasingly used to effectively store excess energy to be redistributed to other users on a network. However, when batteries are undercharged or

overcharged with energy, performance decreases, which can lead to a shortened battery life. Intelligent systems that monitor a battery's state of charge can help prevent premature failure.

EV charging can also be IIoT-based. The integration of fossil-fuel-powered vehicles with EVs is one of the key indicators to measure the reduction of carbon emissions in the years to come. At the same time, the exponential growth of the EV market presents a number of critical issues, including the charging infrastructure required to support millions of EVs. Adopting an IIoT smart-grid-based approach to EV charging can optimize the management of the charging process by identifying and coordinating optimal strategies for drivers. Smart networks implemented in individual EVs can monitor charge levels during a journey, while the monitors connect to a GPS network of other charging stations, resulting in a real assistant capable of recommending the time and optimal place for refueling. This is done by taking into account the vehicle's charge level, the EV location and destination, the location of available charging stations, and the availability and activity of the stations in the vicinity of the EV to be charged. The adoption of IIoT-assisted technology for charging EVs could accelerate electrification for consumer and commercial use, enhancing the achievement

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SMART ENERGY

of broader objectives related to the reduction of atmospheric emissions.

Energy providers can also use vehicle-to-grid (V2G) technologies. V2G systems exploit the efficiency of batteries by transferring unused energy from the vehicle to the smart grid, helping to balance peaks in electricity consumption and reducing grid overload during peak hours.

Another noteworthy use case is preventive maintenance, which involves addressing problems before they occur by taking measures like proactive monitoring and fixes. Preventive maintenance helps you immediately identify and correct faults, potential failures and power quality issues. A predictive approach plans maintenance activities to reduce downtime and improve the overall reliability of the energy grid.

For example, IoT-connected HVAC systems using internet-connected microcontrollers in smart buildings can perform constant, real-time control by sending notifications to the central system and real-time asset monitoring via remote and interconnected devices. The IoT allows you to receive real-time alerts for system deterioration and other features, saving time on energy infrastructure repairs and more quickly notifying suppliers of the need for intervention. Smart grids also allow consumers to take full control of their energy consumption, significantly improving the user experience.

Overall, smart grids derive multiple benefits from IoT-enabled capabilities. The rapid evolution of

energy systems is moving toward an “internet of energy,” whereby smart IoT devices communicate with the grid to optimize energy use at a higher level.

THE FUTURE OF SMART GRIDS

Every year, the need for efficient, sustainable and flexible energy solutions grows. The energy infrastructure is the physical place where the critical issues of energy supply and climate change intersect. Smart grid technology changes the way we interact with energy systems and the electricity market, allowing us to become increasingly aware of our consumption and make smarter choices. Traditional electricity grids will continue to be revolutionized by the IoT and smart grids. On the other hand, electricity companies must implement effective energy optimization strategies.

Scalability, security and convenience are the key points of revolutionary smart grid technology. Despite this, converting current energy grid structures into a new energy model requires significant efforts and a redesign of more open and collaborative networks. We also need to change our relationship with the internet. With clear benefits like interoperable connectivity, remote control, performance optimization, low-cost maintenance and waste reduction, smart grid solutions can benefit not only energy providers and consumers but also our community’s energy and the entire planet.

The final energy goal is to achieve the reduction of CO₂ emissions. The key is building a renewable energy innovation ecosystem that delivers a sustainable energy future.

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TEST & MEASUREMENT



Large-Area Sintering for High-Performance Power Module Packaging



By André Schwöbel, Heraeus Electronics; Francesco Ugolini, AMX Automatrix; Federico Belponer, AMX Automatrix; and Alessio Greci, AMX Automatrix

Traditionally, silicon power devices like IGBTs or MOSFETs were soldered onto the metal-ceramic

substrate, aluminum wire bonds were used as interconnection technology, and solder paste or thermal grease was used to connect the power module to the baseplate or cooler. Such a structure is shown in Figure 1 (left).

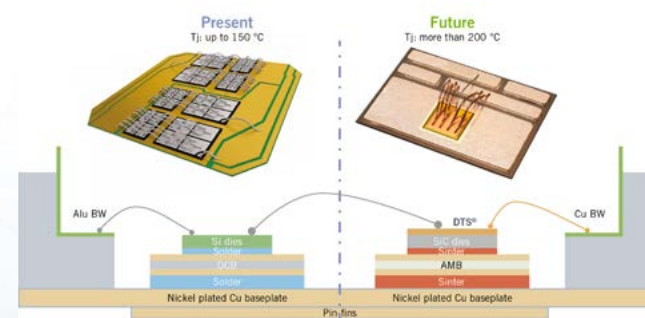


Figure 1: Traditional package for silicon devices (left); future high-reliability package for SiC devices (right)

Power module package technology must undergo drastic changes due to the fast market introduction of silicon carbide wide-bandgap (WBG) devices for automotive, new energy and industrial applications. SiC devices like diodes or MOSFETs can operate at higher temperatures, increase power densities and thereby impose larger thermomechanical stress on packaging materials. Figure 1 (right) shows an advanced packaging concept optimized to achieve

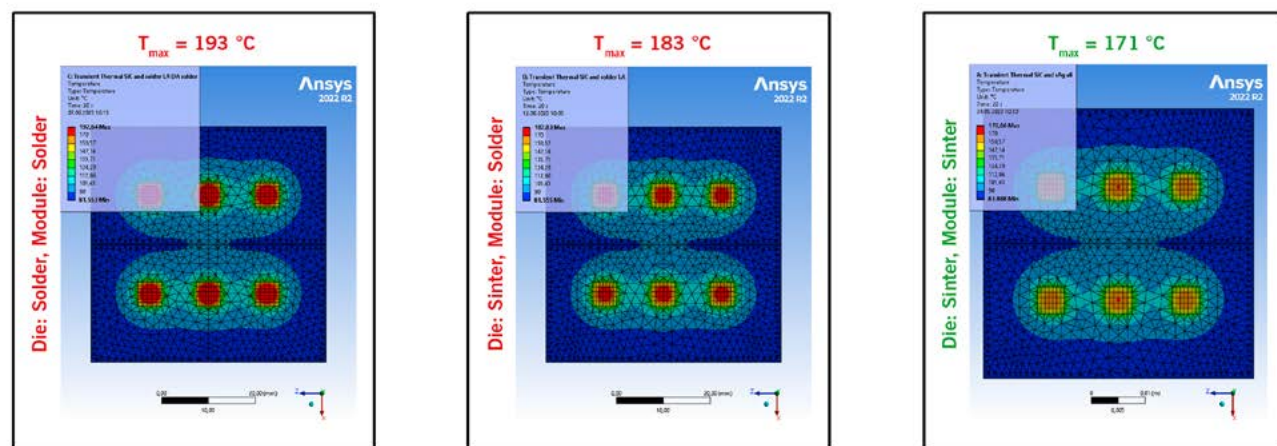


Figure 2: ANSYS simulation results of the steady-state temperature distribution of various packaging concepts. From left to right: Module- and die-soldered, module-soldered and die-sintered, fully sintered module. Simulation details: $P_{loss} = 202 \text{ W per chip}$, SiC die size $5 \times 5 \times 0.15 \text{ mm}^3$.

the highest reliability and maximum efficiency in combination with WBG semiconductors.

The future module is equipped with the Heraeus Die Top System to enable copper (Cu) wire bonding on top of the die, combined with silver (Ag)-sinter technology to connect the chip to the substrate. The Al_2O_3 -based metal ceramic substrates from the traditional package must be substituted by highly thermal-conductive Si_3N_4 -based active metal brazed (AMB) substrates to increase reliability and performance (Figure 1, right). Finally, the solder material, which attaches the module to the baseplate, is replaced by a highly reliable and highly thermal conductive Ag-sinter material. This process is termed “large-area sintering,” as complete modules are sintered onto a cooler.

