POWER ELECTRONICS WORLD
CONNECTING THE GLOBAL COMMUNITY

ISSUE 4 2019
WWW.POWERELECTRONICSWORLD.NET

Sigfox powers new IoT/IIoT connectivity

GaN to move deeply into power applications

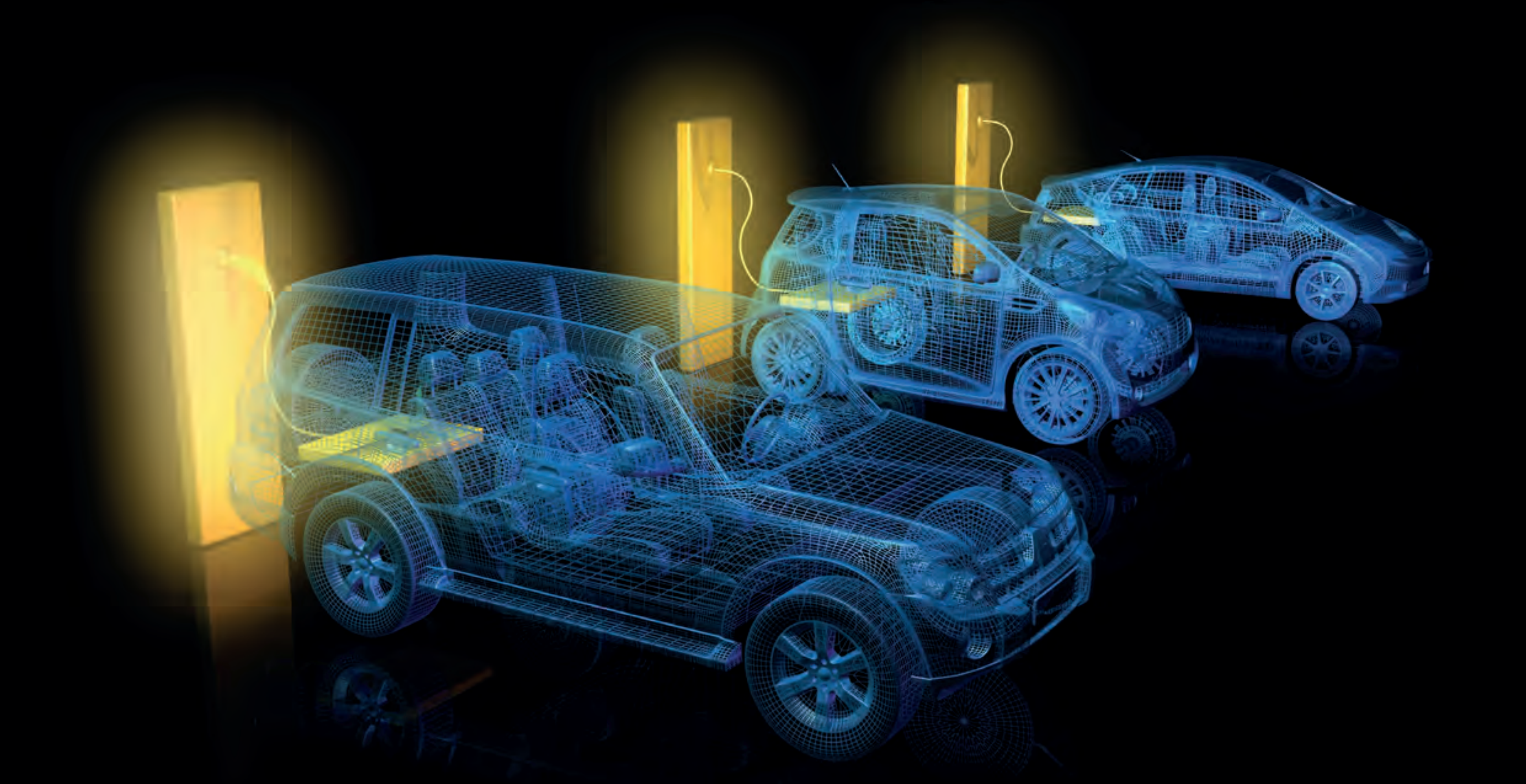
Trade disputes fuel supply chain worries

Siemens smart infrastructure

KaSiLi to make better batteries for EVs

GaN & SiC to power next decade?

POWER ELECTRONICS WORLD
CONNECTING THE GLOBAL COMMUNITY
News Review, News Analysis, Features, Research Review and much more.
Free Weekly E News round up , go to WWW.POWERELECTRONICSWORLD.NET
AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION

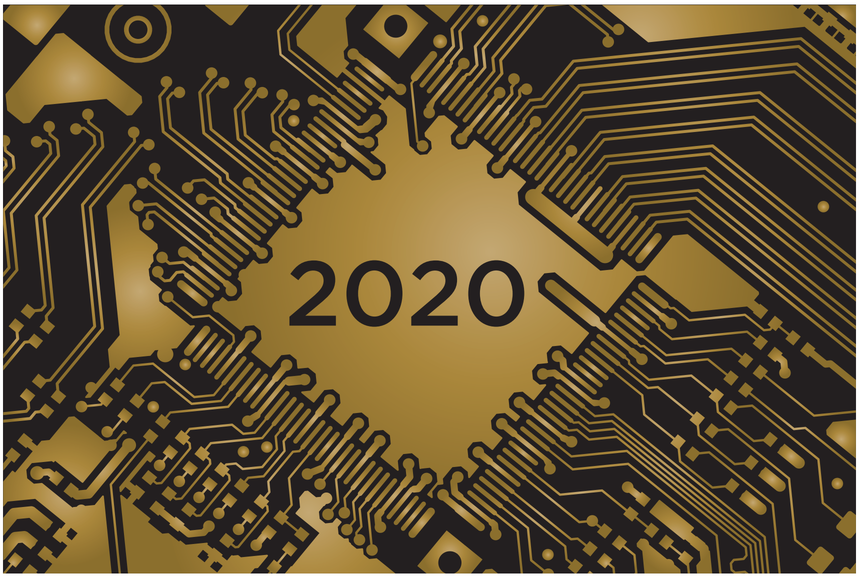



AIXTRON
AIXTRON

Viewpoint

By Mark Andrews, Technical Editor

Power-up for 2020 and beyond



EVEN AS global trade disputes continue, insiders point to likely resolutions and prospects that 2019 will close on an upbeat note thanks to continuing power electronics sector growth and possibilities of a rebound for general IC and fab equipment sales.

The overall 2019 semiconductor market figures are still a work in progress. But SEMI said in its mid-December report that manufacturing equipment sales will drop 10.5 percent to $57.6 billion compared to last year's historic $64.4 billion peak – In the same breath they added that the stage is set for a 2020 recovery and new highs in 2021.

The growth of GaN and SiC technologies were center stage for power electronics throughout much of 2019, even while trade issues continued to strain relations between the United States and China. The performance advantages of SiC and GaN technologies are driving growth at a time when other semiconductors were largely 'holding their own' this year.

This edition of Power Electronics World looks at the growth of power technologies through the eyes of companies building present and future GaN / SiC devices. The experts at Power Integrations discuss their work to build advanced GaN switching technologies for mobile electronics charging systems and a wide array of other applications. We also examine work by researchers at Arizona State University that point to innovative solutions for reducing current leakage in GaN p-n junctions. Participants in the PowerAmerica initiative describe their work to eliminate the primary obstacles to widespread adoption of wide bandgap power electronics: costs; reliability and ruggedness that are typical concerns surrounding any new technology, and the need for greater workforce expertise.

Industry looks to a 2020 expected to deliver more gains for SiC and GaN devices even as incumbent silicon technologies break old performance barriers.

2020 is going to be a powerful year!

Editor & Publisher Jackie Cannon	jackie.cannon@angelbc.com	+44 (0)1923 690205
Technical Editor Mark Andrews	mark.andrews@angelbc.com	
Sales Manager Shehzad Munshi	shehzad.munshi@angelbc.com	+44 (0)1923 690215
USA Representatives Tom Brun Brun Media	tbrun@brunmedia.com	+001 724 539-2404
Janice Jenkins	jjenkins@brunmedia.com	+001 724-929-3550
Director of Logistics Sharon Cowley	sharon.cowley@angelbc.com	+44 (0)1923 690200
Design & Production Manager Mitch Gaynor	mitch.gaynor@angelbc.com	+44 (0)1923 690214
Circulation Director Scott Adams	scott.adams@angelbc.com	+44 (0)2476 718970
Chief Executive Officer Stephen Whitehurst	stephen.whitehurst@angelbc.com	+44 (0)2476 718970
Joint Managing Director Sukhi Bhadal	sukhi.bhadal@angelbc.com	+44 (0)2476 718970
Joint Managing Director Scott Adams	scott.adams@angelbc.com	+44 (0)2476 718970

Directors Jackie Cannon, Sharon Cowley

Published by Angel Business Communications Ltd, Unit 6, Bow Court, Fletchworth Gate, Burnsall Road,
Coventry CV5 6SP, UK. T: +44 (0)2476 718 970 E: info@angelbc.com

ISSUE 4 2019

CONTENTS

18 COVER STORY

GaN set to move deeply into power applications

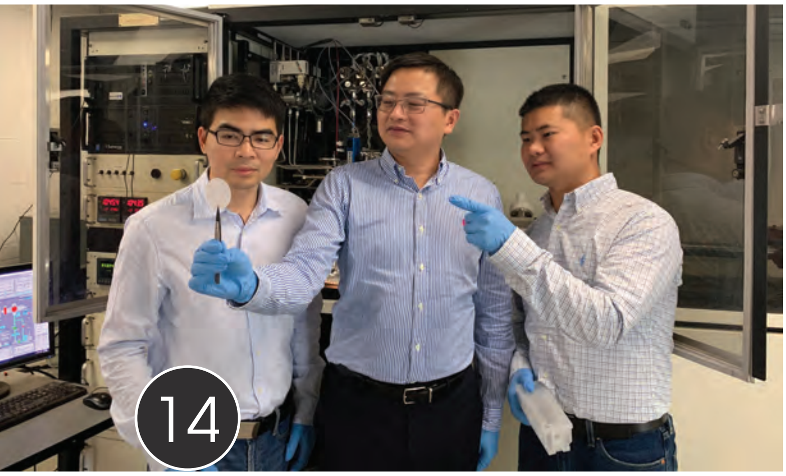
PEW Technical Editor Mark Andrews spoke with Power Integrations' Director of Training, Andrew Smith, about the company's expanding portfolio of GaN devices

