POWER ELECTRONICS WORLD

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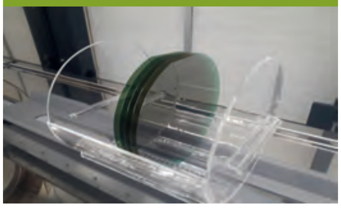
Greener SiC wafer with Smart-Cut technology



Understanding current transformer design

Setting its sights on SiC

Integrating electrified power

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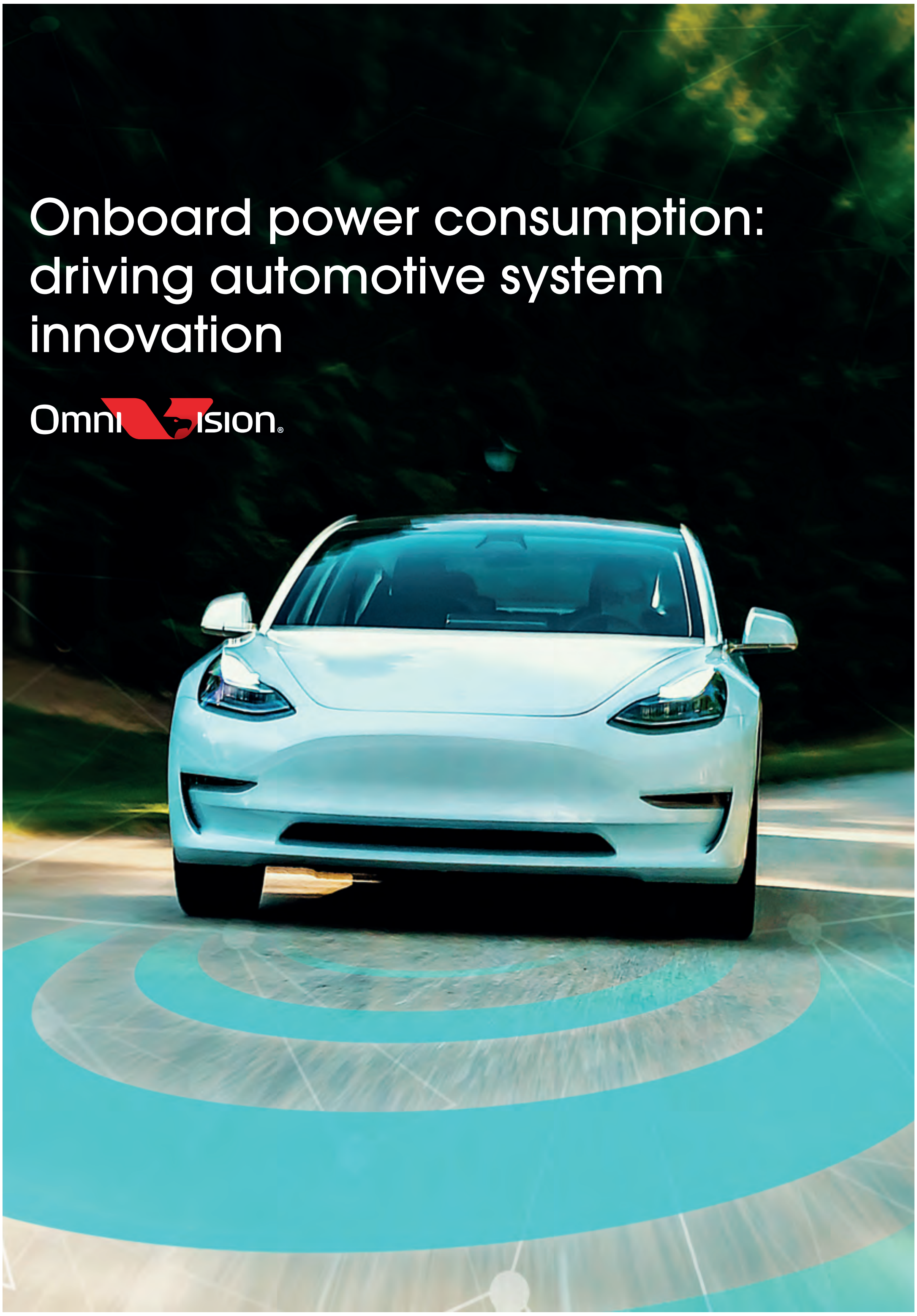
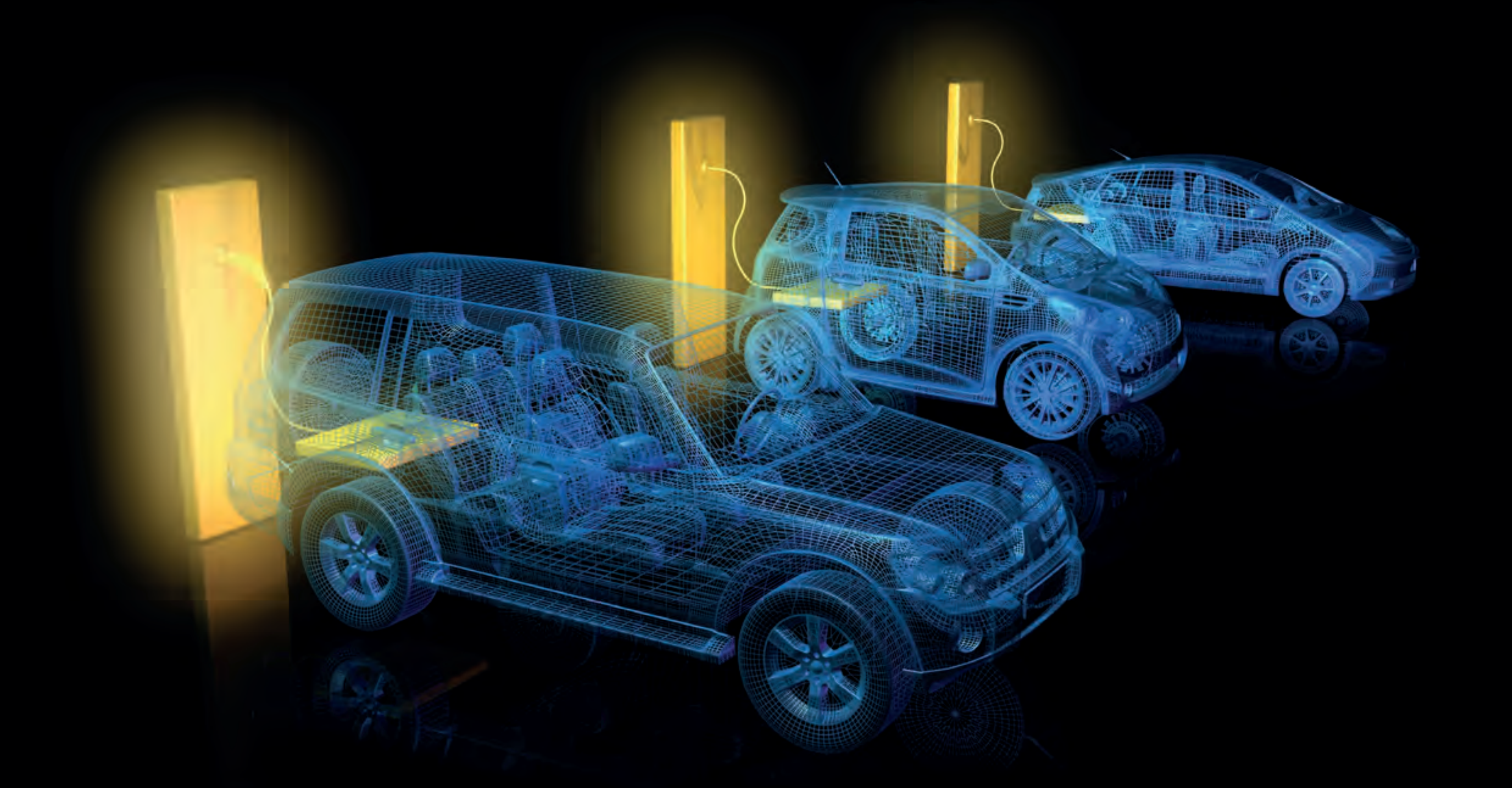
Onboard power consumption: driving automotive system innovation





editor's view

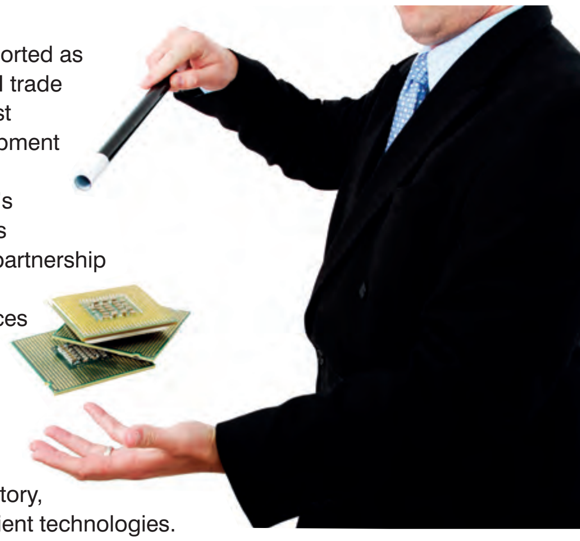
By Mark Andrews, Technical Editor

End chip shortages overnight? **All it takes is a magic wand**

IF YOUR COMPANY is part of the semiconductor supply chain you can't miss the drumbeat of oh-so-simple and often unrealistic solutions for ending chip shortages coming from pundits who have little to no idea how a fab operates. We have heard: just make more chips; on-shore manufacturing; add capacity. They're all appealing, yet none can end shortages in the near term.

Some commentators almost make it sound as if solving the shortage should be as simple as tossing another log on a fire. Add capacity? Sure—semiconductor fabs only cost about a billion euros; they take three or more years to build, another year to qualify equipment and 'just' another 12-18 months to achieve profitable yields. The same applies to on-shoring manufacturing or building more devices in plants that are already operating 24/7.

While not a solution, the shortage has at least focused attention on a critical part of the global economy—the supply chain—and ways to build resiliency. Everyone wants to get busy. There are efforts to build more chips within the US, yet Intel still needs a year-plus to open its newest Southwest fab. TSMC's US project has yet to break ground. The EU also seeks to ensure supply / increase competitiveness through its European Chips Act. All will take time. For now, some manufacturers are making do while others redesign systems using ICs they can find while existing fabs work to squeeze ever drop of efficiency from already fine-tuned processes.



In positive news reported as 2Q ended, the SEMI trade organization forecast manufacturing equipment sales to crest $100 billion by year's end. General Motors announced its SiC partnership with Wolfspeed to provide power devices for future EVs; GlobalFoundries is preparing to go public and GaN devices continue to march into new territory, displacing less efficient technologies.

In this edition of Power Electronics World we take a detailed look at the challenges of industrial electrification amidst new and better battery options.

We explore ways that automotive suppliers are partnering to create more energy efficient digital camera systems. We look at ways that current transformers can be valuable additions to many systems and how SiC MOSFETS are key to next generation Infineon power tech.

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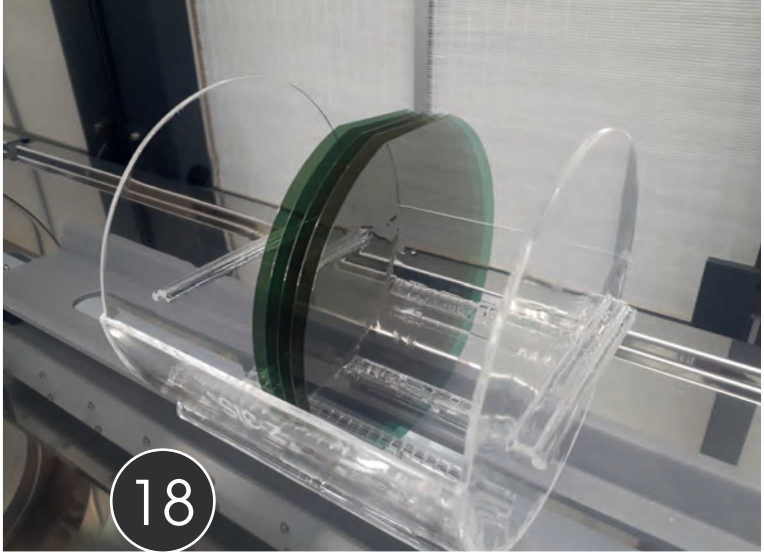


news

General Motors and Wolfspeed forge SiC agreement

GENERAL MOTORS and Wolfspeed (formerly Cree) have announced a strategic supplier agreement to develop and provide SiC power device solutions for GM's future electric vehicle programs. Wolfspeed's SiC devices will enable GM to install more efficient EV propulsion systems that will extend the range of its rapidly expanding EV portfolio.

The SiC will specifically be used in the integrated power electronics contained within GM's Ultium Drive units in its next-generation EVs. As a part of the agreement, GM will participate in the Wolfspeed Assurance of Supply Program (WS AoSP), which is intended to secure domestic, sustainable and scalable materials for EV production.

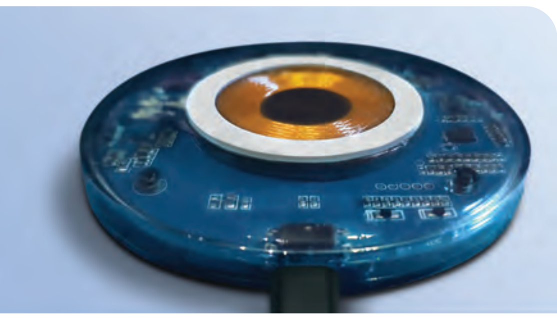
"Our agreement with Wolfspeed represents another step forward in our transition to an all-electric future," said Shilpan Amin, GM vice president, Global Purchasing and Supply Chain. "Customers of EVs are looking for greater range, and we see SiC as an essential material in the design of our power electronics to meet customer demand. Working with Wolfspeed will help ensure we can deliver on our vision of an all-electric future." "Our agreement with GM further demonstrates the automotive industry's commitment to delivering innovative EV solutions to the market and using the latest advances in power management to improve overall vehicle performance," said Gregg Lowe, CEO of Wolfspeed. "This agreement ensures long-term supply of SiC to GM to help them deliver on their promise of an all-electric future."