The improvement in thermal performance by using large-area sintering instead of soldering is shown in Figure 2, where a decrease in die temperature of 22°C was simulated when changing from a fully soldered packaging concept (left, $T_{max} = 193^\circ\text{C}$) to a fully sintered packaging concept (right, $T_{max} = 171^\circ\text{C}$). The improvement in thermal resistance allows for the use of smaller and therefore more cost-efficient chips to achieve the same output power of a device or run more current through the same semiconductors at the same overall cost. Additionally, the question of joint’s reliability regarding thermal cycling is one of the key aspects that must be considered.

Large-area sintering for areas beyond 300 mm^2 is still a rather young technology, and not many modules using this technology are in the field. However, increasing demand is foreseen due to the rapid electrification of passenger cars and car manufacturers striving for the highest reliability. The trend sets new requirements for sinter paste manufacturers like Heraeus and sinter press suppliers like AMX Automatrix. Whereas die attach is limited by the chip size, the areas for large-area sintering are significantly larger—in the range of $>2,500 \text{ mm}^2$, depending on the module size. Several concepts, such as wet and dry placement of the module into the paste, and several paste application methods, such as stencil printing or dispensing,

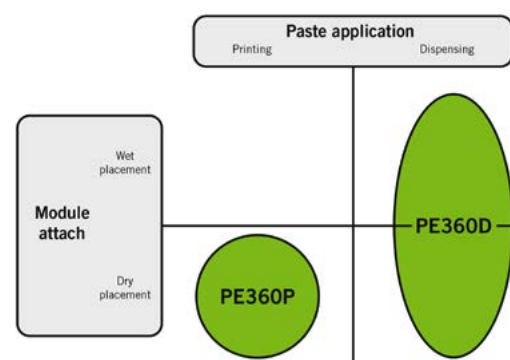


Figure 3: Heraeus Electronics’ PE360 paste variants suitable for large-area sintering applications

have emerged, all with their specific advantages and disadvantages. Therefore, a careful selection of the suitable paste, application method and sintering technology must be made for each package.

HERAEUS PASTE VARIANTS FOR LARGE-AREA SINTERING

Heraeus reacted to the trend toward large-area sintering by developing two Ag pressure-sinter pastes, **PE360P and PE360D**, as depicted in Figure 3. This section focuses on the joint properties of PE360P; the results obtained by dispensing properties are expected to be the same and will be discussed elsewhere.

PE360P is designed for printing applications like stencil or screen printing and ensures a processability of more than 8 hours on the printing machine. PE360P was designed to place molded packages or bare substrates in the $40 \times 40\text{-mm}^2$ to $100 \times 100\text{-mm}^2$ range onto the pre-dried paste. For this size, a dry placement process is favorable, as the drying process of the paste is done without covering the paste with the module or baseplate, which ensures efficient evaporation of solvents and additives before the actual sintering process. However, the influence of the warpage of the module and baseplate is a drawback for the dry placement process, which needs to be addressed. The process flow for dry placement and wet placement is shown in Figure 4.

An example of the performance of the PE360P paste is shown in Figure 5. AMB substrates with a silver surface were sintered onto flat baseplates made from copper. The baseplates were used for sintering either with a bare Cu surface or an Ag plating. The sintering was done on the AMX P101 equipment with 20 MPa and 250°C in nitrogen for 5 minutes. The paste was fully dried before sintering. The corresponding ultrasonic scans show excellent connection and almost no visible voiding on Cu- and Ag-plated baseplates, indicating an optimal thermal and mechanical connection between the substrate and cooler.

Furthermore, the reliability of the sinter joint underwent temperature cycle testing (TCT). For this purpose, Ag-plated AMB substrates with 0.3-mm Cu thickness were sintered onto Ag-plated Cu-core baseplates (P360P paste, 230°C sinter temperature, 5-minute sinter time, 12-MPa pressure). The delaminated area was inspected by ultrasonic scanning after 1,000 cycles and 2,000 cycles of thermal shock. The resulting pictures are presented in Figure 6. After 1,000 cycles of thermal cycling, almost no delamination can be seen when using large-area sintering. Only minor defects can be detected at the corners of the test samples, which can be addressed to the highest stress levels occurring at these positions. The delamination is mainly located at the baseplate side of the connection. Only minor changes are seen upon 2,000 cycles of TCT, which proves the excellent reliability of the sinter joint.