12 Better etching enhances selective doping for vertical GaN power devices

Multi-step etching slashes the leakage current in regrown GaN p-n junctions for selective area doping

20 Trade disputes fuel supply chain worries, opportunities

Long-smoldering trade disputes between the United States and China have impacted many sectors of global economies with semiconductor manufacturers amongst those hardest hit


14

24 Empowering power electronics with PowerAmerica

PowerAmerica targets the primary obstacles to widespread adoption of wide bandgap power electronics: high costs, concerns with reliability and ruggedness, and a lack of expertise in the workforce

32 Will all roads eventually lead us to EVs?

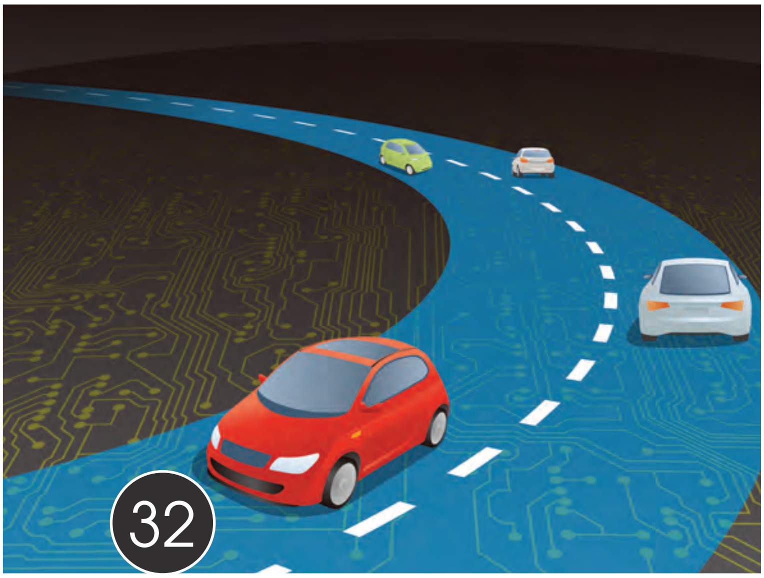
Siemens Smart Infrastructure: concerns persist over the charging infrastructure and price of electric vehicles (EVs)

34 Current sensing rises to the challenges of advanced embedded systems

The embedded electronics development community is currently experiencing the biggest changes in our industry since the creation of the integrated circuit


20

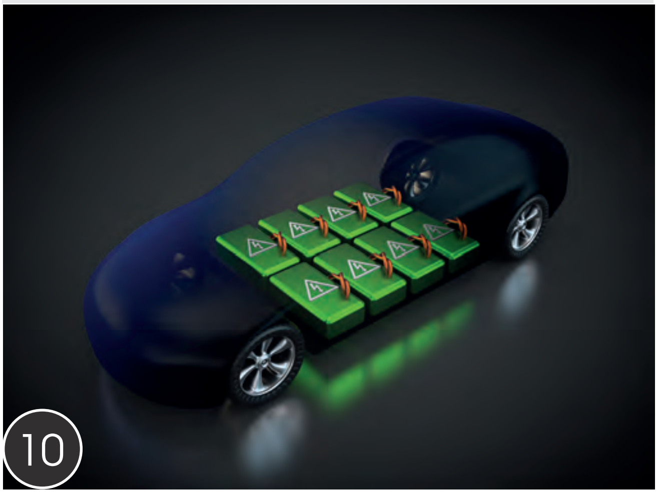

24


32


36


40

news


10

Transphorm GaN in Airbus and Boeing power supplies

TRANSPHORM as confirmed that customer AES Aircraft Elektro/Elektronik System GmbH has released its first 650 V GaN-based power supplies.

Serving the aviation industry, AES supports customers with various products and services ranging from electrical engineering to certification and testing.

The company's newest Switch Mode Power Supplies are currently used by large CS-25 airplane manufacturers (e.g., Airbus A318-A321, A330, A340, A380 and Boeing B767, B787 VIP aircraft) and use Transphorm's GaN FETs to increase overall system efficiency by more than 10 percent compared to competitive Silicon-based power supply unites (PSUs).

The two GaN-based Switch Mode Power Supplies are the PS250X 500 W system and the PS6120 1200 W system. Both products support a 96-130 VAC/360 Hz – 800 Hz input voltage with a 28 VDC continuous power output at 15 amps for the 500 W system and 42 amps for the 1200 W system.

Further, AES certified the PS250X and PS6120 as DO-160 compliant – meeting the more than 25-point stringent Standard of the Radio Technical Commission for Aeronautics (RTCA). This Standard assesses system impact and performance under various external and internal conditions on aircraft – ranging from pressure and temperature to voltage spikes and RF emissions.

The flagship 500 W PS250X is the industry's first passively cooled power supply at 420 W and deploys Transphorm's GaN in a single-phase CCM boost power factor correction (PFC) topology. It offers more than 92 percent overall system efficiency at full load, which is more than 10 percent greater than its competition. The system also yields a more than .98 power factor and 200 mVpp nominal at 115 VAC/400 Hz input at full load. All within an end product that is 1.4 kg (~3 lbs).