The SiC power device solutions will be produced at Wolfspeed's 200mm-capable Mohawk Valley Fab in Marcy, New York, which is the world's largest SiC fabrication facility. Launching in early 2022, this state-of-the-art facility will dramatically expand capacity for the company's SiC technologies, which are in increasing demand for EV production and other advanced technology sectors around the world.

The widespread adoption of SiC as an industry standard semiconductor for transportation supports the automotive industry's rapid transition to clean energy vehicles. SiC enables greater system efficiencies that result in longer EV range while lowering weight and conserving space. Wolfspeed's technology is fueling electric propulsion systems across the entire voltage spectrum – from 400V to 800V – and beyond.

SiTime enables up to 25% faster wireless charging

SiTIME CORPORATION, in MEMS timing, has introduced the SiT3901 μPower digitally controlled MEMS oscillator (DCXO) targeting power-sensitive and space-constrained mobile and IoT applications. The SiT3901 improves wireless charging speed by up to 25% while reducing the overall timing solution area by up to 90%. The MEMS oscillator is ideal for wireless charging systems for smartwatches, activity trackers, hearing aids, and wearables.



"As electronics evolve, SiTime's combination of innovative MEMS, programmable analog, and rapid release methodology continues to solve challenging timing problems quickly," said Piyush Sevalia, executive vice president of marketing at SiTime. "The power and size requirements of new wireless applications demand a new approach to timing. The SiT3901 DCXO is the industry's first μPower digitally controlled oscillator, and it delivers by improving charging efficiency and reducing the area."

Wireless charging standards such as Qi and AirFuel rely on resonant power transfer to enable proximity charging. However, environmental interference may dynamically impact the resonant charging frequency, which slows down the charging process. The SiT3901 enables the charger to dynamically tune the resonant frequency, maximizing power transfer and delivering up to 25% faster charging.

The digital control feature on the SiT3901 DCXO eliminates the need for additional passive components on the board, reducing the timing solution area by up to 90%. The resulting charging system works better and is smaller, more manufacturable, and more reliable.

Microchip adds support for SiC MOSFETs

AS DEMAND for electric buses and other electrified heavy transport vehicles increases to meet lower emission targets, SiC-based power management solutions are providing greater efficiencies in these transportation systems.

To complement its broad portfolio of SiC MOSFET discrete and module products, Microchip Technology has announced a new 1200V production-ready digital gate driver, providing system developers with multiple levels of control and protection for safe, reliable operation and qualified to stringent transportation requirements.

For designers of SiC-based power conversion equipment, Microchip's AgileSwitch® 2ASC-12A2HP 1200V dual-channel digital gate driver with its Augmented Switching™ technology is production qualified and fully configurable. To ensure reliable, safe operation, the 2ASC-12A2HP gate driver provides multiple levels of control and a higher level of protection for SiC MOSFET-based power systems. When compared to conventional gate drivers, key performance attributes of the AgileSwitch gate driver products include the ability to dampen drain-source voltage (Vds) overshoots by up to 80% and slash switching losses by as much as 50%. The 2ASC-12A2HP digital gate driver can source/sink up to 10A of peak current and includes an isolated DC/DC converter with low capacitance isolation barrier for pulse width modulation signals and fault feedback.

Microchip's 2ASC-12A2HP gate driver is compatible with the company's latest release of the Intelligent Configuration Tool (ICT). This interface allows users to configure gate driver parameters including the gate switching profiles, system critical monitors and controller interface settings. The result is a gate driver that is tailored to their applications without having to change hardware, helping to speed development time from evaluation through production and enabling designers to change control parameters during the design process. The ICT, which is a free-of-charge download, can save designers approximately three to six months of development time on new designs.

"The societal trend toward electrification of all vehicles including buses, trains, trams and agriculture transportation hinges on innovative power electronic solutions to get more productivity from less energy," said Leon Gross, vice president of Microchip's discrete product business unit. "When combined with our SiC power devices, this gate driver technology enables engineers to achieve new levels of power density in transportation systems and industrial applications."

In addition to commercial vehicles, other applications include charging infrastructure, energy storage systems, solar inverters and aircraft flight actuators. Microchip's 2ASC-12A2HP gate driver is compatible with the company's broad portfolio of SiC power devices and modules and is interoperable with other manufacturers' SiC products. The company's combination of SiC power modules and digital gate drivers enables designers to influence dynamic issues including voltage overshoot, switching losses and electromagnetic interference. Microchip provides SiC MOSFET avalanche and short-circuit ruggedness alongside total system solutions designed to streamline development from benchtop to production.

NREL and John Deere collaborate on SiC performance

A STATE-OF-THE-ART thermal management system developed by the US National Renewable Energy Laboratory (NREL) in collaboration with John Deere promises to significantly increase the power density of SiC inverters within heavy-duty EV applications.

Within heavy-duty applications, the power inverter is responsible for controlling the power flow between DC and AC electrical systems in order to run vehicle systems, accessories, and electric machines, such as motors and generators. A high-efficiency inverter is a critical component necessary for environmentally friendly vehicle alternatives that reduce greenhouse gas emissions such as hybrid, full electric, or fuel cell vehicles. Recent studies indicate that the improved inverter design boasts a 378 percent increase in power density over the previous silicon-only inverters.

"The key to NREL's design innovations for SiC thermal management is to improve the heat transfer coefficient, which allows this system to cool itself efficiently and continuously during operation with the engine coolant," said Kevin Bennion, NREL senior researcher and thermal management expert. "This design facilitates an unmatched power density and keeps the system running safely and efficiently."

The SiC inverter thermal management system was tested in John Deere hybrid loaders, similar to the one pictured above.

In general, heavy-duty vehicles demand more power and far higher torque during operation than the average light-duty sedan. NREL's leading research in wide-bandgap power module thermal management helped reduce component footprint, improve performance and efficiency, and support higher-frequency operation of SiC inverters for heavy-duty applications.

However, power outputs rely on the maximum temperature limits of the inverter's power module, which runs the risk of overheating and shutting down. As a result, NREL researchers developed a state-of-the-art thermal management system to optimize system efficiency while regulating operating temperatures of the SiC modules directly cooled with 115°C water-ethylene glycol coolant. The technology developed by the NREL team has been extensively evaluated by the John Deere engineering team led by Brij Singh.

"Starting in 2015, NREL's contributions have been extremely valuable in the successful execution and completion of impactful tasks in the DOE-funded PowerAmerica project with John Deere," Singh said. "This project has resulted in the in-vehicle demonstration of the high-temperature SiC inverter technology."

A Simplified Solution To Optimise Heat Transfer

A common strategy for the thermal management of EV inverters is to run a fluid coolant parallel over the component's surface to transfer heat and cool the system quickly. The advanced system designed at NREL incorporates perpendicular jet flow with mini-channel- and mini-manifold-based cooling systems to extract heat from the inverter and power module. This design enables an impressive heat-transfer coefficient—as high as 93,000 watts per square meter per degree Kelvin (W/[m2-K]) which is over four times higher than current commercial systems.

In addition, the NREL design uses the existing diesel engine cooling system for a simplified engine-coolant-capable architecture. Conventional heavy-duty inverters require a separate coolant system to operate successfully while ensuring the inverters' durability.

By eliminating the need for a separate cooling circuit, NREL's novel thermal and thermomechanical research contributed to the inverter achieving a staggering 43 kilowatts per liter power density. This is a 378% improvement over baseline silicon systems.

Real-World Improvements in Fuel Efficiency

The thermal and mechanical innovations in the SiC design significantly reduced the inverter footprint, creating a smaller and lighter system. The lighter overall weight and improved performance have clear benefits to fuel efficiency and operating costs.

"The SiC inverter technology stands out among all competing technologies in terms of energy efficiency, fuel economy, performance, and system integration," Bennion said. "With the premium cost of the SiC power converter, the market adoption of this new technology will likely take place where those factors are more important than the initial cost. We believe this inverter will have significant impacts in heavy-duty machinery, aviation, and military applications."

EPC eGaN FET helps Innosonix boost audio power

IDLE POWER CONSUMPTION and overall efficiency were key concerns of Innosonix GmBH when designing its latest high-end Maxx Series multi-channel power amplifier. By changing from traditional silicon FETs to EPC's EPC2059 eGaN FET the company reduced idle loss by 35 percent and lowered the on resistance to increase the total power efficiency by 5 percent.

The EPC2059 is a 6.8 mΩ, 170 V eGaN transistor offering superior audio performance for high-end amplifier applications. The low on resistance and low capacitance of the EPC2059 enables high efficiency and lowers open loop impedance for low Transient Intermodulation Distortion (T-IMD). The fast-switching capability and zero reverse recovery charge enable higher output linearity and low cross over distortion for lower Total Harmonic Distortion (THD).

By using the EPC2059 eGaN FET, innosonix was able to decrease the idle switching loss as the total gate charge was nearly reduced by half. The output capacitance only doubled for tripling the max drain voltage enabling Innosonix to switch from a full-bridge to a half-bridge design, which also reduced component count costs. The low package inductance gives a clean switching waveform which leads to a nearly perfect switching voltage and, therefore, better linearity.

This resulted in a reduction in harmonic distortion of almost 6dB and the subjective audio quality has improved audibly, to benefit customers.

The MAxx multi-channel power amplifiers mark an unprecedented standard for high-end audio installations in residential, science, industry and many other applications where high channel count is required. Paired with an unseen low power consumption per channel, the MAxx series perfectly fits the modern world's requirements to reduce CO2 emissions since many devices are running 24 hours a day, seven days a week. The MAxx series will offer the highest channel count per rack space in one single unit. This high-density package offers a completely new design perspective not possible with conventional solutions.

"We are delighted to be working with EPC. As a small company, it's not always easy to do business with some large semiconductor manufacturers and to be taken seriously. We chose the EPC2059 eGaN FET as it perfectly matches innosonix's voltage current and price requirements and its' small form factor is an impressive feature for designing high-density circuits", commented Markus Bätz, CEO, innosonix.

Wolfram Krüger, EPC's VP sales Europe added: "This application is a great example of the real benefits that GaN brings and, together with our distriubtion partner FinePower, we have worked closely with innosonix to find the best eGaN FET to meet the design challenges that the Maxx power amplifier brings."

UnitedSiC announces best 6mΩ SiC FET

UnitedSiC, a manufacturer of SiC power semiconductors, has responded to the power designer's requests for higher-performance, higher-efficient SiC FETs with the announcement of the industry's best 750V, 6mΩ device.

At a $RDS_{(on)}$ value of less than half the nearest SiC MOSFET competitor, the new 6mΩ device also provides a robust short-circuit withstand time rating of 5µs.

The announcement includes nine new device/package options in the 750V SiC FET series, rated at 6, 9, 11, 23, 33, and 44mΩ. All devices are available in the TO-247-4L package while the 18, 23, 33, 44, and 60mΩ devices also come in the TO-247-3L. Complemented by the already available 18 and 60mΩ devices, this 750V expanded series provides designers with more device options, enabling more design flexibility to achieve an optimum cost/efficiency trade-off while maintaining generous design margins and circuit robustness.

Gen 4 SiC FETs from UnitedSiC are a 'cascode' of a SiC JFET and a co-packaged silicon MOSFET. These together provide the full advantages of wide band-gap technology - high speed and low losses with high temperature operation, while retaining an easy, stable, and robust gate drive with integral ESD protection.

The advantages are quantified by Figures of Merit (FoMs) such as RDS(on) x A, a measure of conduction losses per unit die area. Gen 4 SiC FETs achieve the lowest values in the market at both high and low die temperatures. FoM RDS(on) x EOSS/QOSS is important in hard-switching applications and is half the nearest competitor value. FoM RDS(on) x COSS(tr) is critical in soft-switching applications and UnitedSiC device values are said to be around 30 percent less than competitor parts, rated at 650V compared with UnitedSiC's at 750V.

For hard switching applications, the integral body diode of SiC FETs is superior in recovery speed and forward voltage drop to competing Si MOSFET or SiC MOSFET technologies.

Other advantages incorporated into the Gen 4 technology are reduced thermal resistance from die to case by advanced wafer thinning techniques and silver-sinter die-attach. These features enable maximum power output for low die temperature rise in demanding applications.

With their latest improvements in switching efficiency and on-resistance, the new UnitedSiC SiC FETs are ideal for challenging, emerging applications. These include traction drives and on- and off-board chargers in electric vehicles and all stages of uni- and bi-directional power conversion in renewable energy inverters, power factor correction, telecoms converters and AC/DC or DC/DC power conversion generally. Established applications also benefit from use of the devices for an easy boost in efficiency with their backwards compatibility with Si MOSFET and IGBT gate drives and established TO-247 packaging.

As Chris Dries, president and CEO of UnitedSiC states: "The UnitedSiC Gen 4 SiC FETs are unquestionably the performance leaders within competing technologies and set a new benchmark in wide bandgap switch technology. The new range additions now provide further options for all performance and budget specifications, and a wider range of applications."

Pricing (1000-up, FOB USA) for the new 750V Gen 4 SiC FETs range from \$4.15 for the UJ4C075044K3S, to \$23.46 for the UJ4SC075006K4S. All devices are available from authorised distributors.

Axcelis ships family of SiC implanters

AXCELIS TECHNOLOGIES, a US-based upplier of ion implantation solutions, has announced shipments of the company's full family of Purion SiC Power Series implanters to several leading power device chipmakers located in Asia and Europe.

The shipments include follow on orders for the Purion H200 Power Series SiC high current implanter and the Purion M Power Series SiC implanter, as well as a Purion XE Power Series SiC high energy implanter, which is a new evaluation tool to a new customer. The systems shipped in the third quarter and will be used in high volume production of SiC power devices supporting automotive, mobile and the IoT markets.

Executive VP of product development, Bill Bintz, commented: "The growing momentum in the electrification of the automotive industry is driving a strong demand for SiC power devices, and Axcelis is the only company with a complete family of ion implanters to support this transition. Our leadership position in the power device market continues to grow due to the Purion SiC Power Series platform's common and flexible architecture, coupled with its highly differentiated silicon carbide process capabilities. We look forward to supporting our customers' goals to improve power device performance and expand manufacturing capacity, by providing innovative, segment-focused Purion products that solve customers' high value, high impact emerging implant challenges."

Vincotech rolls out online simulation tool

VINCOTECH, a supplier of module-based solutions for power electronics, has unveiled VINcoSIM, its new online simulation tool.