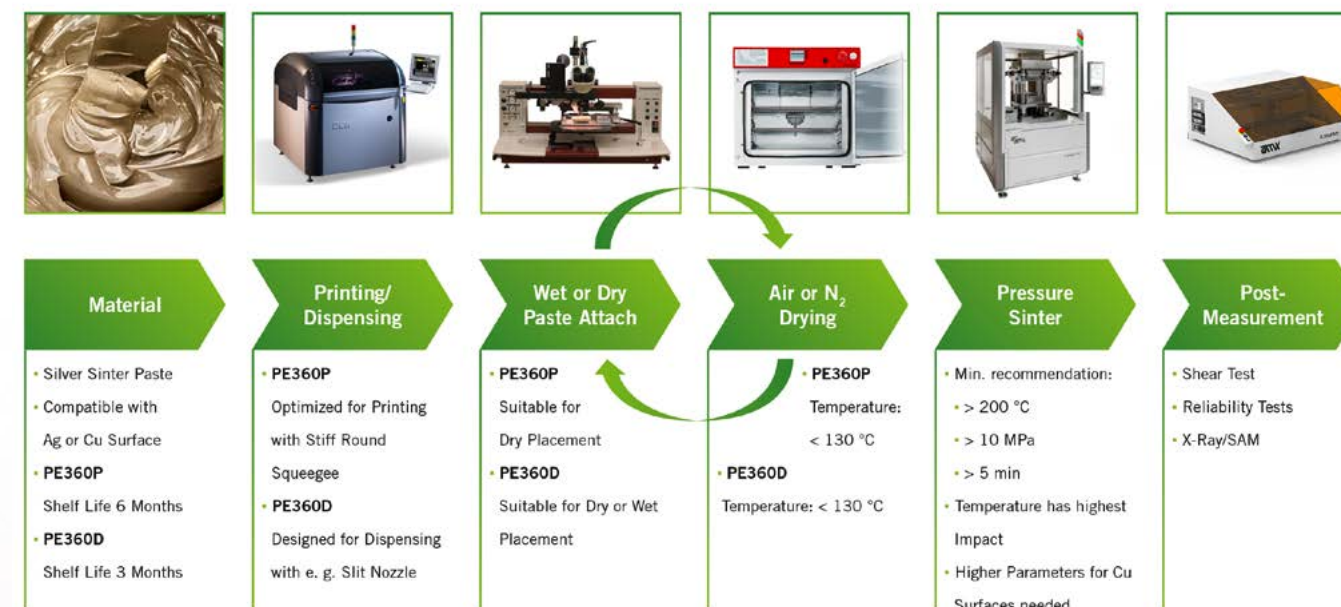


Figure 4: Process flow for both PE360 variants, including wet or dry placement

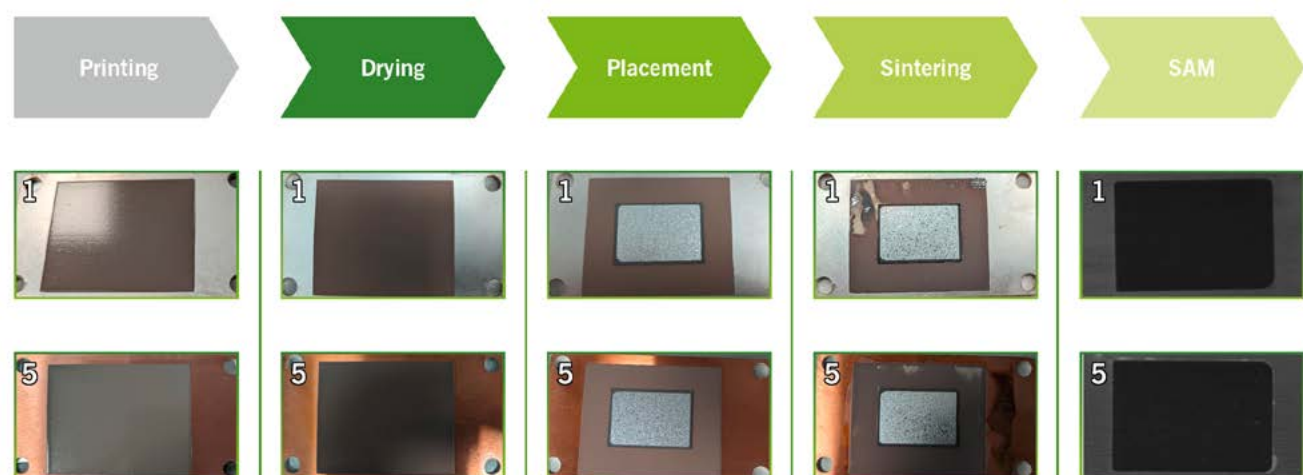


Figure 5: Process flow and scanning acoustic microscopy images of PE360P sintered AMB substrates on Ag-plated and bare Cu baseplates

P201X HS LARGE-AREA EQUIPMENT

In response to the discernible demand emanating from the automotive industry and Tier 1 suppliers, AMX has expanded its existing equipment portfolio, specifically directed toward the incorporation of specialized machinery tailored to meet the immediate needs of large-area sintering applications.

Within this initiative, the sintering area has been significantly augmented, reaching dimensions of 300 x 300 mm for the research and development unit (X-Sinter P55). Simultaneously, the mass-production equipment (**X-Sinter P201X**) has undergone enhancements to accommodate the demands of heatsink pressure-sintering applications,

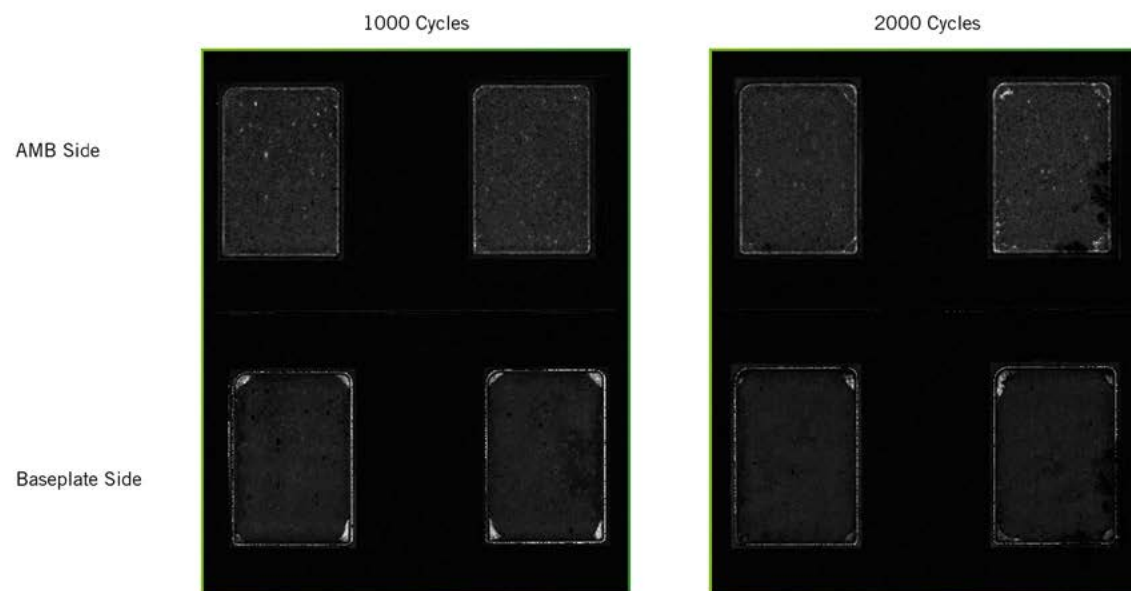


Figure 6: Scanning acoustic microscopy images of the AMB side and the baseplate side after thermal cycling. The area of each of the substrates is approximately 1,000 mm². TCT condition: -55°C/150°C (20-minute dwell time)

culminating in the introduction of the X-Sinter P201X HS model.

The primary objective of these modifications has been to optimize production batch processes while sustaining a high production rate, as evidenced by the VDI 3423 standard exceeding 99%. The design of the units is crafted to seamlessly integrate within a fully automated workflow scenario. On the software front, these units are adaptable to Industry 4.0 networks through compatibility with communication systems like SecsGem, OPCUA, OPCON or other advanced MES platforms.

Furthermore, the process cycle time has been enhanced by integrating a pre-heating system, ensuring the maintenance of elevated temperatures in the cooler, complemented by a post-cooling plate after sintering. An optional full nitrogen cabinet is also available, serving as a preventive measure against busbar oxidation. This comprehensive approach underscores **AMX's** commitment to advancing technological capabilities in compliance with industry demands.

Heraeus's PE360 paste and AMX's equipment demonstrate the benefits of large-area sintering,

including improved thermal resistance and reliability. Both companies offer leading-edge solutions for future sinter application demands.