The 1200 W PS6120 deploys Transphorm's GaN in a fan-cooled, three-phase CCM boost PFC topology. It offers more than 91.5 percent overall system efficiency at full load, which is 11.5 percent greater than its competition.

The PS6120 also yields the same power factor and nominal ripple voltage at 115 VAC/400 Hz input at full load as the PS250X 500 W PSU. All within an end product that is 4.0 kg (~8.8 lbs).

"The aviation industry is working toward reducing climate impact through any means possible," said Dr. Andreas Hammer, Head of Competence Center Power, AES. "Considering, we sought out Transphorm's GaN to replace previously used Silicon MOSFETs so that we could provide a more efficient, lighter weight power supply.

These supplies have the potential to make a notable impact when considering each aircraft deploys several such PSUs. After only a year of redesign, we were able to offer our customers a better power solution, while also raising the performance bar within our own industry."

Interested in the technology's inherent higher switching frequency, AES reviewed GaN power switch converters from several GaN device semiconductor manufacturers. The company ultimately selected Transphorm's 650 V GaN technology due primarily to its ease of drivability and designability – specifically because Transphorm's GaN FETs do not require custom drivers.

As a result, system design is simplified while engineers can drive the switches using technology, they are already familiar with (i.e. drivers and packages). Other factors affecting AES' selection included Transphorm's proven reliability – which is underscored by its GaN platform earning both a JEDEC qualification and AEC-Q101 qualification at 175°C.

"Transphorm designed its GaN devices to enable designers, not challenge them," said Philip Zuk, VP of Worldwide Technical Marketing and NA Sales, Transphorm., "Our two-switch normally-off GaN devices come in standard packages and require minimal supporting circuitry to drive them, which reduces the overall system size, increases reliability, and simplifies design.

"It's crucial to us that our customers can come to market quickly with a product they have confidence in. We're honored to be AES' GaN supplier of record and are proud that they appreciate the work we've done to bring the benefits of GaN technology to the masses."

Isabellenhütte receives type examination certification

AS A SPECIALIST for shunt measurement technology, Isabellenhütte presents the first shunt-based, calibration law-compliant DC energy reference meter IEM-DCC-500 for charging infrastructure following the successful completion of the type examination. The DC meters are now available for purchase by manufacturers of charging stations and can be integrated into the designs of their applications.

The basis of the type examination certification was the successfully conducted metrological measurement series (accuracy class B), the operation of the software in compliance with calibration law, the corresponding documentation for the customers and institutes, as well as the positive completion of the EMC and environmental impact studies.

Andreas Prüfling, Director of the Business Unit Measurement at Isabellenhütte: "We thank PTB Braunschweig for this good collaboration, which has ultimately led us to achieving a solution for the market that complies with calibration law. Simultaneously, we have expanded series production so that the DC meter is now directly available to recharging station manufacturers."

The design features integrated current and voltage measurement (500 A and 1,000 V) as well as the calibration law-relevant periphery in a compact housing that is secured against manipulation.

The good news didn't only bring relief to the development partner positive Innogy, which is itself still in the process of completing the type examination for its own recharging station solution with integrated IEM-DCC-500, but also for Isabellenhütte's other strategic cooperation partners. Tobias Wolff, Business Development Manager for Smart Grid at Isabellenhütte had this to say: "We are currently helping five recharging station manufacturers to integrate our DC meter into their hardware structure. We would like to use our experience to support more companies with design integration in order to make the certification process for recharging station concepts easier."

The topic of "calibration-compliant DC energy measurement" has further potential for Isabellenhütte. Aspects such as adaptation to various power classes, increases in cost coefficients, and perspectives beyond the boundaries and market requirements of the EU promise an expanding field of business.

SPARX invests in GaN Systems

GaN SYSTEMS has announced that SPARX Group 'Mirai Creation Fund II' has made an investment in GaN Systems. The Mirai fund provides capital to companies to accelerate innovation, Vehicle Electrification being one of the major targets. Mirai fund's investors include Toyota Motor Corporation.

"After evaluating a variety of power semiconductor technologies and designs, GaN has emerged as a critical building block for power in automotive applications and our investment in GaN Systems complements our vision to shape the future and impact our world," said Shuhei Abe, president and CEO of SPARX Group, which is based in Japan.

At the 2019 Tokyo Motor Show this October, the very first All GaN Vehicle was revealed. Developed by Nagoya University Institute for Future Materials and Systems and Toyota Advanced Power Electronics Research Division, the All GaN Vehicle features multiple applications of GaN in an electric car: in the traction inverter, where GaN improves efficiency by 20 percent extending the driving range of the car on one battery charge; in the DC-DC converter, which allows a 75 percent reduction in size of the system, in the On-Board Charger, and in the LED lighting, where GaN lights the road during night driving.

The All GaN Vehicle has been spotted driving in and around Tokyo recently which was confirmed in videos playing during the Tokyo Motor Show.