The latest in a long line of Vincotech simulation environments, VINcoSIM is the first simulator to launch from a webpage. It features leading-edge topology modeling and a remarkably accurate, proven loss and temperature calculation engine. Users can even define custom heatsink builds in a one-step configuration. A click or two is all it takes to quickly assess the options and choose the best fit.

"This tool is a great leap forward," says Vincotech CEO Eckart Seitter. "As a reliable partner, we aim to bring speed and flexibility to our business relationships. Part of that is helping customers make fast but well-informed decisions. We have always gone to great lengths to provide accurate, reliable simulation tools. And VINcoSIM is our most powerful and convenient power module selection tool yet."

The company's first ISE simulation tool debuted 20 years ago, setting a benchmark for customer support in the power module business.

Drawing on two decades' experience advancing the state of the art in simulation tools, the company has now created an easy-to-use environment to rapidly test and evaluate any of its power modules, regardless of sub-topology or components. No compromises in functions or features is demanded.

Designed to fast-track simulations, VINcoSIM configures automatically when the user selects a product on the website. It is the only tool of its kind to simulate any type of topology, even the most advanced. VINcoSIM runs on substantiated data from measurements taken in high-tech labs. It is reliable; its results are accurate.

The user interface has been designed to be as easy-to-use as possible. Specifications are submitted in a single configuration step. VINcoSIM delivers results in a matter of seconds, presenting all information for users to take in at a glance. It marks a milestone achievement in customer support, and that satisfying experience will only get better as VINcoSIM evolves and advances.

Infineon tech powers Sungrow PV inverter

INFINEON'S EasyPACK power modules equipped with the newly released CoolSiC MOSFET (the latest generation CoolSiC diode along with the latest TRENCHSTOP chip technologies) provide the technology behind a new 1500V PV string inverter SG350HX developed by Sungrow.

Sungrow's inverter features a maximum output power of 352 kW and compared to its last generation inverter, the new inverter offers an increase in output power of about 40 percent.

"Sungrow is dedicated to paving the way for global carbon neutrality with growing technical innovations. We are accelerating our steps to fulfill the corporate mission of 'Clean power for all'," said James Wu, VP of Sungrow. "To make this possible, the new SG350HX redefines the super-high power string inverter and helps Sungrow's customers to reduce the cost of energy."

"We are very pleased to continue our successful collaboration with Sungrow and leverage our technology expertise in the area of renewable energy," said Dr. Peter Wawer, president of the Industrial Power Control Division of Infineon. "Leveraging our expertise on technology and production allows us to tailor solutions based on customer needs while giving full support during ramp-up."

The inverter supports a DC/AC ratio of up to 1.8 and is highly compatible with 182 mm and 210 mm large-sized high-efficiency modules with a maximum input current of 20 A. This allows to use solar modules with power ratings of 600 W and higher. The device can operate stably in extremely weak grid conditions.

Weighing 110 kg, the inverter features twelve MPPTs (Maximum Power Point Tracking) at 40 A. With two strings connecting to one MPPT, there is no threat of a string reverse connection. Each one helps to increase the power density by approximately 28 percent compared to the previous generation. Thanks to smart-forced air-cooling technology and IP66 protection, the solution can be installed in harsh conditions.

Navitas expands into China

GaN CHIP COMPANY Navitas Semiconductor has opened a new office in Shenzhen, China which offers a 300 percent increase in capabilities to support high revenue growth in that region.

The state-of-the-art facility offers significant engineering capacity for Navitas to co-develop GaN-based power systems with customers and design partners. This investment supports the rapid growth of GaN mobile fast chargers, as well as the company's recently-announced expansion plans to enable GaN-based data centres, solar installations and electric vehicles, which represent a multi-$B market opportunity for the company.

Navitas' GaNFast power ICs integrate GaN power and drive plus protection and control to deliver simple, small, fast and efficient performance. With over 130 patents issued or pending, and significant trade secrets including a proprietary process design kit (PDK), Navitas believes it has a multi-year lead in next-generation GaN power ICs.

Data centre upgrades from legacy silicon to GaN are estimated to save almost $2B/year in electricity costs, while GaN adoption in solar microinverters has been estimated by Enphase Energy to enable 10x faster switching and a significant reduction in costs. Per-vehicle GaN content in passenger EVs is estimated as $50 for on-board fast chargers, $15 for DC-DC converters and then up to $200 for later adoption in traction drive.

"Alongside Hangzhou and Shanghai, the new state-of-the-art Shenzhen office is another, significant addition to Navitas China," said Charles (Jingjie) Zha, VP and general manager of Navitas China. "Chinese demand for next-generation power systems is growing exponentially and with the world's only fully-integrated GaN power ICs, Navitas is in a fantastic position to capitalize on that growth. The new facilities demonstrate our commitment to support expanded customer demands in China."

Navitas' new office is in the Baidu International Building, in the high-density Nanshan District. The building won the Council on Tall Buildings and Urban Habitat 2019 award for sustainable and healthy cities. Navitas estimates that each GaN power IC shipped saves 4kg of CO2 emissions vs. legacy silicon chips.

Rohm extends partnership with Chinese EV maker

ROHM, together with Geely Automobile Group, a Chinese automobile manufacturer, have entered into a strategic partnership to develop advanced technologies in the automotive field.

Both companies have been collaborating on a variety of automotive applications since 2018, when they first agreed to carry out technical exchange. This partnership is expected to further promote cooperation and accelerate innovation for automotive applications.

Geely is working to extend the cruising range of electric vehicles while reducing battery costs and shortening charge times by developing high efficiency traction inverters and onboard charging systems that adopt Rohm's advanced power solutions centered on SiC power devices.

At the same time, Geely is committed to improving user experience through the development of high performance ADAS and intelligent cockpit systems using a wide range of products and solutions, including communication ICs and discrete devices.

As a first step, traction inverters equipped with Rohm's SiC power devices are being integrated in electric vehicle platforms currently being developed by Geely.

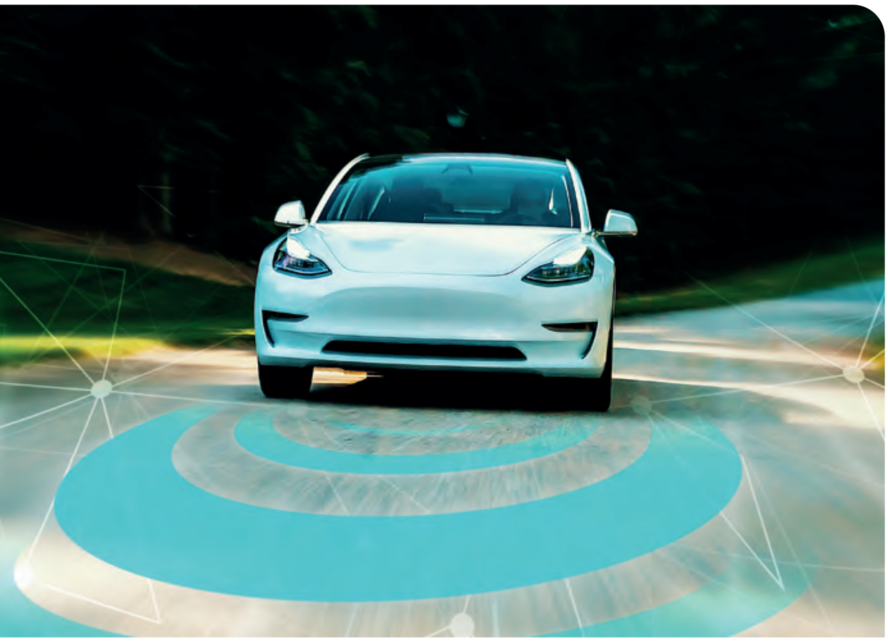
Through this partnership, Rohm and Geely will contribute to sustainability by promoting the development of low carbon technologies in the automotive industry and offering solutions for achieving greater safety and security in our increasingly mobility society.

Addressing onboard power consumption is driving automotive system innovation

The power consumption of onboard electrical and electronic systems is a hot topic for manufacturers as automobiles morph into rolling computers and electric vehicles (EVs) grow to dominate new car manufacturing. Even though many of today's onboard systems modestly 'sip' power, their rapid and accelerating growth means every milliamp counts, according to the experts at OmniVision.

BY ANDY HANVEY, DIRECTOR OF AUTOMOTIVE MARKETING, OMNIVISION & MARK ANDREWS, PEW TECHNICAL EDITOR

DIGITAL IMAGING has become much more sophisticated and is a critical aspect of power consumption in many commercial and consumer products including mobile phones; security and surveillance; tablets, notebooks, webcams and entertainment devices, as well as medical, AR/VR, drone and robotics imaging systems. One market that is witnessing a transformation thanks to digital imaging is the automotive sector. Each year, manufacturers add imaging sensors and digital cameras along with radar and other sensory systems to increase safety, add passenger benefits, and continually increase a vehicle's ability to support a transition to greater levels of autonomy. There is always a balance, however, between adding new advanced capabilities while also trying to maintain or reduce power consumption.



Companies in the industry are partnering together to offer new products that deliver benchmark capabilities. One such example is the recent announcement of an integrated reference design for a High Definition automotive camera system by Renesas Electronics Corporation and OmniVision Technologies.

The new design (figure 1) features Renesas' recently-introduced Automotive HD Link (AHL) technology that transmits high-definition video over low-cost cables and connectors. The AHL components in the design pair with OmniVision's OX01F10 1.3MP SoC, which provides the industry's best imaging performance across a wide range of challenging lighting conditions, along with the most compact form factor and lowest power consumption.

OmniVision's OX01F10 SoC integrates a high performance 3.0 micron image sensor and an advanced image signal processor (ISP) with

Figure 1: Industry leaders in the automotive supply chain are increasingly combining forces to offer streamlined integration of advanced electronic systems that save power and increase performance.

OmniVision's PureCel®Plus technology for low noise, solving the automotive rear view camera and surround view system challenges of achieving a small form factor with excellent low-light performance, ultra-low power and reduced cost while improving reliability by enabling single printed circuit board designs.
"The 1.3MP OX01F10 provides automotive designers with the industry's best imaging performance across a wide range of challenging lighting conditions, supporting HDR up to 120dB and high performance ISP. The sensor features ASIL-B, which targets cost-effective solutions, along with the most compact form factor and lowest power consumption," said Michael Wu, Senior Vice President of Global Sales and Marketing at OmniVision. "This reference design with Renesas takes that concept further by pairing with another high-quality, economical solution."

Power Electronics World technical editor Mark Andrews asked OmniVision's director of automotive marketing, Andy Hanvey, about the importance of power management in automotive designs as well as power consumption beyond automotive imaging systems.

MA: *What, in general, are the areas to consider regarding power management in automotive designs, on a higher level?*

AH: On a higher level and not specific to OmniVision components, you can think about it from the perspective that obviously cars run off a battery and there is a growing trend towards having much more sophisticated electronic content in cars. As a result, there will be a push to reduce the power consumption. So, when I say electronic content, it's the smart chips that are driving and not necessarily related to cameras. They could be doing anything in the car related to a type of semiconductor being used. Basically, you can say from that perspective that you want to be the most efficient and for the battery, you want to try and minimize your electrical content.

MA: *How does the OmniVision system (or component) function to reduce current consumption? Are new techniques being employed?*

AH: What we can do at the image sensor level, and camera module level, is to design our sensors in a power efficient way. For example, when we go to stacking technology, we can very carefully choose the process nodes, and select the process nodes of the logic layer to provide lower power solutions. Another benefit for lower power is that an engineer can determine or have a direct impact on the type of heat sinking that is used in the camera module. You have to use a heat sink to take thermal energy away, so when the power is low enough, you can use plastic covers that have a secondary benefit to reduce cost. Thermally, the camera will be at a lower temperature, resulting in better performance.

MA: *Is energy conservation or achieving more efficient energy management a driving factor in development?*

Figure 2: Image sensors used in miniaturized advanced digital cameras are moving to CMOS-based technology for increased performance including lower power consumption.

AH: We can effectively say yes, so obviously the requirements we get from Tier 1s and OEMs is that they're always pushing to get lower power, and from the sensor, to get more out of it.

MA: *Can you discuss design constraints outside automotive markets and how a company approaches energy management within these designs?*

AH: According to OmniVision, outside the automotive market, the pandemic has had an impact on the increasing demand for portable clamshell devices such as notebooks, 2-in-1s, and tablets. Consumers want crisp video quality, long battery life, and ease of use. However, there are design challenges in meeting these needs.

Compact clamshell devices have limited space for the front-facing camera module. Edge-to-edge displays with bezels that are as narrow as possible constrain the design. There is typically a trade-off between size of the camera module and performance. An ideal solution offers high-resolution, responsive video at either 30 or 60 frames per second (fps) that does not sacrifice battery life.

Portable devices also need to be protected from overheating without resorting to fans or large heat sinks, as there is no available space for those parts. So, power consumption of every component is, therefore, an important consideration for any design. OmniVision's "always on" feature reduces overall power consumption, extends battery life and helps to minimize the risk of the device overheating when using human presence and surroundings detection applications.

The camera remains in a low-power streaming mode when not in active use for human vision applications like taking pictures or video conferencing. This allows it to respond quickly when activated while saving energy the rest of the time.

The "always on" feature provides the additional benefit of enhanced security. The camera can, for example, detect movement and blur the image of someone walking by in the background. This protects privacy when devices are used in public settings and also minimizes background distractions during video calls.

MA: *When a manufacturer seeks to reduce energy consumption, one motivator within the medical device industry can be heat reduction. Can you explain?*

AH: OmniVision states that power consumption concerns for medical image sensors, unlike for consumer electronics and other applications, are not related to battery life. The critical issue is heat generation at the distal tip of the endoscope, which must never exceed 43 degrees Celsius. The small size of endoscopes does not allow space for mechanical heat sinks, so power consumption must be low enough for device operating temperature to stay in a safe range. Chip size concerns aside, 4K resolution requires four times the number of pixels as 1080p. For endoscopes based on CCD technology, this increases power consumption from 250 milliwatts (mW) to 1 Watt per chip. Power consumption per pixel must drop to avoid excessive heat while the endoscope is inside the body.