Heraeus Electronics

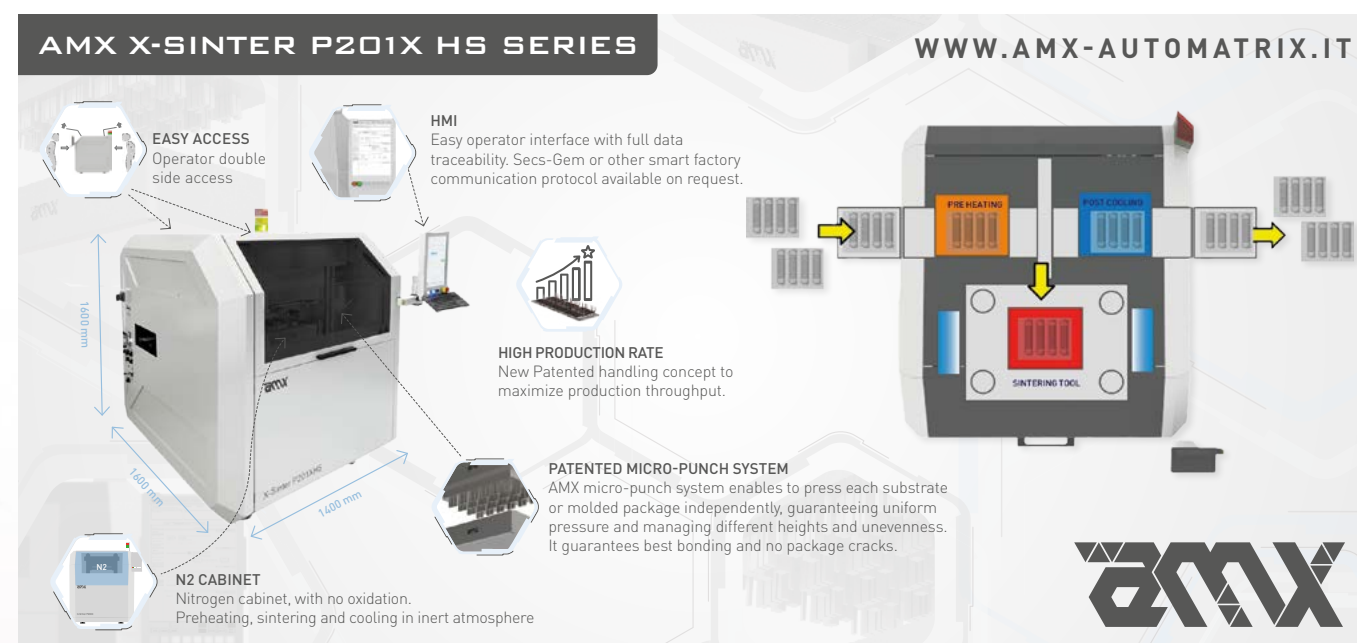


Figure 7: X-Sinter P201X HS



Automotive-Qualified SiC Power Devices



By Stefano Lovati, contributing writer for Power Electronics News

In the ever-evolving field of automobile engineering, the pursuit of improving efficiency, performance and reliability is ongoing. The automotive industry is shifting toward electrification, leading to an increased need for power electronics that can provide improved efficiency, power density and dependability.

Silicon carbide power devices have developed as a disruptive technology, providing significant advantages over older, silicon-based competitors. Automotive-certified SiC power components are a significant development that has the potential to transform the electric-vehicle industry and automotive power systems.

ADVANTAGES OF AUTOMOTIVE-QUALIFIED SiC POWER DEVICES

SiC is a wide-bandgap semiconductor material that demonstrates superior electrical characteristics in comparison with silicon, such as increased breakdown voltage, quicker switching rates and reduced conduction losses. SiC possesses inherent features that make it well-suited for power semiconductor devices, especially in high-power and high-frequency applications. SiC power devices include Schottky

diodes, MOSFETs and JFETs, designed to meet specific application needs.

SiC power devices have lower switching losses and on-state resistances than traditional silicon devices, resulting in increased system efficiency and decreased energy losses, which are crucial in EV propulsion systems. Moreover, the exceptional material characteristics of SiC allow for the creation of small and light power electronics systems with increased power density and higher switching frequencies, aiding in the general downsizing and weight reduction of automotive powertrains.

SiC power devices for automotive applications are engineered to function dependably across a broad temperature range, guaranteeing strong performance in challenging automotive conditions, such as high temperatures and thermal cycling. SiC power devices provide increased thermal conductivity and greater material stability, resulting in improved reliability and lifespan. This reduces the chances of system failures and maintenance needs, thus boosting the whole lifecycle of automotive electronics.

SiC APPLICATIONS IN AUTOMOTIVE

The transition from 400-V to 800-V battery systems in EVs has elevated the importance of SiC semiconductors in traction inverters, on-board chargers (OBCs) and DC/DC converters. The move is propelled by increased power levels of DC fast charging and efficiency improvements in driving cycles, with SiC playing a crucial role in high-voltage EV batteries and chargers.

SiC is suitable for high-voltage applications ranging up to several hundred volts and can withstand high temperatures in EV powertrains. SiC semiconductors are well-suited for OBCs, inverters and other power electronics in plug-in hybrid vehicles and fully electric cars.

SiC MOSFETs and diodes are commonly used in electric car traction inverters to facilitate effective power conversion from the battery to the electric motor. Utilizing SiC devices in EV powertrains leads to enhanced efficiency, extended driving range and superior overall performance. SiC's low losses and high-temperature tolerance make it perfect for enhancing the driving range and performance of EVs.

SiC-based power modules are used in OBCs for EVs to enable quicker charging and enhance the efficiency of power conversion from the grid to the vehicle's battery pack. The high-frequency functioning and small size of SiC devices lead to quicker charging and smaller system dimensions.

SiC power devices are used in auxiliary systems like DC/DC converters in EVs to efficiently adjust voltage

levels across subsystems, such as the traction battery and auxiliary systems. SiC-based converters provide increased efficiency and power density in comparison with silicon-based converters.

COMMERCIAL DEVICES

Rohm Semiconductor

Rohm Semiconductor produces automotive-certified SiC Schottky diodes, MOSFETs and power modules tailored for high-voltage and high-temperature automotive applications. The gadgets are equipped with sophisticated packaging and thermal management techniques to guarantee strong performance and durability.

EVs are getting increasingly popular, but their short range remains a challenge. Batteries are getting bigger and charging faster to improve driving distance. This requires 11-kW and 22-kW OBCs with great power and efficiency, increasing SiC MOSFET use (Figure 1). Power devices with low loss and higher withstand voltages are needed for 800-V batteries.

The **SCT3022KLHR** for instance, is a 1,200-V, 95-A, trench-structure SiC MOSFET for automotive-grade products with AEC-Q101 qualification. This device features low on-resistance (22 mΩ), fast switching speed and reverse recovery and is simple to drive and easy to parallel.

Infineon Technologies

Infineon Technologies offers a range of automotive-qualified SiC MOSFETs and diodes under the CoolSiC portfolio. These devices are designed to meet the

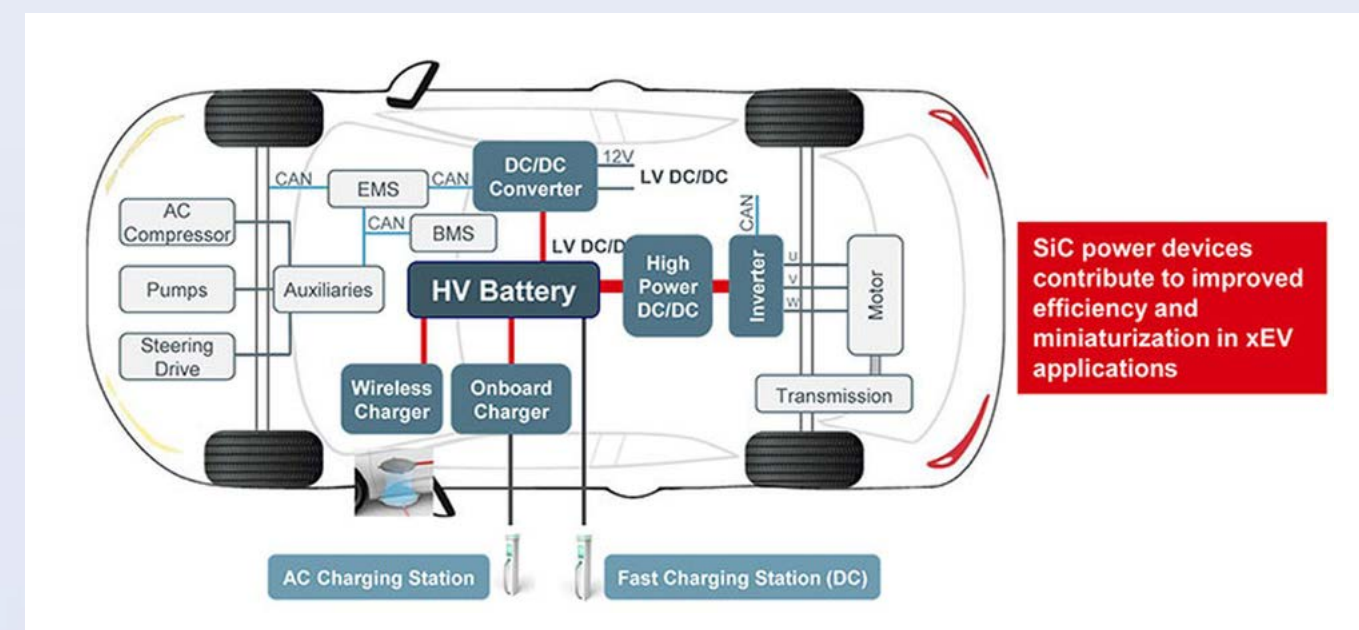


Figure 1: Usage of SiC power devices in xEV applications (Source: Rohm Semiconductor)

AUTOMOTIVE

stringent requirements of automotive applications, including traction inverters, OBCs and DC/DC converters, providing high efficiency and reliability for EV power electronics.