GaN Systems continues to establish a strong position in the automotive industry with additional customers and strategic investors realising the value proposition of GaN and using the transistors in EV powertrain applications, namely, Traction Inverter, On-Board Charger, and DC-DC converter. "The combination of confidence in our best-in-class device performance, the release of the industry's highest current rated devices, and our device reliability exceeding the AEC-Q101 automotive industry standards, has contributed to more and more automotive OEMs and Tier 1 companies investing in our company and using our devices," said Jim Witham, CEO for GaN Systems. "It's great to see so many automotive companies taking advantage of the benefits of our GaN as the industry shifts from internal combustion engines to Electric Vehicles."

Dana shows SiC inverters at CTI Berlin

DANA, a US company that develops power-conveyance and energy-management for vehicles, is showing a highly efficient SiC inverter developed for e-racing at CTI Berlin, Dec. 9-12 (an industry event covering developments in automotive drivetrains). The Dana TM4 SiC inverter can support up to 900 volts – a higher voltage level than traditional inverters – and helps maximise battery efficiency.

Originally developed for the high-performance requirements of racing, which has served as a testbed for Dana's technology over the last five years, the Dana TM4 SiC technology inverters are capable of supporting more than 800 volts for passenger cars and 900 volts for race cars. The SiC technology enables higher system voltage and improves the overall system efficiency.

With the capability to increase the switching frequency when compared with traditional inverters technology, the quality of the output current can be improved, and a higher electrical frequency output current can be controlled, adding essential flexibility to the motor design. Another core benefit of the high-switching-frequency inverter is that it can deliver equivalent or greater power in a smaller package, while also reducing losses during power conversion – improving vehicle efficiency.

The showcased inverter with SiC embedded achieves 195 kW per litre, which is close to double the 2025 U.S. Department of Energy target of 100 kW per litre. Similarly, because of the SiC power module's high-performance properties, batteries and other critical vehicle elements of the system such as motors can be reduced in size, in turn supporting OEMs in their pursuit to develop more compact and lightweight vehicles. Dana TM4 is developing the technology for large-volume production to meet the growing demands for high performance inverters.

"Leveraging more than 30 years of know-how in power electronics design, Dana continues to lead the way in the development of new and enhanced inverter solutions," said Christophe Dominiak, chief technology officer for Dana. "Our SiC-based technology inverter demonstrates our leadership and capabilities in next-generation inverters. These new technologies are central to helping our customers achieve their power, range, and efficiency targets in the upcoming years."

ZF and Danfoss seal strategic partnership

ZF FRIEDRICHSHAFEN AG and Danfoss Silicon Power GmbH have stepped up their existing cooperation with a new strategic partnership for silicon- and silicon-carbide power modules. The partners plan to improve the efficiency of electric drivelines by leveraging engineering and cost benefits at the interface between power modules and inverters.

"This is a robust long-term partnership that enables ZF and Danfoss to pool their strengths. Coming together on this opens up significant innovation potential to improve the technical and commercial competitiveness of our inverters. We will utilize this advantage in all our drivetrain applications, from hybrid up to full electric applications," explains Jörg Grotendorst, Head of ZF's E-Mobility Division.

The partnership will see the two companies engage in joint research and development, with Danfoss also supplying power modules for silicon applications. One of the first major milestones in this new initiative is a supply contract for Danfoss power modules destined for large-scale ZF volume production projects. Beside 400 Volt standard applications the two companies have also begun co-developing an 800 Volt Silicon Carbide power module for a large volume production project, aiming to position themselves at the forefront of this new segment.

ZF's E-Mobility division supplies electric drive systems and components, while Danfoss Silicon power GmbH (DSP) is a specialist in silicon and silicon-carbide power modules. By joining forces to produce innovative open technology solutions for e-mobility drivelines, they aim to make a vital contribution to cutting vehicle emissions. In electric and hybrid vehicles, power modules control the efficiency of the energy supply to the drive, battery and onboard electronics. This means that the development of space-saving inverters and more efficient power modules is crucial to reducing emissions over the long term.

"We are proud to join this partnership with ZF. We believe this closer cooperation between Danfoss and ZF has the potential to be a game changer for the development and innovation of future drivetrains for electrification of vehicles. Together we can enable an acceleration of the transition of the transport sector," Kim Fausing, CEO of the Danfoss Group concludes.

Danfoss' power modules could also use power-chips developed by ZF in the recently announced cooperation with semiconductor specialist Cree. As one of the leading manufacturers of electromobility solutions, ZF aims to further advance electric driveline technology through the strategic partnerships.

Since January 2016, ZF has bundled its electromobility activities in the E-Mobility Division headquartered in Schweinfurt, Germany. More than 9,000 employees work in this division, spread across various locations around the world. Danfoss Silicon Power is a subsidiary of the Danfoss Group, the largest industrial company in Denmark.

For decades, Danfoss Silicon Power has been helping top tier manufacturers and system suppliers meet stringent reliability, design and cost targets by designing, developing and manufacturing customized power modules for automotive, industrial and renewable applications.

EDF Group acquire Pivot Power

EDF GROUP has announced the acquisition of a British start up called Pivot Power, specialising in battery storage and infrastructure for electric vehicle charging. This move will allow EDF, already the largest low carbon electricity producer in the UK, to become a leader in battery storage.