CMOS image sensors are the next logical step for endoscope manufacturers facing the limits of CCD image sensors (figure 2). The lengthier and more complex the procedure, the more important it is to limit the temperature of the distal tip. Because CMOS image sensors consume far less power per pixel than CCD sensors, even a high-resolution endoscope can remain at a safe operating temperature.

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Understanding current transformer design specifications

Current transformers can provide valuable current measurement data and galvanic separation, but while very similar to power transformers in principle, they have unique characteristics to bear in mind, especially when working with them for the first time. The experts at SIGA Electronics offer insights to help ensure making the right choices for any new design.

BY ALEX DEAKIN, BUSINESS DEVELOPMENT MANAGER, SIGA (ELECTRONICS) LTD

CURRENT TRANSFORMERS are a low cost and effective method of current measurement as well as providing galvanic separation between the current carrying conductor and the measuring device. They are also an effective means of detecting and measuring over currents, and as such they are increasingly widely used in green energy applications. Although clearly their principle of operation is the same as that of power transformers, these devices have some specific design characteristics that need to be borne in mind in specification. This article looks at those characteristics, reviews the relevant safety standards and provides a guide as to how to specify these components.

What is a Current Transformer?

A current transformer (CT) is an instrument transformer in which the secondary current, in normal conditions of use, is proportional to the primary current and differs in phase from it by an angle which is approximately zero. In an ideal CT, the current in the secondary winding will reflect the actual primary current without current ratio error or phase displacement. However, under normal conditions there will be current ratio error and phase displacement between primary and secondary currents.

The basic operating principle of CTs is the same as that of power transformers. The CT has a primary and

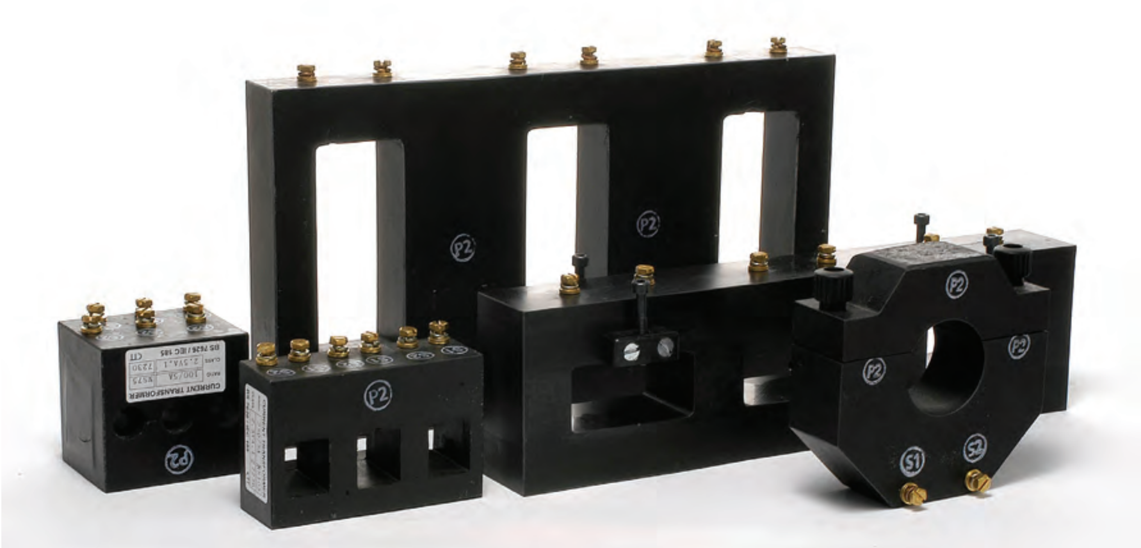

Figure 1: rectangular and ring type current transformers

a secondary winding. An alternating current flowing in the primary winding induces an alternating current in the secondary winding. But, unlike voltage or power transformers, a CT provides just one or very few turns as its primary winding, depending on the transformation ratio required.

The primary winding can be either a single flat turn, a coil of heavy-duty wire wrapped around the core or simply a conductor or bus bar placed through a central hole. The secondary winding is terminated on the rated burden resistor, the value on which the accuracy requirements of the CT is based.

Current Transformer Specification

When specifying a CT, the most important points to be considered are the ratio, the burden and the accuracy class. The most significant spec-point is the ratio, which typically ranges from 1000 to five, through 1000 to one, then 5000 to five and 5000 to one. But there is another important factor – the voltage × current value, or "burden". Typically, 5VA is the standard burden required, and manufacturers like SIGA (Electronics) can accommodate any burden from 1A up.

A further consideration is accuracy class of the device. There is always some difference between the expected value and actual value of output of an instrument transformer current error and phase angle error count in CTs. This is because the primary current of the CT must contribute the excitation component of a CT core. The accuracy class of CTs is a measure of the highest permissible percentage composite error at rated current. Standard accuracy classes of CT, per IS-2705 standards, are 0.1, 0.2, 0.5, 1, 3 and 5 for metering CTs. Accuracy class of 0.1 means the maximum permissible limit of error is 0.1%. IS-2705 categorises standard accuracy classes for the protection CT, such as 5P (5%), 10P (10%) or 15P (15%), where 'P' stands for protection.

The broad portfolio available offers ring type CTs suitable for primary currents from 50A-10000A along with rectangular CTs with primary currents from 60A to 6300A having 1A or 5A secondary. These meet accuracy classes from 0.2 for metering purposes and class PX for protection. Fitted in applications with rated system volts 0.72/3kV, they can be built to meet a 3kV insulation level for up to 1 minute. SIGA (Electronics) boasts capabilities going down to class 0.2 all the way up to Class 5 in metering. From the protection side, capabilities extend to Class 6 or Class PX.

For the protection side, further factors need to be considered, for example where the secondary resistance is at 75°C. Normally specified by the customer, this provides an idea of where the design needs to be. Also, some customers want a CT that can handle a specific secondary fault current, and this parameter is also specified by the customer.

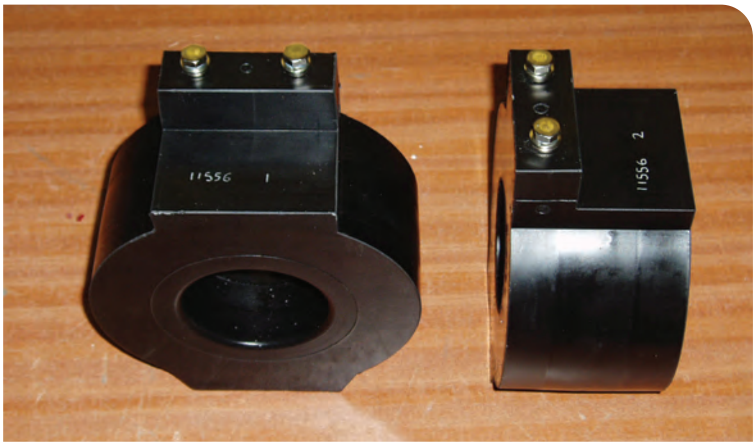

Figure 2: Ring CTs are mainly used for cables

Current Transformer Standards

CTs need to conform to IEC regulations from design, through manufacturing to final test. Standards including IEC 61869 are addressed by specific conformance testing for CTs. The design and testing of CTs is governed by standard IEC 61869-2:2012 (replaces IEC 60044-1:1996). Further specific test requirements are needed to verify that they meet the IEC 61869 prototype manufacturing stage. These include power frequency withstand measurements. This involves on-site checks for accuracy and ratio error, together with phase angle and winding resistance.

Another key measurement is the saturation point, usually performed using a CT analyser in the manufacturer's test department. This needs to be calibrated on an annual basis. Further, a primary injection tester allows manufacturers to make measurements at 3000, 4000 or 5000 amps. The test rig can produce the required current. Testing the transformer secondary side at 1A and 5A will confirm that the solution is fit for purpose.

Finally, a word on safety. Whilst most safety hazards are mitigated by device protection, others are

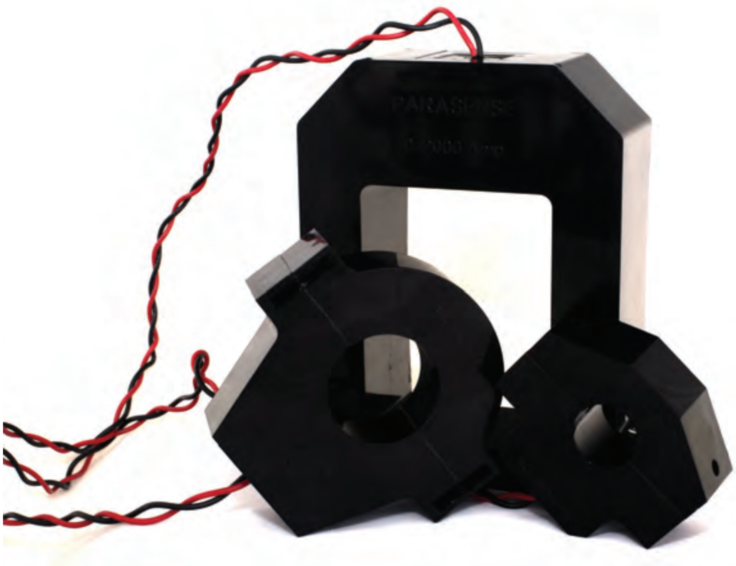

Figure 3: Rectangular CTs are a good fit for a busbar

Figure 4: Further example of a SIGA ring type CT

alleviated through the method in which CTs are wound. Resin, or tape-wound versions require the correct amount of space around the windings. For example, a resin block typically provides 10mm of resin around the outside of the component. In the case of tape-wound components, protection depends on the ability of the CT at temperatures where it is going to be installed. Normally class H materials are used, which are safe up to around 180°C.

Styles and Finishes

Manufacturers offer full block or split core style CTs, finished with UL-recognised semi rigid cast resin or an IP-rated plastic box. There is no right or wrong answer as to which style or finish to specify, there are different advantages of each style depending on the application.

Considering the style first, the full block is used in systems being built from scratch. Customers tend to like these because in building their equipment they can just slide the blocks out straight-on so that nothing further is needed. The advantage of the split coil is that it can be retrofitted to existing systems, for example to measure from different points. An alternative approach uses regular rectangular CTs. If ring CTs are specified, they are mainly used for cables. In the past they were used for bus bars going through their centre. However, the spacing on a bus bar is rectangular, so there is also the option to use a rectangular CT. This fits the busbar perfectly, providing more space around it to work in.

Turning to the finish, one of the advantages of cast resin is that it provides a solid, hard-wearing block, which can be mounted very easily within their enclosures. This is frequently used for the protection CTs as well, as it gives them a good insulation around the actual job itself. IP rated plastic boxes are commonly supplied with lugs and mounted in threes. In retrofit applications, the boxes are often low with two bars closer and one mounted high. Such innovations provide better utilisation of space, and the system is much more compact overall. An alternative solution is the tape-wound CT; these are mounted enclosures that can be filled with oil. A choice of finishes is usually available to meet individual customer preferences.

Current Transformer Applications

Common uses of CTs include current measurement and fault detection in systems. Standard measuring CTs are used in conjunction with ammeters to measure high currents which are stepped down to a standard output ratio of either 5A or 1A. The VA rating of the CT is matched with VA rating of the measuring instrument or ammeter. For example, SIGA's 200/5A FSD series CT is used in conjunction with a moving iron ammeter with a scale from zero to 200A. The ammeter is calibrated so that full scale deflection (FSD) occurs when output of CT is 5A. With the ring CT within, sometimes there is a need to double turn the cable and provide further flexibility. Using a round cable straight through the centre with the ring keeps everything flush and easy to use.

In addition, CTs can be used to detect faults in systems. A protection CT is designed to operate well into the overcurrent range. This enables the protective relays to measure fault currents accurately, even in very high current conditions. Core material for this type of CT has high saturation level and is normally made from silicon steel. The secondary current is used to operate a protective relay with which it can isolate part of the power circuit experiencing a fault condition. Typically, the low current side of a CT is designed to activate switchgear such as fuses, switches and circuit breakers that control, protect and isolate equipment. CTs signal the faults, and with this switchgear they can de-energise the product so personnel can work safely on clearing the faults. A concrete example is the use of CTs installed in switchgear fitted on London Underground, electrical data centres, and electrical substations. They are also the basis of Parasense units used in supermarket refrigeration and in the rapidly growing data centre industry. Other customers include providers of switchgear to aerospace, automotive, power generation, MOD applications and rail transport.

Conclusion

Many CTs for switchgear are used in the renewable energy and green project markets; where their units are becoming more efficient, they are being designed with minimal losses. As for the toroidal transformer, it's all about efficiency and driving down losses; the benefits this brings extend to other applications as well. These versatile devices have wide applications. By following the notes in this article, design engineers unfamiliar with their characteristics will have the confidence to specify and use them.

Visit **www.sigatransformers.co.uk** for additional information.

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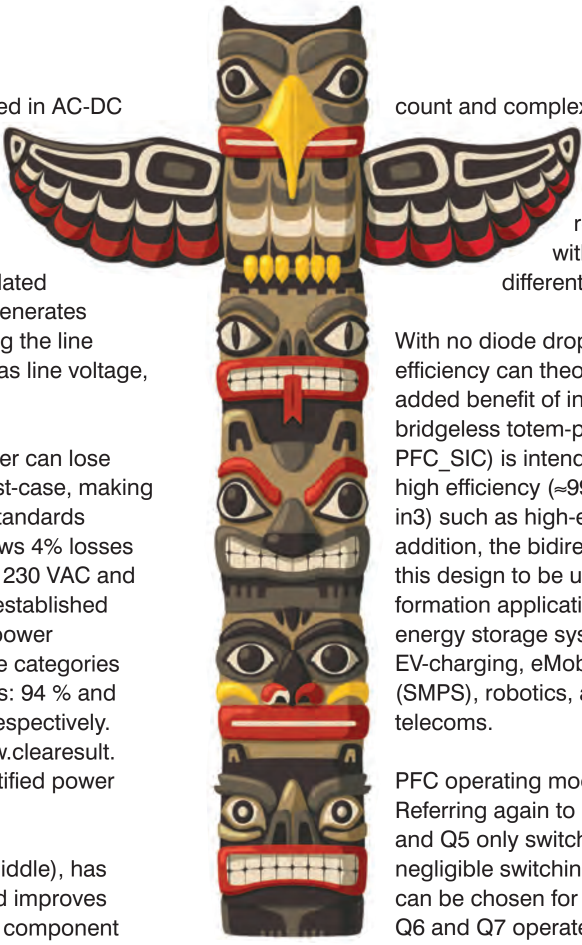
Totem-pole PFC stages benefit from CoolSiC MOSFETs

Infineon demonstrates ways that Silicon Carbide (SiC) devices continue to supplant other technologies in high voltage AC-DC converter applications. The company's CoolSiC MOSFETs deliver more than 99 percent efficiency, enabling new generations of power supplies for computing, telecom and similar applications across commercial, industrial and consumer sectors.