The fifth-generation CoolSiC automotive Schottky discrete diode family is designed for present and future OBC applications in hybrid and electric vehicles. This product line demonstrates enhanced efficiency across all load circumstances due to its compact design and technology utilizing thin wafers, which leverage thermal properties and a low figure of merit ($Q_c \times V_f$). This product line was created to enhance Infineon's IGBT and CoolMOS portfolio. This guarantees compliance with the strictest automotive application standards within the 650-V voltage category.

CoolSiC MOSFETs are developed in trench technology with a breakdown voltage of 1,200 V and are available in the TO-247 and TO-263-7 (Figure 2) packages. Increasing the switching frequency of a converter with CoolSiC MOSFETs can lower the size and weight of magnetic components by up to 25%, leading



Figure 2: Infineon's 1,200-V CoolSiC MOSFET in a TO-263-7 package for automotive applications (Source: Infineon Technologies)

to a notable cost increase for the application. The performance improvement meets the new regulations' greater efficiency standards for EVs. The exceptional gate oxide dependability and high-quality Infineon SiC ensure a long and secure operational lifespan, meeting demanding mission profile specifications. Additional characteristics like minimal gate charge and device capacitance levels, absence of reverse-recovery losses in the internal commutation-proof body diode, temperature-independent low switching

losses and threshold-free on-state properties ensure a straightforward design process and easy control in applications.

Navitas Semiconductor

With the acquisition of GeneSiC, Navitas Semiconductor, a renowned GaN power IC maker, has strengthened its portfolio for high-power applications, such as EVs, solar power and industrial. SiC in EVs, in particular, offers compact, lighter and more effective solutions, leading to increased driving range or reduced battery size.

Today, Navitas offers a broad spectrum of SiC technology, with voltages ranging from 650 V to 6,500 V. The GeneSiC SiCPAK (Figure 3) offers a range of package options, from 8 × 8-mm surface-mount QFNs to through-hole TO-247s, making it suitable for higher-power applications. A detailed plan for power modules is being developed, incorporating high-voltage SiC MOSFETs, MPS diodes, GaN power ICs, high-speed digital isolators and low-voltage silicon control ICs.

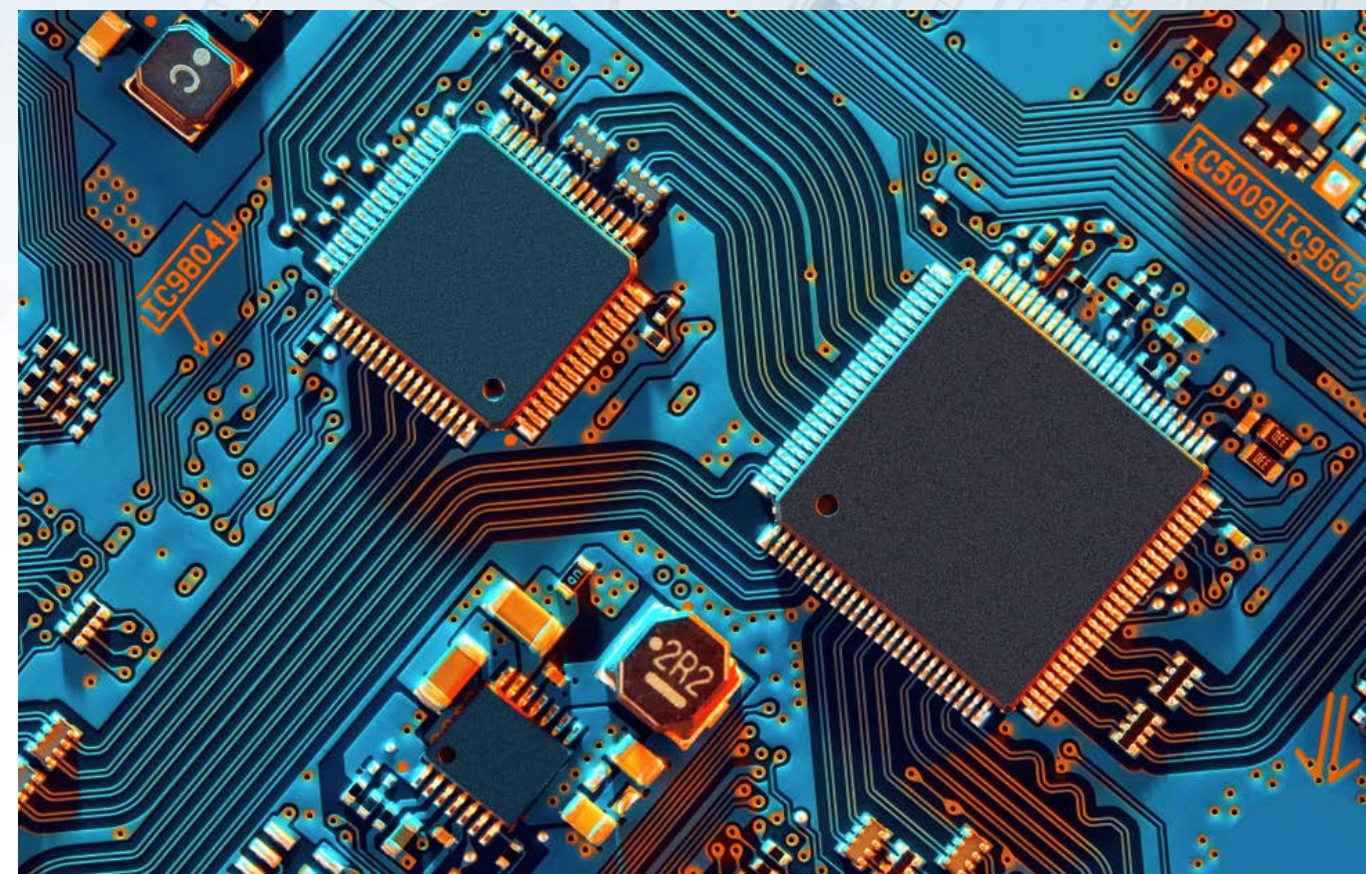
SiCPAK modules use "press fit" technology to provide small sizes for power circuits and offer cost-efficient, high-power solutions to consumers. The modules are constructed using GeneSiC die known for their exceptional performance, reliability and durability. An example is a SiCPAK half-bridge module featuring trench-assisted planar-gate SiC MOSFET technology, rated at 6 mΩ at 1,200 V.

Each SiC chip in the lead-free SiCPAK is bonded to the module's substrate using silver sintering to enhance cooling and reliability. The substrate is made of direct-bonded copper and produced utilizing an active-metal brazing method on silicon nitride ceramics, suitable for power-cycling uses. This structure provides exceptional strength and flexibility, fracture resistance and high thermal conductivity for dependable, durable and long-lasting performance.