Now a wholly owned subsidiary of EDF Renewables, Pivot Power has an extensive portfolio of projects across more than 40 locations throughout the country. There are plans to install batteries connected directly to the high-voltage transmission system - with a total capacity of up to 2 GW. The first two storage projects at Kemsley (Kent) and Cowley (Oxford) have land, planning and grid connection agreements in place and are expected to be commissioned in 2020. As part of its projects, Pivot Power will develop a private wire infrastructure to enable, among other opportunities, the development of mass rapid charging points across the UK.

Each of Pivot Power's projects has the potential to host a battery capable of exporting 50 MW of power and to provide support for hundreds of rapid EV chargers, potentially suitable for large retail sites, logistics centres, bus depots and park and rides.

Battery storage and EV rapid charging infrastructure are two significant enablers for the UK's goals to reach net zero by 2050. Battery storage integration in the electricity transmission grid will also provide flexible capacity which will enhance the reliability of the network and boost the integration of renewable electricity. Providing the nationwide connections to power rapid charging stations supports the uptake of electric vehicles. instead of the internal combustion engine.

As part of the Electricity Storage Plan, this acquisition contributes to EDF's target of being the leader in Europe with 10 GW of additional storage by 2035. The acquisition is also in line with the EDF Electric Mobility Plan, to become the leading electric mobility company by 2022 in the UK, France, Italy and Belgium. Beyond this 2022 date, the Group's goal is to provide power for 600,000 electric vehicles and providing 75,000 charging points.

Bruno Bensasson, EDF Group's Senior Executive Vice President, Renewable Energies and Chairman & CEO of EDF Renewables, said: "Following PowerFlex Systems recent acquisition in the United States, this new acquisition of smart electricity storage and electric vehicle charging systems player is strengthening our expertise globally. Thanks to the skills developed within this specific field of new uses of electricity, the Pivot Power team will be a great addition to EDF. This is another positive step in the rollout of the Group's Electricity Storage and Mobility Plans."

Simone Rossi, EDF Energy CEO said: "Battery storage and electric vehicles are two key technologies which will help lower carbon emissions, alongside generation from renewables and nuclear. The acquisition of Pivot Power shows EDF is investing in a wide range of projects to deliver the huge shift to low carbon energy the UK will need to reach net zero by 2050."

Matt Allen, co-founder and CEO of Pivot Power, said: "Pivot Power's purpose from the start has always been to accelerate the UK's transition to a cost-effective, reliable, low-carbon energy system and in parallel fast-track the rapid adoption of clean transport. EDF Renewables shares our vision and of course brings the expertise, resources and platform to make this a reality."

Sumitomo ramps GaN-on-SiC production with Aixtron tool

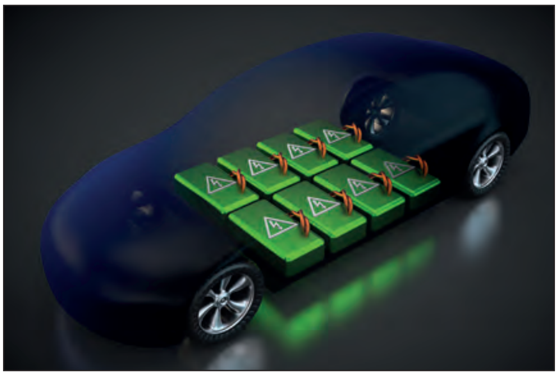
DEPOSITION equipment firm Aixtron SE has announced that Japanese group Sumitomo Electric Device Innovations, Inc. (SEDI) has ordered an AIX G5+ tool with 8x6-inch wafer configuration in order to expand the production capacity of GaN-on-SiC radio frequency (RF) devices for wireless applications such as radars, satellite communication and base stations for the rapidly expanding 5G mobile networks. The system is scheduled for delivery in 2019.

SEDI has already been successfully relying on Aixtron's Showerhead technology for the production of 4-inch GaN epitaxial wafers. The progressive deployment of 5G networks but also the introduction of new technologies like beamforming is foreseen to drive a rapid upturn in demand steering the adoption of more efficient 6-inch substrates for RF applications on Aixtron's proven Planetary systems.

By selecting the AIX G5+ Planetary MOCVD platform, SEDI relies on the tool-of-record for GaN-based HEMTs warranting not only superior process yields but also enabling lowest cost of ownership of the market. The system has an unmatched reputation for wafer uniformity and precise process control, which is especially important for device production on cost-intensive silicon carbide wafers. The new reactor is equipped with an EpiCurve TT metrology system as well as with Auto-Feed Forward and P400 UV Pyrometer Close Loop temperature control.

SEDI already has a range of GaN HEMT devices on offer for radar, mobile phone base-stations, and general applications. These GaN-on-SiC HEMT devices enable high power amplification at operating frequencies of 28-40 GHz and beyond as required by new 5G communication standards.

Dresden-based KaSiLi to make better batteries for electric vehicles in Germany



AS PART OF THE CLUSTER of competence for battery materials “ExcellBattMat“ funded by the Federal Ministry of Education and Research (BMBF), Dresden’s “ExcellBattMat Center” (project KaSiLi: structural cathode adaptation for silicon and lithium materials) contributes key components for this new battery generation. On November 1, 2019, researchers from Fraunhofer, TU Dresden and Leibniz started working together on innovative battery electrodes consisting of ultra-thin silicon or lithium layers to achieve high energy densities.