BY DAVID MENESES HERRERA, SENIOR STAFF APPLICATION ENGINEER, AND NICO FONTANA, SENIOR STAFF PRODUCT DEFINITION ENGINEER, INFINEON TECHNOLOGIES



Power factor correction (PFC) is required in AC-DC converters above 75 W for most products to avoid losses in the distribution network. Correction is classically achieved by full-wave rectifying AC and passing the resulting waveform through a pulse width modulated 'boost' converter (see Figure 1). This generates regulated high voltage DC, while forcing the line current to follow the same waveshape as line voltage, achieving close to unity power factor.

The bridge rectifier in the circuit however can lose nearly 2% in conversion efficiency worst-case, making it difficult to achieve compliance with standards such as '80+ Titanium' which only allows 4% losses end-to-end in server power supplies at 230 VAC and 50% load. The 80+ standard is a well-established benchmark for computing and server power supplies. Platinum and Titanium are the categories with the highest efficiency requirements: 94 % and 96 % at 50% load for 115V and 230V, respectively. More information can be found at: www.clearesult.com/80plus/ This website also lists certified power supplies available in the market.

A dual boost arrangement, Figure 1 (middle), has two fewer diodes in the power path and improves efficiency, but at the expense of higher component count and complexity. The optimum approach is the 'bridgeless totem-pole' arrangement, Figure 1 (right), which uses MOSFETs for line rectification, boost switch and diode, with the devices swapping function on different line polarities.

With no diode drops in the conduction paths, efficiency can theoretically approach 100% with the added benefit of inherent bidirectional capability. The bridgeless totem-pole PFC board (EVAL_3K3W_TP_PFC_SIC) is intended for applications that require high efficiency (≈99%) and high power density (72 W/in3) such as high-end computing / telecom servers. In addition, the bidirectional power flow capability allows this design to be used in battery chargers or battery formation applications. Potential applications include energy storage systems, battery formation, charging, EV-charging, eMobility, industrial power, power supply (SMPS), robotics, automated guided vehicles, and telecoms.

PFC operating mode affects efficiency

Referring again to Figure 1, it is notable that Q4 and Q5 only switch at line frequency, so each has negligible switching losses and low RDS(ON) devices can be chosen for minimal dissipation. However, Q6 and Q7 operate with 'hard' switching at high

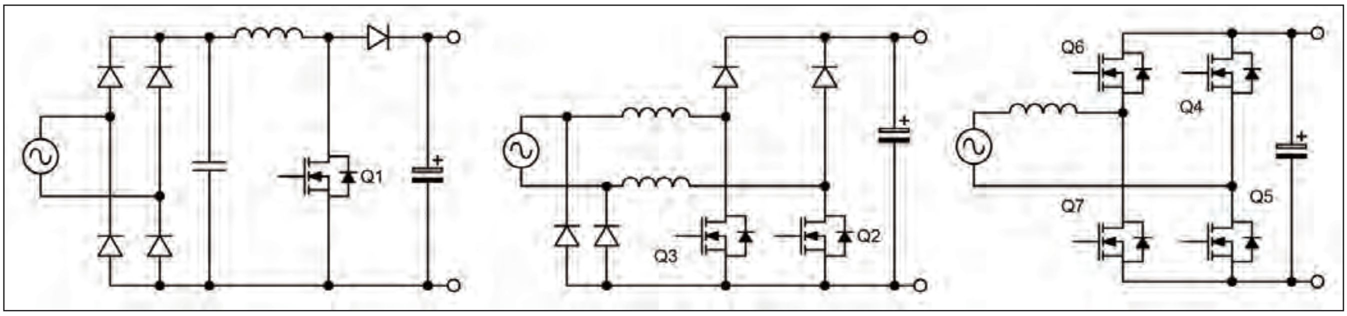


Figure 1: PFC arrangements (left to right): Traditional, Dual boost, Bridgeless totem pole

frequency in continuous conduction mode (CCM), so dynamic losses are potentially high. CCM is necessary at medium to high power as the alternatives, discontinuous and critical conduction modes, produce excessive conduction losses and stress from the inherently high peak currents. When hard switched, the boost MOSFET switches on at high drain voltage with transient dissipation. The boost synchronous MOSFET turns on at zero voltage as its body diode has been turned-on by ‘commutation’, however this stores energy (QRR) in the body diode which is discharged into the boost switch when it subsequently turns on, again producing significant dissipation.

Silicon MOSFETs, even super junction types, have relatively high QRR and worse, their output capacitance COSS and charge QOSS are also high. COSS also varies by a factor of typically 10,000 with drain voltage swing and temperature, causing a proportional variation in dead time between the boost switch turning off and the synchronous MOSFET conducting, as the switching node voltage resonantly rises. The effect practically limits the high-frequency operation of the circuit. In total, losses and delays with silicon MOSFETs are unacceptable in a totem-pole PFC stage.

CoolSiC™ MOSFETs enable high efficiency

Wide band-gap silicon carbide MOSFETs are a solution to reducing losses dramatically. For the same ratings, the SiC die are smaller yielding lower COSS and QOSS and the body diode has much lower QRR. Figure 2 shows the improvement comparing Si CoolMOSTM and CoolSiCTM 650 V 90 mΩ class devices. SiC MOSFET QRR also varies less with temperature and COSS varies 1000x less with voltage than silicon. Losses are therefore far lower and dead time can be set shorter for even better efficiency and higher frequency operation.

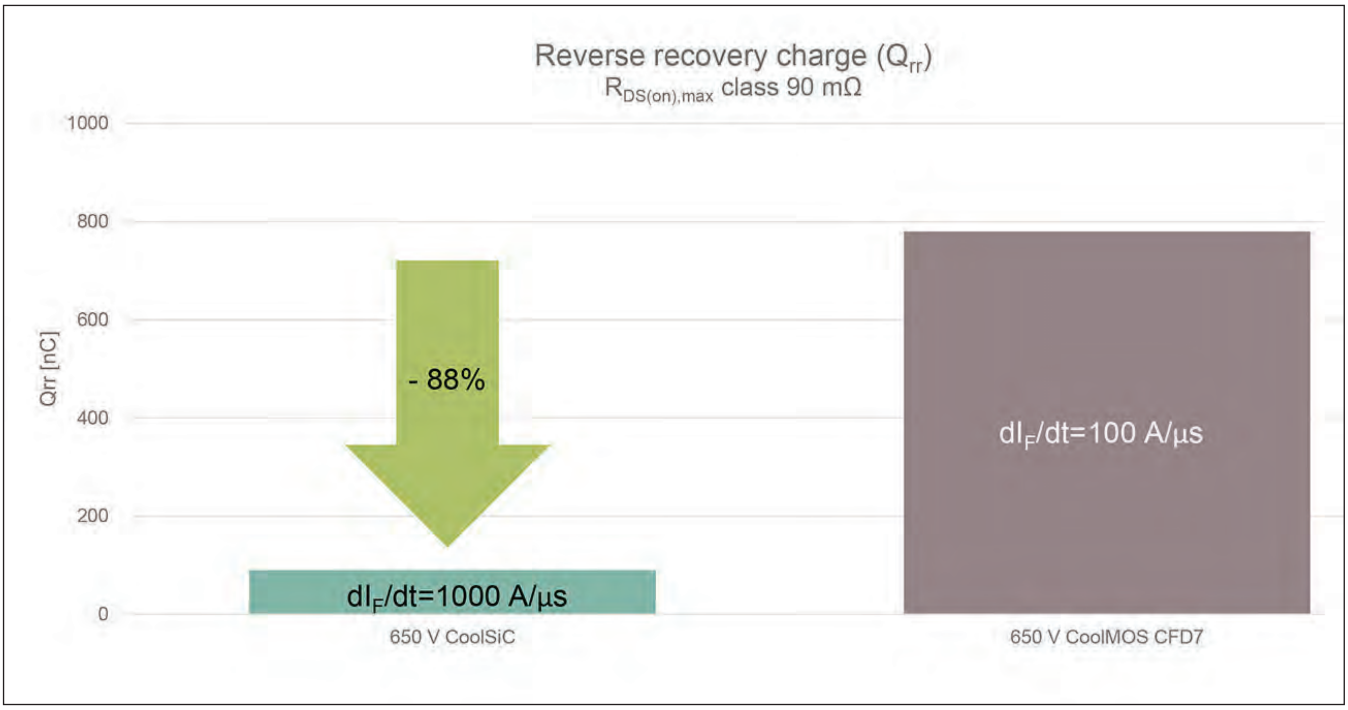


Figure 2: SiC reverse recovery is much less than Si (Source Infineon)

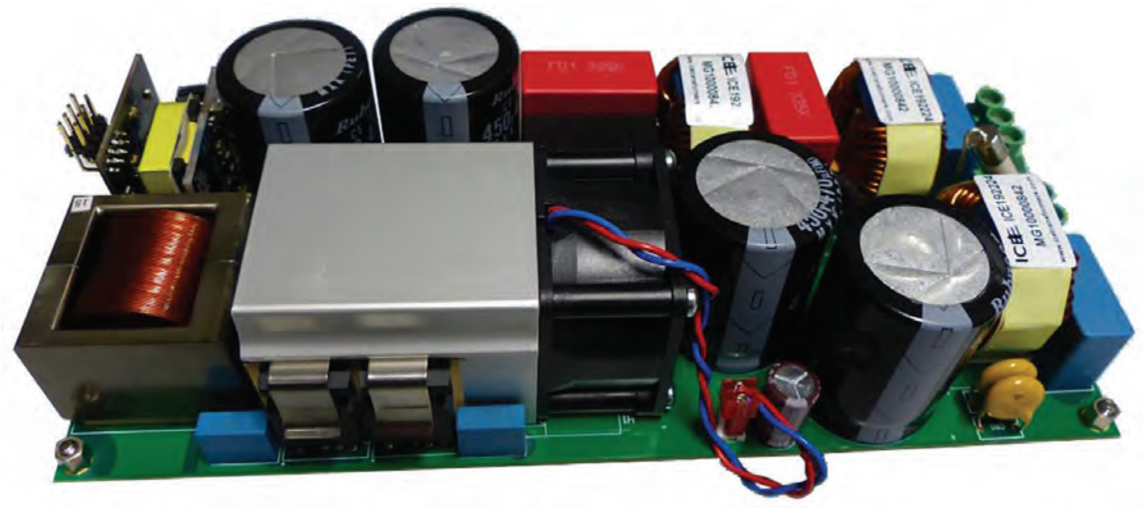


Figure 3: A 3.3 kW totem-pole PFC stage from Infineon using CoolSiCTM MOSFETs

Practical results

CoolSiCTM performance in the totem-pole PFC circuit is demonstrated in the Infineon 3.3 kW reference design (EVAL_3K3W_TP_PFC_SIC) , which achieves 99.1% peak efficiency at 230 VAC input/400 VDC output (Figure 3). Power density is 73 W/in3 (4.7 W/cm3) and the performance figures include losses in EMI filters and inrush suppression to represent a practical design.

From 20% load, power factor achieved is better that 0.95 and current total harmonic distortion (THD) is less than 10%, meeting the requirements of EN 61000-3-2. 650 V, 64 mΩ CoolSiCTM MOSFETs type IMZA65R048M1 are used for the high-frequency switches and 600 V, 17 mΩ CoolMOSTM parts IPW60R017C7 for the low frequency switches. Figure 4 shows the variation in efficiency with load.

Conclusion

Target efficiency levels in a totem-pole PFC stage for the toughest standards can be met using Infineon CoolSiCTM MOSFETs. A wide range is available in discrete and module formats, along with matching EiceDRIVERTM gate drivers, microcontrollers, and current sensing ICs.

To learn more about Infineon's SiC-based solutions, please visit **infineon.com/SiC**

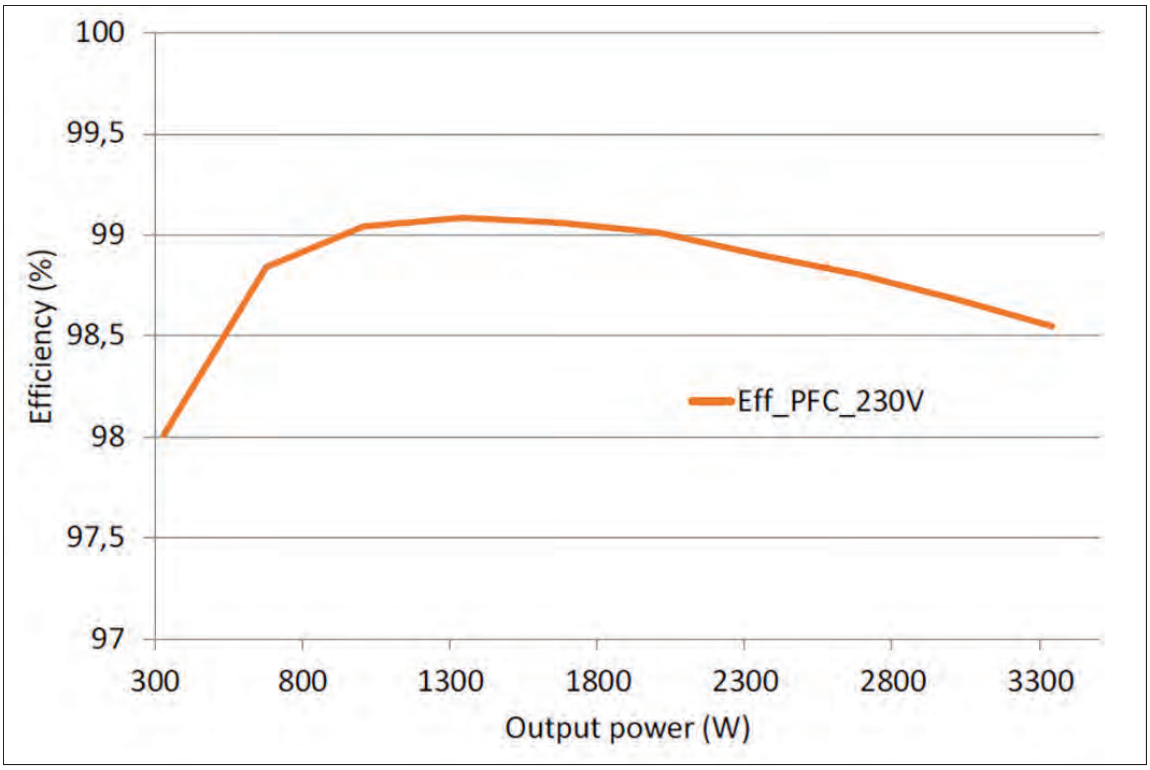


Figure 4: Efficiency variation with load for the Infineon totem-pole PFC demonstrator

Five things worth considering before integrating electrified power

What was primarily the province of logistics managers is now appreciated by all: our world's supply chain is very sensitive to disruption. As bad as the pandemic has been, it is sobering that contagion is one of many unknowns affecting world trade. Everyone has seen that power electronics and integrated circuit shortages affect whole industries; yet we know these issues will be resolved. As pipelines unclog, we'll see greater availability of products supporting the aggressive electrification of the automotive industry and many other initiatives arising wholly or in part around climate change mitigation, The experts at Briggs & Stratton describe key considerations for making smart energy choices in the months and years ahead.