Figure 3: GeneSiC SiCPAK module (Source: Navitas Semiconductor)

SEMICONDUCTORS



Recessed-Gate Technology Revamps E-Mode GaN Transistors



By Filippo Di Giovanni, contributing writer for Power Electronics News

The focus of power electronics (PE) is energy conversion from one form to another. Because the system designer's ultimate goal is efficiency and energy density maximization, PE must rely on continuous innovation in power semiconductors. Silicon has played a dignified role in the last four decades, but inherent limitations have prompted the development of new technologies like wide-bandgap devices, of which gallium nitride and silicon carbide represent distinct and respectable associates. In response to mounting interest in GaN, related to its undisputed benefits over silicon, feverish activities have flourished in terms of investments, acquisitions, strategic collaborations and industry consolidation.

GaN devices are based on AlGaIn/GaN heterostructures, which allow the creation of a two-dimensional electron gas (2DEG) with high mobility to achieve high current density, a key element for PE. Such a heterostructure is grown on very competitive 150-mm and 200-mm silicon substrates that are today manufactured in very high volumes and can also be integrated using the well-established silicon CMOS technology.

GaN HEMTs

GaN is a binary compound with one atom of gallium (Group III, Z = 31) and one of nitrogen (Group V, Z = 7) with a wurtzite hexagonal structure.

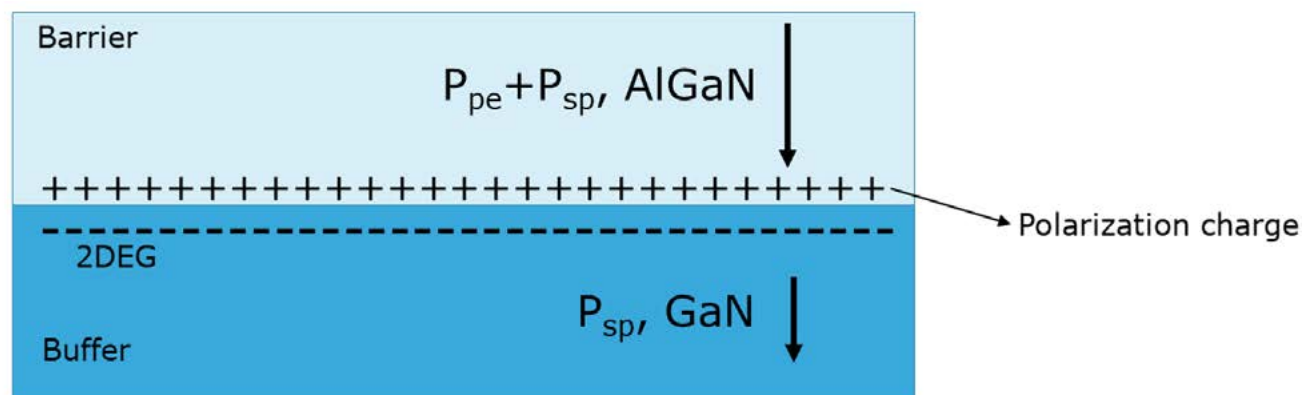


Figure 1: Simplified cross-section of GaN-AlGaN heterostructure

Gallium and nitrogen atoms are tied by a very strong ionic chemical bond that produces a large energy bandgap. This feature makes GaN very stable and well-suited to operate at high temperatures and in rough environments. Transistors—commonly exhibiting a lateral structure—built with this technology are called high-electron-mobility transistors (HEMTs). The HEMT owes its name to the low-resistance conductive channel formed by 2DEG at the interface of the AlGaN barrier and GaN buffer layers. 2DEG buildup can be understood with the help of Figure 1.

Nitrogen has a higher electronegativity—which quantifies a given atom’s propensity to attract a shared pair of electrons—than gallium and aluminum. Therefore, charge displacement causes electric spontaneous polarization (P_{sp}). On the other hand, mechanical stress and strain at the epi layers with different lattice constants¹ cause piezoelectric

polarization (P_{pe}). This happens because deformation favors the displacement of charged atoms within the crystal, producing a net electric dipole moment. P_{pe} is negative for tensile and positive for compressive strained AlGaN layers. Therefore, the orientation of the spontaneous and piezoelectric polarization is parallel in the case of tensile strain and antiparallel in the case of compressive strain. In AlGaN, the lattice constant is smaller than that of GaN. Therefore, AlGaN applies a strain on the GaN layer, resulting in additional P_{pe} .

The total polarization ($P_{sp} + P_{pe}$) of AlGaN is thus larger, which creates a net-positive charge at the AlGaN/GaN interface. Free carriers (electrons) that are generated at the heterointerface to neutralize fixed spontaneous and piezoelectric polarizations result in the formation of the 2DEG layer with very high electron mobility (in the range of 1,500 to 2,000 cm^2/Vs). This 2DEG is highly conductive, mainly by virtue of the



Figure 2: E-mode (normally off) HEMT realizations: p-gate (left) and recessed gate (right) (Source: STMicroelectronics)

confinement of the electrons within a very small region at the interface. As the mobility is higher, no doping is necessary, which minimizes ionized impurity scattering phenomena.

The 2DEG layer would yield a normally on (depletion-mode, or d-mode) switch—that is, with negative threshold voltage (V_{th}). To simplify the gate drive and make the transistor function safely as power electronic circuits typically demand, extra steps are needed to ensure the device can be off with 0 V applied to the gate. Figure 2 shows two general structures of an enhancement-mode (e-mode), or normally off, HEMT.

E-MODE HEMT

Figure 2 depicts two implementations of intrinsically normally off GaN HEMTs: p-gate (with Schottky gate contact) and recessed gate, respectively. A third option, not shown, consists of a d-mode HEMT in cascode configuration with a silicon low-voltage MOSFET, adopted by some suppliers.

Insulated-gate field-effect transistors with an insulated-gate dielectric provide desirable properties, such as diminished gate leakage and large gate-voltage swing. Metal-insulator-semiconductor FETs (MISFETs) attain e-mode operation by completely removing the AlGaN barrier layer under the gate through a local plasma-etch process so that the gate is turned off under zero gate voltage. When the gate voltage in a MISFET goes above the positive V_{th} , an accumulation layer of electrons is created underneath the gate interface, which restores the integrity of the 2DEG conductive channel so that the device can be turned on. A variant of the MISFET is represented by partially recessed-gate metal-insulator-semiconductor heterojunction FETs (MISHFETs).

Clearly, a very critical step in manufacturing MISFETs is the recess engraving. The most common etching techniques are inductively coupled plasma-reactive ion etching (ICP-RIE). This technology associates both chemical reactions and ion-induced etching, whereas the independent control of ion flux enables high flexibility. However, UV light in the plasma causes serious damage to the surface of the semiconductor, owing to the longer plasma irradiation time. The surface damage, in turn, leads to an increase in leakage current, V_{th} instability and current collapse (dynamic on-resistance increase). An alternative etching method that provides a high-quality interface after etching is dry atomic-layer etching (ALE). Self-limiting chemical modification affects only the top atomic layers of the wafer, and selective etching removes only the chemically modified areas, atomic layer after atomic layer. The ALE process can be used in place of ICP-RIE

to reduce the roughness of the gate-recess surface and further improve its trapping states at the interface.

INTEREST IN RECESSED-GATE HEMTs

Most of today’s GaN makers have opted for either cascode or p-gate. Consequently, the recent announcement by **CEA-Leti** over new milestones reached with the recess technology raises genuine interest and enhances market growth prospects. According to Omdia, a global analyst and advisory firm, the GaN market is set to reach \$3.89 billion in 2030, with a compound growth of 37% from 2022. Sectors benefiting from such market expansion are data centers—owing to an exponential increase in data traffic needed to power AI— and consumer applications like chargers, automotive and telecom. Big tech companies like Microsoft, Google and Meta are today fiercely competing to release products that use generative AI models to process and generate vast amounts of text and numeric data. Such models must rely on a lot of computing power, requiring gigantic server farms where chilled water and electricity are used to **cool down equipment**. The availability of ever-efficient GaN products is a real boon for building more eco-friendly power converters.