Electric vehicles are to travel up to 700 kilometers with one battery charge, and smartphones to be charged much less frequently. Dresden-based “KaSiLi” under the auspices of the Fraunhofer Institute for Material and Beam Technology IWS, will carry out research into new electrode technologies for three years.

“This is a quantum leap for battery technology,” hopes Prof. Christoph Leyens, Head of Fraunhofer IWS and director of the Institute of Materials Science at Technische Universität Dresden. “This disruptive technology has the potential to significantly advance Germany as a business location,” adds chemistry professor Stefan Kaskel from TU Dresden, who also heads the “ExcellBattMat Center” (Centre of Excellence for Battery Materials, EBZ for short) at Fraunhofer IWS and the KaSiLi project sponsored by BMBF.

In the long value-added chain from the battery cell to the finished electric car, German economy could thus gain significantly in importance. “Ultimately, we want to establish a modern battery cell production facility in Germany. As a result, we would be less dependent than before on supplies from the Far East or the USA for the transition to electromobility and renewable energies,” Kaskel emphasised. To achieve this, the researchers are developing new materials, design principles and processing technologies for the electrodes in the smallest energy storage units of an accumulator. Important components in such a cell are the anode and cathode. The electrical charge carriers move back and forth between these two poles when a battery is charged or when it is supplying electricity for the electric motor in an electric car. Today, the anode in a lithium-ion battery usually consists of a copper conductor a few micrometers (thousandths of a millimetre) thin, covered with a graphite layer about 100 micrometers thick.

The Dresden chemists want to replace this graphite layer with much thinner layers of silicon or lithium. These will then measure only about ten to 20 to 30 micrometers. In the lab, this already works quite well and already provides more energy storage capacity. “Today’s lithium-ion batteries have an energy density of around 240 watt hours per kilogram or up to 670 watt hours per liter,” explained Stefan Kaskel. With our electrodes, we want to achieve well over 1,000 watt hours per litre.

On the way, however, the developers not only have to further improve the chemistry and coating processes for their cells, but also solve a mechanical problem: Under the microscope it has been shown that the electrodes, which are thinly coated with silicon or lithium, shrink again and again and expand when the batteries are charged or discharged – as if the cell were breathing. However, this poses a problem because the mechanical stress can quickly destroy the electrodes through this “breathing”. For this reason, the partners are now experimenting with tiny springs. They are working on special layers for the cathode formulations. “These are to be given cushioning properties through a special adaptation of their microscopic properties to contribute significantly to a higher energy density of the new battery generation,” said Dr. Kristian Nikolowski from the Fraunhofer Institute for Ceramic Technologies and Systems IKTS.

In order to cast all these technologies into prototypes and finally bring them to series maturity, the KaSiLi partners combine various research strengths that complement each other. Fraunhofer IWS contributes its experience in thin-film technology. The Fraunhofer IKTS deals with oxide cathode technology and its scaling. The nanoelectronics laboratory “NaMLab” at Technische Universität Dresden (TUD) uses special spectroscopy equipment to investigate the newly designed anodes. The Leibniz Institute for Solid State and Materials Research (IFW) Dresden focuses on the structural analysis of electrode layers. The TUD Chairs for Inorganic Chemistry of Prof. Stefan Kaskel and for Inorganic Non-Metallic Materials of Prof. Alexander Michaelis are responsible for the preliminary research for new electrode structures. In addition, these Dresden institutes are cooperating with the other three German ExcellBattMat centres in Münster, Munich and Ulm. The Dresden researchers act as a kind of high-tech hotbed for new materials within the Germany-wide umbrella concept “Battery Research Factory”, which unites numerous battery funding activities of the BMBF under one roof.

The KaSiLi partners intend to have functional demonstrators ready by 2022. The new battery design will then flow into a “research production battery cell” in Münster. All this ultimately aims to establish a large-scale production of battery cells in Germany. This should improve the competitiveness of electric cars “Made in Germany” and secure jobs there.

angel tech

CS INTERNATIONAL CONFERENCE

31 MARCH - 1 APRIL 2020
BRUSSELS, BELGIUM

Why should you choose to sponsor with CS International?

- Are you looking to accelerate your growth and reach the major players in the compound semiconductor industry?
- Do you want to educate, influence and network with the industry?

If you have answered yes to any of the questions above, then CS International 2020 is the perfect event for you. Here are but a few reasons why you must consider sponsorship.

Reasons to sponsor

1. **Access and network with the top strategists within the compound semiconductor industry**
   Celebrating its tenth anniversary, CS International 2020 will allow you to engage with 450+ key senior decision makers from the major companies across the compound semiconductor industry in one dedicated exhibition hall, including over 30 international experts, who will speak at the conference.

2. **Raise brand and company awareness**
   We have an intensive and multi-faceted marketing program available and already underway, which includes email marketing, social media, conference partners, direct mail and live events in addition to promotion in the prestigious Compound Semiconductor print and digital magazine. Coupled with the marketing program, the support of our highly esteemed Conference association and media partners ensure your company, product and service will achieve maximum visibility within the compound semiconductor industry for the next 7 months.

3. **Thought leadership and credibility**
   Aligning with the premier compound semiconductor conference will give you a great opportunity to be positioned as a thought leader in the industry. Engage in debate, share insights and expertise on industry challenges with your peers.