CO-AUTHORED BY PAUL BRAMHALL, DIRECTOR MARKETING, EMEA, BRIGGS & STRATTON TOMAS POSPICHAL, MARKETING MANAGER, TECHNOTRADE

THE ELECTRIFICATION of commercial grade machinery is one of the biggest talking points for OEMs today. Lead acid or lithium-ion? Design and manufacture in-house or collaborate with an electrification partner? These are fundamentally the most important decisions you will need to make at the beginning of your electrification journey.

Traditionally, most OEMs source petrol or diesel engines from specialized engine manufacturers and rarely produce them in-house. This is in part due to the complexity of design and manufacturing processes required. But it's also because of the capital investment and technical know-how needed to achieve best performance – and all while maintaining durability and adhering to stringent global emission regulations.

When it comes to batteries, sourcing cells and components off the shelf to manufacture your own system seems easier and less capital intensive than with traditional engines – providing an alternative path to gain flexibility, increased customization and ultimately save costs. However, producing and integrating electrification effectively into machinery can be full of potential pitfalls…

Here are key factors that will enable the successful integration of electrified power:

Gauge market expectations

While everyone talks about finding greener alternative power solutions, whether that's battery, hydrogen fuel cells, or otherwise, remember that the market has established performance and cost expectations – and failure to align with these will result in costly consequences.

Developing new technologies is capital intensive and time consuming. Market adoption also takes time and therefore requires a long-term investment to realize the true ROI. Even then, some market segments will question technology performance, for example with battery, which is viewed by some as 'DIY' grade when

compared to traditional internal combustion engine power and performance. Therefore, selecting the correct technology, delivering the right performance, and hitting the most appropriate market price points will determine the success of your electrification strategy.

Before embarking on your electrification project, you should consider the following: charge times, daily usage (hours used), life expectancy, load conditions, peak power draw, cooling requirements, operating temperatures, work environment, weight and price.

Understand real-life application usage

The knowledge and experience of your in-house team is critical to ensure the successful integration of an electrified power solution into your equipment. Most off-the-shelf batteries and controllers have been developed for a broad range of applications and may not be equipped with the specific features, safety and protection devices your application requires.

Durability is extremely important for both the components and the system – including the motor, inverter, battery, controllers, etc. Your components therefore need to be high-grade and incorporate ingress protection (IP), which is critical should your equipment be exposed to dusty or wet environments. Just be sure to remember that IP is not a standard feature on most components, and IP ratings differ based on their intended usage.

In addition, it is important to recognise that different chemistries of li-ion batteries are suited for different applications based on the needs of the application. Briggs & Stratton use both Lithium Iron Phosphate (LiPO) and Nickel Manganese Cobalt (NMC) chemistries. For example, we recommend using LiPO in standby power products where cycle life is the most important characteristic of the battery and NMC on mobile applications where power and energy density are more important. Generally speaking, LiPO does have a longer cycle life, but it comes at the sacrifice of energy and power density. That means that a LiPO battery has to be physically much larger and heavier to provide the same run time and power as that of an NMC battery. Specifically, the energy density of LiPO is 90-120 Wh/kg while the energy density of NMC is 150-220 Wh/kg. Therefore, on average, a LiPO battery needs to be 75% larger than an NMC battery of the same run time.

Further factors to consider are vibration and temperature, which also have a significant impact on battery and component performance. It is crucial that you consider these before sourcing components as failure to get this right can lead to costly premature component failure.

Our recommendation:

Ensure your team fully understands real-life usage conditions – not just internal testing criteria – in order to qualify a product. Make a comprehensive list of all critical parameters, including but not limited to, power peaks, heat (temperature), current draw, cooling requirements, daily hour usage, user life expectations and load response. Also work with a technology partner that can offer the knowledge and expertise required to achieve the right mix of components to optimize integration. This will streamline the process and help you to maximize performance and longevity, while avoiding costly errors in applying the power source.

Obtain the right know-how

Every application has its own unique performance characteristics and power draw requirements, which will require a level of personalized engineering and development to achieve the best results. Likewise, most off-the-shelf batteries, battery components and controllers are designed to provide a generic set of performance characteristics that have not been designed around the very specific needs of your application.

Sourcing different components, for example cells and battery management systems (BMS), from different suppliers can also create challenges related to firmware incompatibility or the inability to communicate between components. Furthermore, battery and component suppliers may have very little experience in applying power to your specific machine and probably do not understand the operating conditions in which it is subjected to on a daily basis. Therefore, any upfront cost savings you may achieve could end up being lost towards extended development and engineering timelines – or warranty claims that could have been avoided.

It is extremely important that you have the know-how to achieve the right power balance across EM, inverter, battery and accessories. This will determine how the machine operates, how much power it delivers, and if the power is applied correctly during the duty cycle. Even simple machines have several microcontrollers (inverter, BMS, master controller, display, HMIs, etc.), which is very different to the ones powered by internal combustion engines and hydraulic solutions.

In addition, all of these parts come from different suppliers, which means you need the expertise and experience to integrate them precisely and efficiently. The OEMs who have limited CAN-bus and programming competencies often underestimate this challenge and struggle to realize the true efficiency gains of electrified systems.

Our advice:

Work with an established and experienced technology partner who can bring vast electrification and application engineering expertise to the table. While this may incur additional upfront costs, they can streamline the electrification process and save you time and money in the long run. The product integration and skillset a technology partner brings will fast track your development and remove numerous pain points during the integration and testing phases, ensuring you deliver an optimized electrified product to market.

Access to new technology

Gaining access to the latest battery components, technology and innovation can be a challenge for most OEMs who choose to assemble in-house. Firstly, the latest battery technology comes at a premium price. Secondly, market-leading cell manufacturers require significant volume commitments from the OEMs and typically only ship in container quantities.

If an OEM does not fulfil these criteria, they will have to source cells and components from smaller, lesser-known suppliers who do not necessarily have the most advanced technology and cannot guarantee the same level of performance quality.

Our suggestion:

Identify a strong partner who has access to the latest technology from Tier 1 and 2 suppliers. Their economies of scale will give you access to industry-leading technology at a more affordable price point. Higher grade components will also ensure consistency across a large volume, and your technology partner will have undertaken all of the critical performance testing to ensure the optimized power solution. They will offer you the flexibility to order and ship in smaller, more affordable quantities too.

Understand safety requirements

Monitoring battery performance at all times is crucial. Failure to do so can result in expensive failures and potential safety concerns. Unlike lead acid batteries, lithium-ion batteries are equipped with BMS, which is essentially the brains of the battery. The BMS monitors the temperature to ensure the battery stays within a safe operating range, it provides data on power utilizations and voltage, and it allows integration with both the machine and Internet of Things (IoT) devices.

However, while keeping tabs on the temperature of the battery may sound simple, the BMS is much more than just a thermometer. To ensure the battery stays within its operating range, the BMS is constantly monitoring and measuring not only the temperature but also the charge and discharge currents – as well as the voltages of each individual cell bank.

Since the primary safety concern with improperly managed lithium-ion batteries is a thermal runaway event, the BMS is therefore a critical component. If a lithium-ion battery exceeds its maximum allowable temperature range, it can go into a thermal runaway event – the temperature rises rapidly, releasing the battery's energy and eventually creating a fire. This will only happen when the battery isn't properly managed or protected with a BMS.

The bottom line:

Lithium-Ion, with the proper system management, is safer, longer-lasting and more powerful than lead-acid. But it is extremely important that your team understands all the safety requirements. Technology partners have this know-how and can ensure you address these critical safety measures in the very early stages of development – ultimately fast-tracking your program and safeguarding you against potential hurdles and costs at a later date.

China's first vertically integrated SiC line at the Changsha high-tech industrial park.

Sanan sets its sights on SiC

With China's first vertically integrated SiC line in tow, Sanan Integrated Circuit intends to take its multi-billion dollar investment to the top spot, reports REBECCA POOL

IN JUNE THIS YEAR, China-based Sanan Integrated Circuit (Sanan IC) opened the nation's first vertically integrated SiC line at its Hunan Sanan Semiconductor plant. Located in the Changsha high-tech industrial park in the Hunan province, Sanan IC's latest manufacturing fab with a $2.5 billion investment, has, so far, taken less than a year to build and handles all wafer and device fabrication steps from crystal growth to power devices, packaging and testing.

"This is phase 1 of our site," highlights Mrinal Das, Director, Technical Marketing and Sales at Sanan IC, which alongside Hunan Sanan, is a subsidiary of Sanan Optoelectronics. "At 15,000 wafers a month, we've brought half of its full capacity online... In phase 2 we will build a mirror image of phase one."

"We have an aggressive plan to get the plant fully operational – meaning equipped to deliver 30,000 wafers a month by 2024," he adds.

From here on in, Sanan IC's Changsha megafab will be delivering a mix of wafers and devices to both domestic and international customers. Describing the site as Sanan IC's 'captive' wide bandgap power semiconductor facility, Das won't be drawn on actually supply figures right now other than to say the facility is currently '15K a month capable'.

Built to churn out six-inch SiC wafers, Das also expects to see eight inch wafers being produced come 2024. As he puts it: "My vision is that during phase 2, if there is enough demand, we will work on eight-inch wafers so that in 2024 we could probably [be producing] 15,000 six-inch and 15,000 eight-inch wafers."

"After that, and if demand continues to rise in the next five to ten years, we will scale phase one and increase capacity to 30,000 eight-inch wafers every month," he says. "Our crystal growth team has put a lot of effort into our [wafer] technology and we have invested in innovation through our patent filings in China and the US."

Indeed, Sanan IC has been manufacturing SiC Schottky diodes for some time now and also has SiC MOSFETs under qualification – 1200 V devices are scheduled to be released soon. According to the Sanan IC Director, the figure of merits for substrates, epitaxy and devices are all 'achieving parity' with industry-best technology.

Das is keen to emphasize that the organization also makes GaN-on-silicon devices for lower-power applications. And as his Sanan IC colleague, Raymond Biagan, Senior Director, Sales and Marketing Communications – North America and Europe, highlights: "Our business model is to offer our entire manufacturing platform to the worldwide market."

In the interim, Sanan Hunan will hire engineers locally and from further afield. Engineers will predominantly come from a pool of domestic talent, but there will also be a portion of technologists from Taiwan, Japan and elsewhere.

Market competition

Still, Sanan IC and its Hunan Sanan Semiconductor plant are hardly operating in a vacuum. Recently, Cree, US, has poured $1 billion into its 200 mm SiC fabrication facility in Mohawk Valley, New York, while Rohm of Japan has just finished building its $190 million SiC wafer and device fab in Chikugo, Japan. US-based II-VI also intends to plough up to $50 million into its China SiC substrate manufacturing capacity and Infineon of Germany is set to increase SiC epitaxy wafer production.

However, Das – who worked at Cree and Wolfspeed for more than 16 years – reckons Sanan's China-based megafab gives the organisation an edge.

"Wolfspeed, for example, has the biggest news on capacity expansion so far with their materials supply stretching from North Carolina to upstate New York, and with packaging typically at various outsourced semiconductor assembly and test companies across Asia," he says.

"But while Wolfspeed is vertically integrated there is still this logistical challenge of moving their product through various stages globally, whereas we have a nice, compact, single site that will do everything," he adds.

Both Das and Biagan believe the Changsha site also sets up their company to more easily target the all-important electric and hybrid electric vehicle markets, in China.

"Analysts indicate that the hockey stick for wide bandgap materials will be automotive markets, so it's been natural to headquarter in China where we can cater for its large automotive market, in terms of logistics and quick time to market." says Biagan. "Our parent company, Sanan Optoelectronics, is already a major supplier of LED chips and car lamps to the automotive industry here, and we can further appeal to that marketplace by delivering SiC and GaN domestically."

Das and Biagan are also confident the burgeoning SiC industry has enough room for everyone. Das points out that the true competitor for all SiC players is silicon, and he and colleagues at Sanan IC hope to work alongside the competition to enable the widespread adoption of wide bandgap materials.

Still as Biagan puts it: "Our aspiration is to be considered a major market shareholder in the SiC space that is today served by companies such as Wolfspeed and STMicroelectronics, and to be known as a viable brand for wide bandgap materials and devices globally."

Making SiC wafers at Sanan IC's Hunan Semiconductor.

Akhan Semiconductor to scale diamond electronics for market

With the manufacture of 300 mm diamond CMOS wafers demonstrated, Akhan is set to bring unprecedented power densities to RF power devices, reports **REBECCA POOL**

IN A VERY SHORT space of time US-based Akhan Semiconductor has signalled a clear intent to massively scale up production of its synthetic, lab-grown electronics-grade diamond materials. In late June, former president of Intel Americas, Tom Lacey, joined the company board as chairman. The semiconductor executive has also spearheaded start-ups, mid-sized and larger public and private companies, and as he says: "Now is the time to unleash diamond's immense capability on chips, as well as optical and glass coatings."