It is known that reliability issues afflict the conventional p-GaN gate structure, including a tendency to fail under even slight overvoltage. Experimentally, a time-dependent breakdown has been detected, which is induced by forward gate stress in GaN-based power HEMTs with a p-type gate, controlled by a Schottky metal/p-GaN junction. When a high stress voltage is applied on the gate, a large voltage drop and an electric field occur in the depletion region of the p-GaN close to the metal interface, promoting the formation of a percolation path. The mechanism of this degradation is compatible with a time-dependent dielectric breakdown: During a test at constant voltage in the off state, the gate current becomes noisy in the beginning, then suddenly increases several orders of magnitude.

Fully recessed MIS gate GaN power transistors, by contrast, offer a wider gate-voltage swing, improved gate reliability and lower gate-leakage current than p-GaN HEMTs.

CEA-Leti contributed to a number of advances, thanks to previous joint development efforts with STMicroelectronics.

There are a number of challenges to solve for getting all the advantages of the recessed-gate approach, though. MISFETs suffer from the deterioration of the channel mobility scattered by the rough surface of

SEMICONDUCTORS

the recessed area and electrically active defects. It is therefore important to optimize interfaces between the insulator and AlGaN/GaN to minimize interface trapping states and enhance current flow. Controlling the insulator charge is also crucial. The most recent developments in manufacturing processes at CEA-Leti have focused on:

- ▶ Wet cleaning, thermal treatment and plasma treatment to obtain a high-quality surface
- ▶ Low-impact etching and ALE for the gate recesses

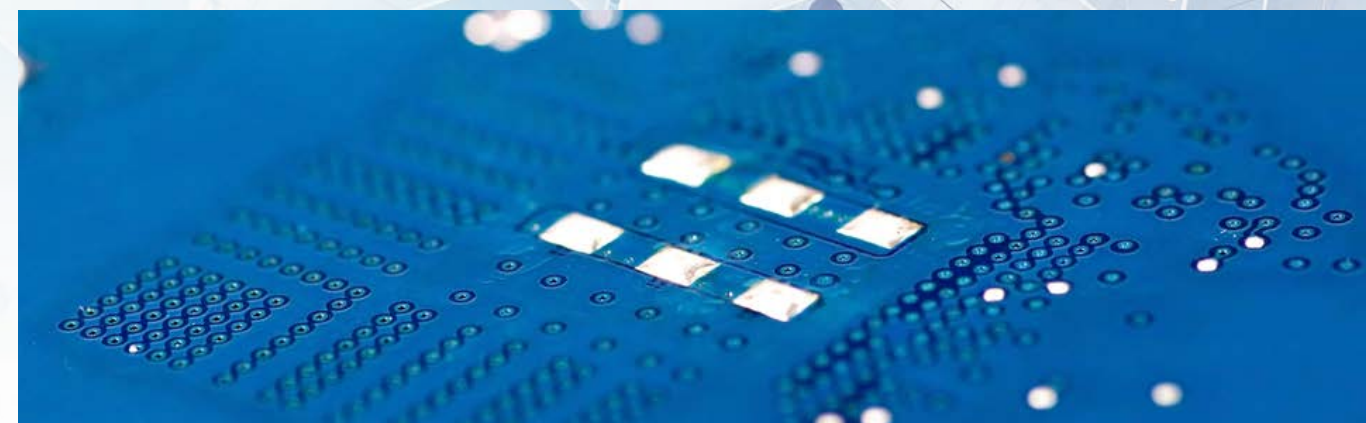
- ▶ Interface layers (AlN, in this case) to further reduce power losses
- ▶ Alternative materials for thin-film dielectric layers to improve reliability

All of these process steps—from surface preparation to etching and deposition of the dielectric layer—must be performed attentively to obtain the desired device specifications. Proper characterization of the damage induced by plasma-assisted etching and an industrially viable process integration present additional challenges that must still be addressed.



References

- ▶ **1**A lattice constant is related to the physical dimensions and angles that determine the geometry of the unit cells in a crystal lattice and is proportional to the distance between atoms.



SEMICONDUCTORS



Industry Leaders Discuss GaN and SiC Challenges and Applications

By Maurizio Di Paolo Emilio, editor-in-chief of Power Electronics News

At the APEC 2024 conference, held in February in Long Beach, California, Power Electronics News interviewed several major industry leaders on the latest advancements and applications of gallium nitride and silicon carbide technologies in the power electronics industry.

The author conducted interviews with the below six speakers during the event.

Experts on GaN technology:

- ▶ Robert Taylor, general manager of industrial applications at Texas Instruments
- ▶ Michael de Rooij, VP of applications engineering at EPC
- ▶ Balu Balakrishnan, CEO of Power Integrations

Experts on SiC technology:

- ▶ Ajay Reddy Sattu, director of the product marketing GIS business unit at onsemi
- ▶ Peter Friedrichs, VP of SiC at Infineon Technologies

- ▶ Ramanan Natarajan, product line marketing for power products at Qorvo

Topics discussed included semiconductor substrates and applications/markets.

MATERIAL SUBSTRATES

GaN

The first question submitted to the GaN experts was to elaborate on the significance of the choice of substrate material for GaN-based power devices and how researchers are addressing challenges related to substrates to improve device performance, reliability and manufacturability.

“At Texas Instruments, we are using traditional silicon substrates for our GaN devices,” Taylor said. “This allows us to not only ramp very quickly in terms of being able to get new devices out, but it also provides a significant cost advantage, since we’re able to use a lot of the manufacturing support staff facilities that we already have in place.”

According to Taylor, this substrate material is very well-understood and very easy to work with. TI thinks that this provides the company with a great advantage

in terms of being able to get out the latest and most advanced types of devices for many different applications.

“EPC makes devices from 15 V through 350 V using low-cost silicon substrate,” de Rooij said. “This is a good material because it is well-matched for the lattice structure to grow the gallium nitride.”

However, the challenges come with high-voltage devices due to thicker requirements for the heterostructure needed to meet the blocking voltage. According to de Rooij, for high-voltage devices, there are four alternative options: GaN, sapphire, SiC and QTS. GaN is an expensive material, but of course, it’s well-matched to GaN. Sapphire is less thermally conductive, so there are challenges to meet the thermal requirements, but it’s still a good match to the GaN lattice structure. SiC is an expensive material but a very good thermal conductor. QTS, an engineered material, is showing good promise, and it also has a good thermal performance and thermal expansion coefficient.

“The choice of materials in GaN directly relates to performance, cost and reliability,” Balakrishnan said. “We choose the substrate so that we can get the lowest cost, highest reliability and very high performance in terms of switching frequency and ability to go to higher voltages.”

Power Integrations has already announced a 1,250-V GaN device. As Balakrishnan said, that will allow the company to directly compete with SiC up to about 10- to 20-kW power levels.

SiC

According to onsemi, there are generally two types of defects affecting SiC substrates: killer defects and non-killer defects. The three areas where the defects can originate are substrate, polishing and epi. While the industry has probably dissolved many of the killer defects that are generally seen in the substrates, the non-killer defects after epi are the ones that can escape.

“What we have done at onsemi is develop many algorithm-based methods to screen out these devices as the material progresses through the fab,” Sattu said. “In addition to that, we have shorter feedback loops from the substrate and from the epi point of view during the device manufacturing.”