Then, only a few weeks later, Akhan revealed it had fabricated 300 mm diamond CMOS wafers at its production facility, northern Illinois Diamond Mine 1. As Adam Khan, company founder, puts it: "From a commercial standpoint, 300 millimetre is the standard, and we want to show that we have these processes that can form even the most advanced chips."

"We've transitioned from laboratory innovations to repeatable and massively scaleable processes," he adds. "With Tom, we're moving from an entrepreneurial phase to operational growth... We want to license our materials to fabs and end-customers worldwide so they can incorporate these into their chip designs."

➤ Akhan Semiconductor engineers holding their 300 mm diamond wafer

Early days

Khan founded Akhan Semiconductor back in late 2012, confident that diamond could deliver excellent display glass properties for smartphone screens and optical performance for mirrors and lenses. He was also certain that diamond semiconductors could replace silicon devices and outperform wide bandgap materials, including GaN and SiC.

Partnering with Argonne National Laboratory, Akhan obtained exclusive rights to license the centre's diamond CVD technology, which enabled nanocrystalline diamond film deposition onto wafer materials at temperatures as low as 400 °C. Combined with Akhan's co-doping method – in which devices are doped with phosphorus and nitrogen, and then doped with boron or lithium to engineer atomic distribution – the pairing looked set to fulfil Khan's hopes.

As Argonne Materials Scientist, Anirudha Sumant, said at the time: "This licensing agreement gives us the impact of a one-two punch, in which we combine Akhan's novel process to achieve efficient *n*-type doping in diamond with Argonne's low-temperature diamond deposition technology... This will break barriers that restricted the use of diamond thin films in the semiconductor industry to only *p*-type doping." Fast forward to today and this approach has been a success. Akhan has filed more than 40 patents worldwide, supplied its technology to Lockheed Martin, an unnamed smartphone OEM and other key industry players, and has now demonstrated the manufacture of 300 mm CMOS diamond wafers.

According to Khan: "We've done this using hot filament CVD [widely used to deposit diamond films] and get exceptionally high yield... the rejection rate has been less than 10 percent with wafers being rejected due to edge-to-edge film variability rather than tolerance."

"This is a robust, scaleable process but 300 millimetre is not our maximum size – we can grow diamond on panels even larger than this," he adds.

The company works with an impressive range of substrates, including silicon, glass, fused silica, sapphire, SiC, GaN and other crystalline semiconductor materials, and refractory metals. Devices for automotive applications are being fabricated on either silicon or SiC substrates.

"We have patents and 'trade secret' processes for each material, including how we prepare the material, growth conditions and post-processing," says Khan. "The seed material and chemicals used to functionalise this vary by material type, and also by material thickness, roughness or finish."

As the Akhan founder also points out, the material's crystal size is altered depending on the applications – for example, a large grain polycrystalline material enhances carrier mobility for high-power, high-frequency applications. "We haven't seen the need to develop single crystal [materials] for the applications we've pursued, as what we are seeing is already so much better than SiC and GaN," he says. Indeed, along the way, Khan and colleagues have been tracking SiC and GaN developments in the RF power sector, and fabricating MOSFETs, MESFETs, bipolar and CMOS structures that bring unprecedented power densities to this application.

"We demonstrated a working diode back in 2013 and are currently deploying technologies with Lockheed Martin... [this includes] a joint effort with our diamond-based electronics and optics on their F-35 platform," highlights Khan.

Performance-wise, Khan says power density of his diamond semiconductors beats that of GaN and SiC, exceeding 40 W/mm, while carrier mobility hits many hundreds of cm^2 V^{-1} s^{-1}. Patent detail indicates a monolithically integrated diamond semiconductor to have conduction electrons with a mobility exceeding 770 cm^2 V^{-1} s^{-1} at 300K. "We know it's quite fast in terms of switching," says Khan.

Khan also reckons his devices are cheaper, per dollar/cm^2, than the GaN and SiC equivalent. "We only use a very thin layer of diamond – just enough for the active layer," he says. "Then the substrate cost is just silicon – which is cheaper than GaN and SiC."

So what now for Akhan Semiconductor and its diamond electronics? The company has historically delivered materials for aerospace and defence applications, but is now preparing to launch products into automotive applications.

"We've focused on this since 2012... we're ready to start licensing our first technologies, including power inverters, and will have them in the [automotive] market by the 2021 time-frame," says Khan. "Once the revenues are there for the automotive side, I think consumer electronics will be next."

➤ Adam Khan, Founder of Akhan Semiconductor.

A greener SiC wafer with Smart Cut technology

Smart Cut substrate technology charts a greener, faster and better path for the production of power electronic components

BY OLIVIER BONNIN, ERIC GUIOT, WALTER SCHWARZENBACH AND GONZALO PICUN FROM SOITEC

THIS YEAR has witnessed horrendous flooding in China and central Europe, along with soaring temperatures in north America. So it would appear that climate change is already underway, driven by rising levels of CO_2 emissions. The prevailing view of the scientific community is that this situation is only going to deteriorate, and if the additional rise in temperature is not restricted to below 1.5 °C, our climate will undergo a substantial change.

Key to trimming CO_2 emissions and staying within that limit for a temperature rise is sustainable development, which includes the introduction of greener technologies and processes. The industrial sector, electricity generation and transportation now accounts for about three-quarters of all CO_2 gas emissions. So there is clearly a need to build a better, greener energy ecosystem. This can be realized by making substantial improvements on three fronts: slashing the energy consumed by data-centres, ramping renewable energy production, and accelerating the production of zero emission vehicles (ZEVs).

Within the ZEV sector, efforts must be directed at taking every opportunity to increase the power conversion efficiency, from electrical generation through to the provision of power at the powertrain. To excel in this endeavour, there must be a shift towards the use of greener power electronic components that deliver better performance and are made from more eco-friendly production processes.

Today's incumbents, which are silicon-based components, are operating at their theoretical limit and cannot deliver the additional performance required for the more-efficient, greener systems needed for next-generation ZEVs. There must be a move to widespread adoption of wide bandgap semiconductors, such as SiC, which enable devices that combine higher operating temperatures with faster switching frequencies and higher efficiencies. Powertrains adopting this technology not only excel in efficiency – they are also smaller, lighter, and lower-cost.

Pioneering the uptake of SiC in ZEVs is Tesla. Back in 2017 it started deploying this technology in its Model 3 cars, importing power electronic components from STMicroelectronics. Where Tesla has led, others are sure to follow, creating a massive market for SiC, given that the ZEV market will account for more than half of all vehicle sales by the end of this decade, and all purchases come 2050 (see Figure 1). Going hand-in-hand with this revolution in transportation, there needs to be a dramatic increase in renewable energy production. Humanity is heading in the right direction, with the installed capacity for producing energy from the sun and the wind expected to increase three-fold by 2040. In both these forms of renewable, the inverter is a key component.

Designers of this component are seeking reductions in volume and weight, alongside an increase in global system efficiency. To accomplish these goals, they will employ simplified bi-directional topologies, enabled by SiC, that handle more than 100 kW.

Hampering efforts to curb CO_2 emission is the rapid growth in the IoT (Internet of Things) and AI (Artificial Intelligence). They contribute to global emissions by digital applications, a sector estimated to account for up to 10 percent of all emissions by 2025, and possibly more than 20 percent by the end of this decade. There is an urgent need for new data centres with smaller CO_2 footprints. One way to realise this is to increase electrical power efficiency. For that, switching to a higher power density by introducing SiC is a valid option.

The Achilles heel of SiC

While SiC has many strengths, production of boules by the conventional technique, physical-vapour transport, requires temperatures of typically 2300°C to 2400 °C – this is far higher than that for silicon, which is grown at 1400 °C to 1500 °C. Additional drawbacks are that it can take a week to grow a SiC boule, and this only yields 40 to 50 wafers.

All these impediments help to explain why today's SiC wafers are up to 50 times the price of silicon equivalents, which are grown in just a few days. The environmental impact of SiC's production process has to be addressed, given that this material offers so much promise in helping to curb global CO_2 emissions. At Soitec of Bernin, France, we have a solution to this problem: a proprietary layer-splitting and wafer-bonding technology, known as Smart Cut. Applying this to SiC allows a thin, monocrystalline layer of this material to be transferred from a SiC donor substrate to a SiC carrier substrate.

Insights from Emmanuel Sabonnadière, Soitec's Vice President, Silicon Carbide

Q: What is Soitec's view on engineered substrate technology?

A: For the last thirty years, we have been successfully promoting the benefits and manufacturing engineered substrates in microelectronics. We are now exploring power electronics with a better, faster and greener path, based on advanced engineered substrates. Silicon carbide is the most promising material for power electronics, especially for the new electrical vehicles market. We are developing an alternative to classic bulk silicon carbide that has a very low environmental budget: Smart Cut silicon carbide. This combines our Smart Cut process, invented decades ago, with SiC materials. This greener technology is perfectly aligned with our efforts over the years at pioneering and leading engineered substrate technology.

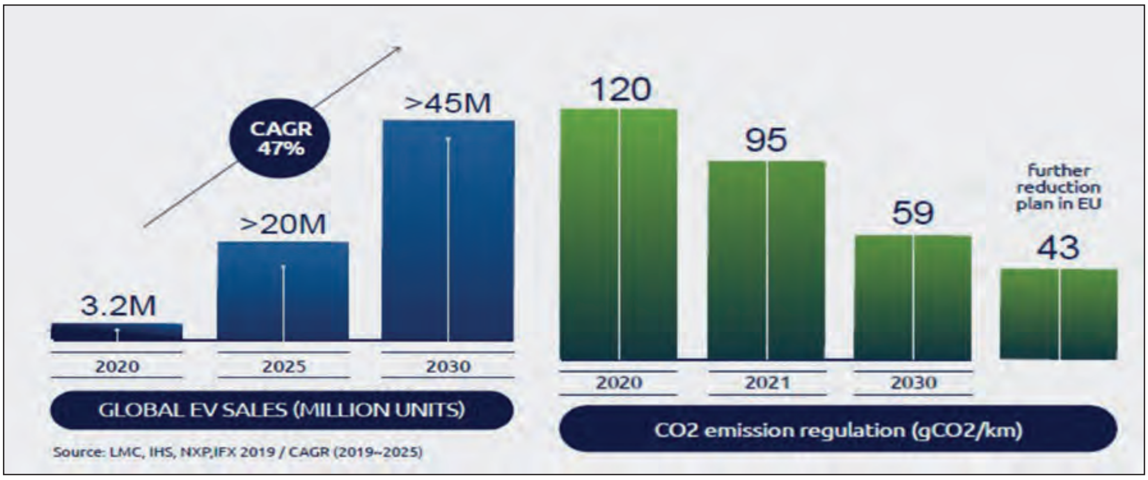
Q: Are you increasing production of Smart-Cut silicon carbide?

A: Smart Cut silicon carbide is at the adoption phase, with some key players involved in the new booming electric-vehicle markets. Smart Cut silicon carbide will also find alternative markets, for applications requiring high-efficiency power conversion at 400-800-1200 volts, for powers of 75-150-300 kilowatts and more. We are expecting high single-digit growth over the coming years with our Smart Cut silicon carbide. This will provide us with a strategic diversification from microelectronics to automotive applications.

Q: How much money will you be investing in Smart-Cut silicon carbide production?

A: It depends on the strategic partnerships under construction. However, we estimate that our Capex investment in Smart Cut silicon carbide production over the next five years will be about 20 percent of our total investment over that period. We announced this intention in June at the *Soitec Capital Markets Day* (for details, see: https://www.soitec.com/media/images/Soitec-CMD_2021.pdf).

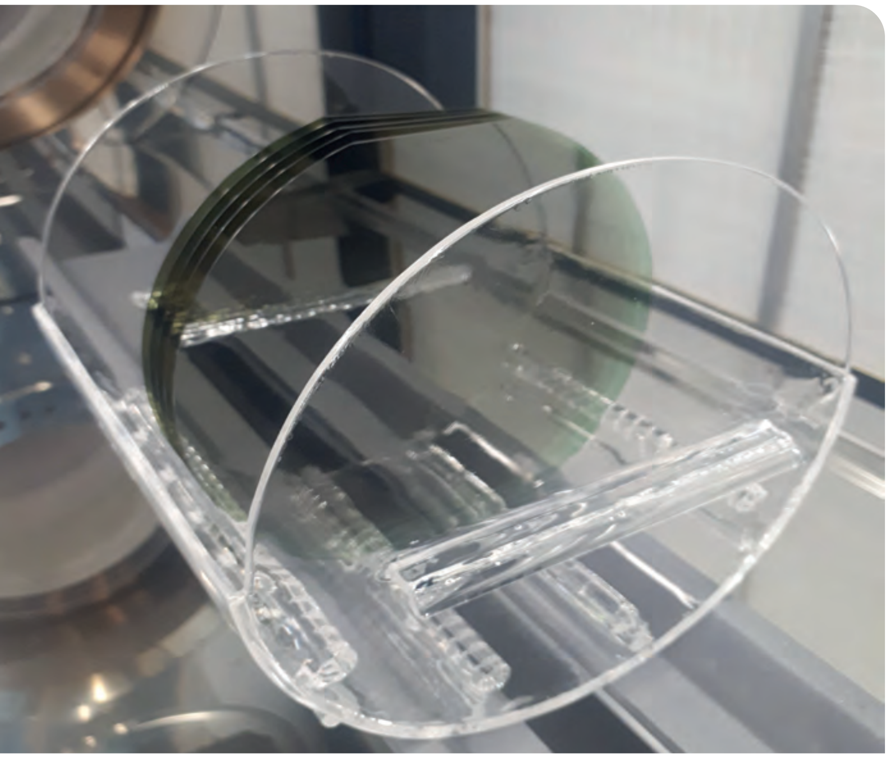
Figure 1. The fast transition towards EVs will be a key factor behind reductions in CO_2 emissions. This transition will be accentuated by governmental regulations on gCO_2/km.



Our Smart Cut technology is a cost-effective, environmentally friendly manufacturing technology that we employ to fabricate advanced engineered substrates. For more than thirty years we have used this technology to manufacture silicon-on-insulator wafers for microelectronics. Recently, we have also applied this technique to the production of piezoelectric materials and compound semiconductors.

Soitec's Smart Cut process, developed to reduce costs in the microelectronic industry, is poised to increase the competitiveness and volume of SiC devices.

The production process that we employ requires two starting wafers, one referred to as the donor and the other the carrier. Preparation of the donor involves ion implantation, to create a cleavage plan at a defined depth. When preparing our donor and carrier wafers, we take into account surface roughness – minimising this is crucial to realising a higher performance with microelectronics. Our approach is highly eco-friendly, thanks to re-use of the donor wafer more than ten times.



When producing SiC substrates with our Smart Cut technology, we have found that optimisation of the bonding step is crucial for realising high levels of electrical and thermal conductivity. Our investigations have shown that the contribution of the bonding interface to the total substrate electrical resistance is equivalent to that of just a few tens of microns of standard SiC material. After Smart Cut splitting and transfer of a thin slice of SiC from the donor to the carrier substrate, we employ a finishing process that ensures that with polishing and anneal, our newly formed substrate is epi-ready and compatible with SiC device processing. Note that our Smart Cut SiC technology produces wafers with a top layer that is free from basal plane dislocations (see Figures 2 and 3).

Today, Smart Cut technology is used in microelectronics on wafers with diameters up to 300 mm, and we see no barrier to using this approach on larger-diameter SiC wafers. Thanks to this versatility, our Smart Cut SiC technology will accelerate the transition from 150 mm to 200 mm substrates while easing the ramp-up of volumes and securing availability for chip production. Another merit of the Smart Cut process is that for transposition to 200 mm SiC, it will be easier and faster to implement than it is for bulk SiC substrates.

Smart Cut's multiple benefits

There are significant benefits to making SiC devices from a Smart Cut wafer, rather than one produced from bulk SiC (see Figure 4 for a comparison of their construction). One merit is that when producing a device, the Smart Cut SiC substrate already includes the conversion buffer layer. This simplifies the drift epitaxy growth process.

Another attribute of Smart Cut SiC technology is that it offers an optimized top layer for device fabrication

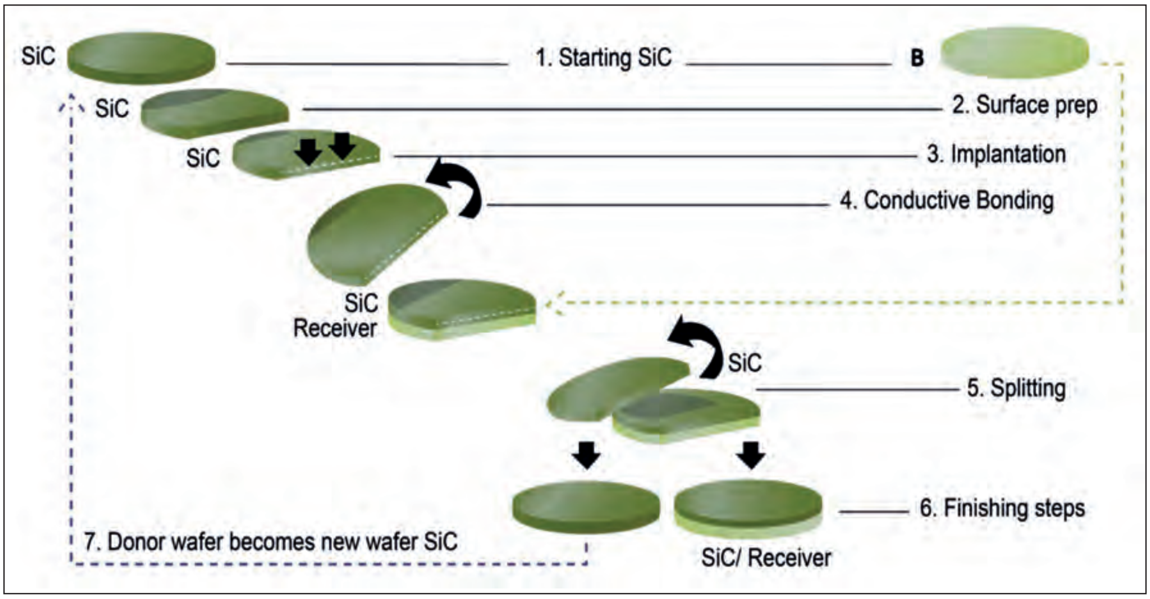


Figure 2. Soitec has adapted its Smart Cut process for the production of SiC.

that features advanced physical properties and crystal quality from the SiC donor wafer, and is independent from the carrier material. This makes Smart Cut SiC technology so efficient and interesting for power electronics.

With substrates made from bulk SiC, there is a trade-off between electrical conductivity and crystal defectivity. If the doping level of 4H-SiC is increased, in order to reduce substrate resistivity, crystal defects increase. For *n*-type 4H-SiC wafers, the compromise involves a typical resistivity between 0.015 Ω cm and 0.025 Ω cm.

Thanks to material engineering of the base substrate, Smart Cut SiC decreases electrical resistivity of the substrate by at least a factor of four. This remarkable reduction of resistivity enables a shrinking of MOSFET dimensions by 5-15 percent, depending on device design. Yet another merit is that it might be possible to reduce or even skip wafer backgrinding. These savings on power electronics devices are substantial, enabling Smart Cut SiC technology to be considered as a powerful alternative to bulk SiC.

Additional strengths of Smart Cut SiC wafers are a high surface quality and reduced roughness, thanks to the specific engineering processes applied to the donor substrate and the transferred BPD-free top layer. These improvements drive down the induced epi-grown defect density, leading to a 20 percent increase in the yield of devices with dimensions above 20 mm^2.

In short, the disruptive approach of Smart Cut SiC technology lies in reusing, more than 10 times, a donor that is free from basal plane dislocations, and the provision of an ultra-smooth top layer on top of a low-resistivity receiver. As re-use allows a ten-fold increase in the number of dies produced, compared to a bulk SiC wafer, the introduction of Smart Cut SiC alleviates the supply chain, while reducing the environmental impact of producing boules.

Figure 3. Pictures of bulk SiC (left), Smart Cut SiC (centre), and Smart Cut SiC with devices (right).

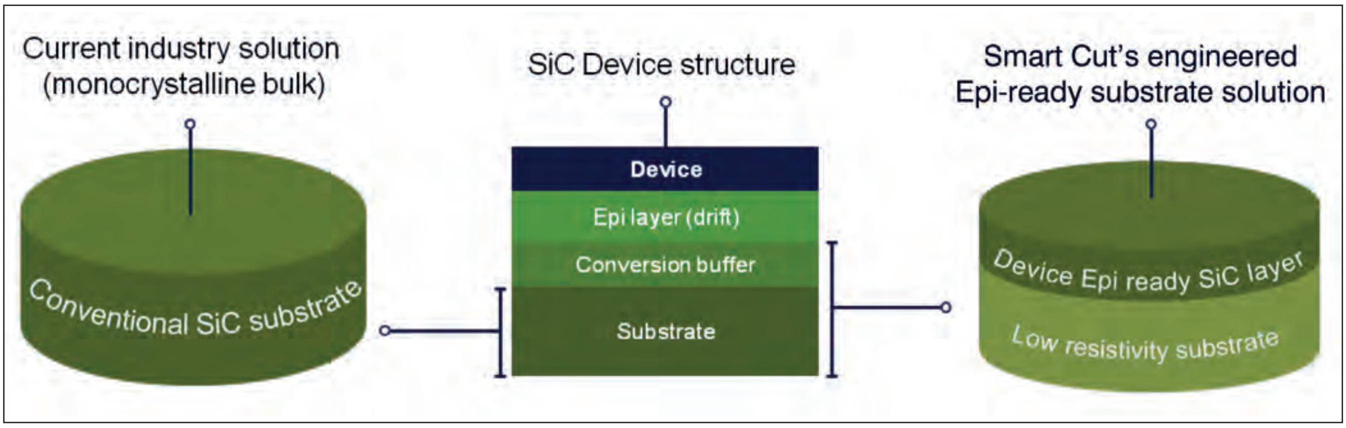


Figure 4. A comparison of Smart Cut SiC and bulk SiC for SiC device fabrication.

Building better devices

Through collaboration with major European industrial and research and technology partners, we have fabricated junction barrier Schottky (JBS) diodes on our first-generation of Smart Cut SiC substrates, using a 20 mΩ cm resistivity carrier substrate. Electrical measurements on these devices reveal a performance equivalent to that of JBS diodes prepared on a reference bulk SiC wafer, which has been issued from the same batch of Smart Cut SiC donor (see Figure 5, left). Based on this result, it is clear that Smart Cut SiC wafers can fully replace bulk SiC for manufacturing power electronics devices.

We have modelled the transfer characteristics of this JBS diode, prepared on our Smart Cut SiC substrate. For this work, we considered the contributions of the measured electrical characteristics from the bonding interface and from the alternative, low-resistivity SiC carrier substrate. Calculations indicate that at a voltage of around 1.4 V, the current rating of this JBS diode increases by 20 percent (see Figure 5, right). This benefit will aid designers of power electronics components. They can design a product with a higher current rating, while keeping their existing design and technology; or they can shrink the total die area by more than 15 percent. As well as reducing die cost, the latter cuts switching losses by 10 percent, thanks to a reduced gate surface.

Cutting carbon footprints

When considering the environmental impact of the life cycle of power electronic devices, from raw materials preparation up to final components usage, the benefits of Smart Cut SiC technology are: a lower energy budget for SiC, thanks to multiple re-use of bulk SiC donors; and the adoption of a low resistivity handle wafer from a simpler, lower-energy manufacturing process. Note that the carrier substrate can be fabricated at lower temperatures – that is, below 1500 °C – with processing taking just one or two days. The upshot is an energy consumption close to that required to prepare a silicon wafer, which is a major breakthrough for SiC.

Using our Smart Cut SiC technology, 500 epi-ready wafers can be produced from SiC boules that yield 40-50 wafers with today's conventional SiC technology. This hike in efficiency by an order of magnitude is a great contributor to reducing the overall carbon footprint of SiC technology, which has a high environmental budget associated with SiC boule production.

As electric vehicle production soars throughout this decade, our technology will come to the fore by offering a reliable, disruptive alternative to bulk SiC that is currently utilized for the most advanced powertrain inverters. The transformation of the automotive industry to more eco-friendly vehicles will include the implementation of evermore advanced SiC technology, which will be aided by the adoption of our Smart Cut SiC, a technology that improves performance and drastically cuts the carbon footprint associated with substrate production.

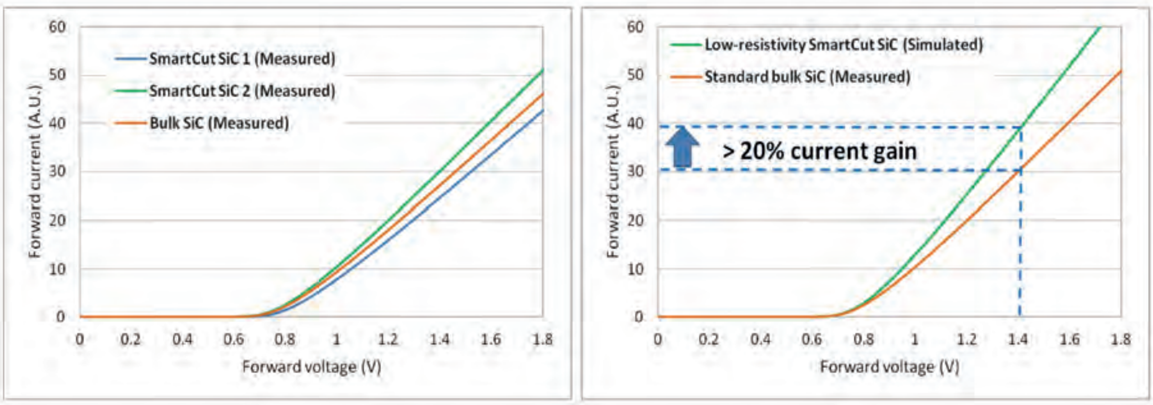


Figure 5. Smart Cut SiC substrate performance.

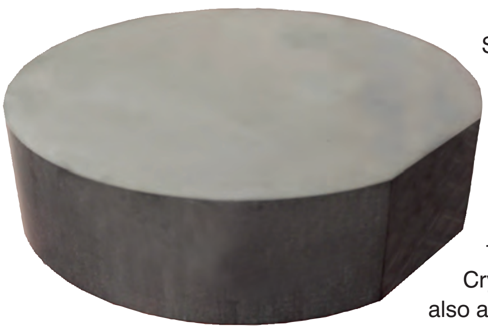
GTAT will be growing its production capacity by 60% this year alone. In addition, more furnaces will be added for R&D on products including 200mm diameter n-Type CrystX® and also SI-Type.

2021: A year of growth and expansion for SiC-producer GTAT

Production capacity Up 60% for 150mm CrystX® with R&D accelerating for 200mm

2021 is a big year for GTAT and its CrystX® silicon carbide (SiC) crystal. First, our quality levels continue to rise dramatically, quarter over quarter. Specifically, Etch Pit Density (EPD) and Basal Plane Dislocations (BPD) are critical quality metrics for SiC. We've made significant progress driving down BPD's to less than 1,000 per cm2 and are set to reduce this by another 50% in the near term. We focus on continuous improvement, investing in R&D to reduce defects and then 'locking down' the process while repeating the cycle. Our inherently stable production metrics enable CrystX® silicon carbide to be made to this high-quality standard, which is available under a single product grade.

150mm diameter CrystX® silicon carbide boule produced in volume and at extremely high-quality levels.



Second, we are expanding our production capacity rapidly. With multiple long-term agreements in place, GTAT is currently increasing capacity for 150mm diameter n-type CrystX® by 60% while also adding more furnaces dedicated to R&D. The R&D capacity will be used to develop and produce semi-insulating (SI) CrystX® but also to transition to larger 200mm diameter boules. Moving from 150mm diameter to 200mm diameter boules while growing usable height means higher material yield for customers. This new capacity will be on-line by Fall 2021, with yet another round of expansion slated to begin soon thereafter.

Bringing highest-quality SiC crystal to rapidly growing markets such as EV and renewable energy is a function of GTATs adherence to important quality-management systems. ISO 9001:2015 and IATF 16949 are two such systems that drive everything we do. In fact, we achieved our ISO 9001:2015 certification in less than a year after beginning the process.

GT ADVANCED TECHNOLOGIES

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https://gtat.com/products/silicon-carbide