“We have already reached very good silicon carbide substrate quality,” Friedrichs said. “We are moving from 150 mm to 200 mm, and with the transition to the new wafer diameter, we see a very good status regarding defect density.”

According to Friedrichs, one of the key topics for further material improvement is lower defect densities. The second topic regarding materials is that the mechanical properties of some modern wafers are still more silicon-like, meaning better flatness, local thickness variations and topics we need in order to use sophisticated technologies. This should be the target for the next steps.

APPLICATIONS AND MARKETS

GaN

“In terms of GaN devices for specific applications, the biggest one that we see currently is in server power supplies,” Taylor said. “Within those data centers, the server PSU is a prime example of where GaN can have a significant advantage over silicon.

“That enables us to use different topologies that were no longer achievable before with silicon, which allow us to boost power, density and efficiency inside of those systems,” he added.

According to TI, another huge market for GaN is solar applications, mainly microinverters. GaN can also play a relevant role in automotive, with 400-V or 800-V systems as well.

According to EPC, GaN makes a difference in various applications, such as DC/DC converters, automotive, motor drives and LiDAR systems. In DC/DC converters, EPC has been primarily focused on 48- to 12-V conversion, being able to shrink down converters dramatically compared with silicon devices and achieving very high performance. Automotive applications include vehicle electrification.

“For higher voltages, GaN is also demonstrated to be a very good device for LiDAR systems, where it achieves enhanced performances and very fast switching rates that cannot be achieved with silicon devices,” de Rooij said.

“In motor drives, GaN can switch them at higher frequency, which yields cleaner sinusoidal excitation of the motor,” he added. “That significantly reduces the torque ripple on motor and can improve mechanical efficiency between 11% and 14%. You can also eliminate many large and bulky components for filtering and simply use ceramic capacitors.”

“For power applications below 30 W, we use GaN,” Balakrishnan said. “That applies to products that go into adapters, which is our early use of GaN. Going forward, we are using it in consumer applications. But we will be offering products for higher power levels, like a few kilowatts.”

These higher-power applications include server power supplies, infrastructure for 5G stations, on-board chargers and DC/DC converters for automotive. According to Power Integrations, any power converter below 10 or 20 kW can be addressed with the technology we have already developed. GaN is not quite ready to go to higher-power levels like 100 or 200 kW.

“GaN will be equal or less than silicon within maybe one or two years,” Balakrishnan said. “GaN has a bright future relative to silicon carbide as the power levels go up and is able to address several hundreds of kilowatts, which is the prime market for silicon carbide today.”

SiC

According to onsemi, the main applications of SiC are in automotive. These include traction inverters, on-board chargers and high-voltage DC/DC converters. In the industry sector, SiC applications include DC fast chargers, UPSes, energy storage and solar.

For on-board chargers and high-voltage DC/DC converters, high power density is a must. To meet these requirements, onsemi has developed the M3S SiC MOSFET technology that achieves high power density and high switching frequency for automotive, motor drives, industrial, UPSes, energy storage systems and solar applications.

“All the applications where power density and high efficiency are extremely important are the ones which have already a very large penetration with silicon carbide,” Friedrichs said. “However, we intend to serve all the markets interested in silicon carbide. These include traction propulsion, motor drives, servo motor drives, UPSes and system power supplies.”

According to Natarajan, SiC devices have energized the power conversion world. They bring benefits over silicon devices, such as higher switching frequency, lower on-resistance and higher efficiency.

“In Qorvo, we are primarily focused on a broad set of industrial applications, such as battery chargers, battery test equipment, test and measurement equipment, renewable energy applications like solar inverters, energy storage systems and, of course, electric vehicles, charging stations, on-board chargers and DC/DC converters,” Natarajan said.

These applications are adopting SiC for a variety of reasons. Data center power suppliers want to reduce the operational expenses of the data center. EV manufacturers want to charge their cars faster and make their vehicles lighter. Renewable energy applications need to be able to run at higher temperatures and have a longer lifetime and higher efficiency with their products. According to Natarajan, it’s a thrilling time to be in power electronics and power semiconductors, and wide-bandgap devices like SiC are paving the way.

Wine Down Friday with Maurizio



NEWS

ST introduces new automotive synchronous buck converters for light-load, low-noise, and isolated applications

These automotive-qualified converters save space and ease integration in car body electronics, audio systems, and inverter gate drivers..

STMicroelectronics has unveiled automotive-qualified step-down synchronous DC/DC converters that offer space-saving benefits and facilitate integration in many applications, such as body electronics, audio systems, and inverter gate drivers.

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SiCrystal, a ROHM group company, and ST extend their agreement for SiC substrate wafers supply

The new multi-year agreement governs the supply of larger volumes of SiC substrate wafers manufactured in Nuremberg, Germany.

ROHM and STMicroelectronics have announced the extension of their current long-term deal with SiCrystal, a firm within the ROHM group, to supply 150 mm silicon carbide (SiC) substrate wafers.

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Virtual Forest to use Navitas' GaNFast power ICs to advance net-zero in agriculture

Navitas' GaNFast technology drives Virtual Forest's solar-powered irrigation pumps, ensuring food security and empowering Indian farmers.

Navitas Semiconductor has announced that Virtual Forest, a prominent electronics design company in India that specializes in motor control and human interface technologies for consumer appliances, fluid movement, and mobility, has chosen to use its GaNFast™ power integrated circuits (IC) technology for a high-performance 3 hp (2,250W) solar-powered irrigation pump with zero emissions.

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Infineon supplies silicon carbide (SiC) power modules to Xiaomi new SU7 smart EV

In addition to silicon carbide devices, Infineon will provide to Xiaomi EV further components such as microcontrollers and gate drivers.

Infineon Technologies has been selected to supply silicon carbide (SiC) power modules, specifically the HybridPACK™ Drive G2 CoolSiC™ and bare die products, to Xiaomi EV for their newly unveiled SU7 model until 2027. Infineon's power modules, which are based on CoolSiC technology, enable operation at elevated temperatures, leading to exceptional performance, driving characteristics, and lifespan.

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Remtec's Chandra Gupta highlights ceramic technology at APEC 2024 (Long Beach, CA)

At APEC 2024 in Long Beach, CA, Remtec's Business Development Manager, Chandra Gupta, had an opportunity to speak at the company's booth with Majeed Ahmad, Editor in Chief for EDN and Planet Analog, about technologies Remtec featured at the expo.

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Experts Weigh in on GaN & SiC at APEC 2024

Welcome to APEC 2024, where leading minds converge to discuss the latest advancements in power electronics. In this video, a lineup of distinguished speakers from semiconductor companies shares insights into groundbreaking developments in gallium nitride- and silicon carbide-based power devices.

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ASPENCORE

AspenCore Media GmbH
245 Main Street, 2nd Floor
Cambridge, MA 02142
Cyrus Krohn, Vice President,
Publisher, AspenCore

Editorial Contact

Maurizio Di Paolo Emilio, Ph.D.
Editor-in-Chief
maurizio.dipaolo@aspencore.com

Lori O'Toole, Chief Copy Editor
lotoole@aspencore.com

For Reader Inquiries please contact:

info@powerelectronicsnews.com

Contact for Advertising

Anthony Martinez
anthony.martinez@aspencore.com

Editorial Design

Hyperbold Studio
www.hyperbold.it

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The AspenCore Guide to

Silicon Carbide

Silicon Carbide (SiC), a wide-bandgap semiconductor, is driving a profound transformation of power electronics and clean energy systems. This 145-page guide offers a detailed analysis of the market trends and an in-depth discussion of key aspects of SiC power technology.



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