4. **ROI and long-term partnerships**
   Many of our sponsors repeatedly support the event year on year, demonstrating how the industry trusts the CS International brand as the leading information and networking resource to deliver the best programme and ROI. Unparalleled networking opportunities enable you to both build existing and generate new relationships and demonstrate ROI by aligning with the conference brand.

5. **Accessibility**
   We have opportunities to suit all budgets.

6. **Post-event exposure**
   Even when the event is over, you will be included in off-season conference promotional activities, plus the CS print and digital magazine as well as the weekly email newsletter.

7. **Expand your audience**
   CS International is part of AngelTech, a brand which uniquely delivers insightful, engaging and high-valued conferences that have tremendous synergy between audiences. The current line-up, attracting more than 700 delegates, consists of co-located Compound Semiconductor (CS) International, Photonic Integrated Circuits (PIC) International, and Sensor Solutions International (SSI). Delegates can choose between which sessions they want to participate in and the single exhibition hall layout enables exposure to 3 different but related audience.

Contact: sponsor@csinternational.net to discuss opportunities with the CS International Conference and Exhibition team or by calling +44 (0)2476 718 970 today.

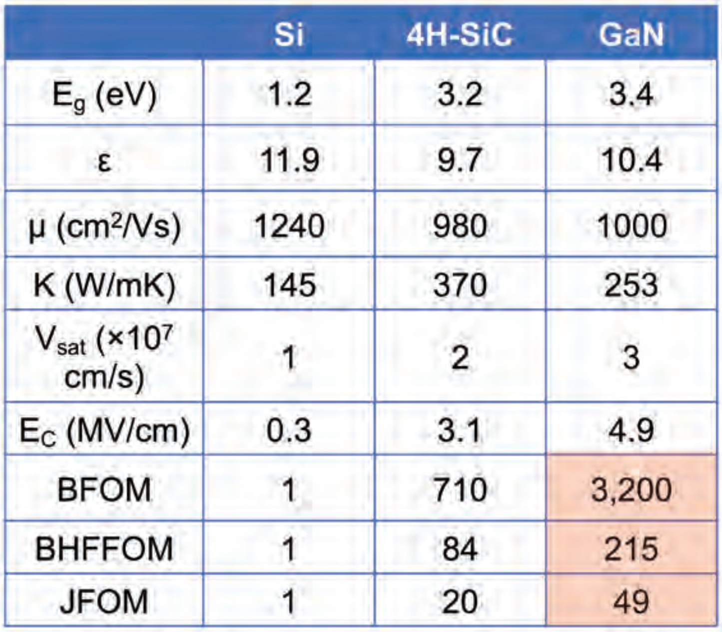
Sponsorship opportunities are limited.

Better etching enhances selective area doping for vertical GaN power devices

Multi-step etching slashes the leakage current in regrown GaN *p-n* junctions for selective area doping.

BY HOUQIANG FU, KAI FU AND YUJI ZHAO FROM ARIZONA STATE UNIVERSITY

GaN IS A VERY ATTRACTIVE material for making power electronics. It has a bandgap that is three times wider than the incumbent, silicon, and a critical electric field that is more than ten times higher. Thanks to these attributes, devices made from GaN can realise higher breakdown voltages when they have the same thickness as those made from silicon, or a similar breakdown voltage with less material.



	Si	4H-SiC	GaN
E_g (eV)	1.2	3.2	3.4
ε	11.9	9.7	10.4
μ (cm^2/Vs)	1240	980	1000
K (W/mK)	145	370	253
V_{sat} (×10^7 cm/s)	1	2	3
E_C (MV/cm)	0.3	3.1	4.9
BFOM	1	710	3,200
BHFFOM	1	84	215
JFOM	1	20	49

Table 1. Material properties and power electronics figures-of-merit (FOMs) for silicon, SiC and GaN. E_g: bandgap; ε: permittivity; μ: mobility; K: thermal conductivity; V_{sat}: saturation velocity; E_C: critical electric field; BFOM: Baliga's FOM; BHFFOM: Baliga's high frequency FOM; JFOM: Johnson's FOM. The FOMs of silicon are normalised to 1 to ease comparison.

Additional strengths of GaN devices are a low on-resistance and a high switching speed, merits that are reflected in outstanding values for various figures-of-merit (see table 1).

However, these excellent material properties are of no practical benefit unless they are harnessed in electronic devices that excel on many fronts, and lead to efficiency gains in the likes of the power grid, electric vehicles, renewables, data centres, wireless charging, and consumer electronics.

Building great GaN devices is far from trivial, with success hinging on the use of the best geometry. Early development focused on lateral GaN power devices, such as HEMTs, grown on foreign substrates. With this architecture, breakdown voltages are held laterally, and currents flow laterally. That's not ideal. Part of the problem is that there are issues associated with surface states that can lead to performance degradation, and also result in reproducibility and reliability concerns. In addition, the heat that is generated concentrates in a very narrow region, causing device temperature to rise; and the higher breakdown voltages require a larger chip area, an impediment to scalability.

To tackle these issues, our research team at Arizona State University has been developing high-performance vertical GaN power devices on bulk GaN substrates. One merit of this architecture is that it employs homoepitaxial growth, significantly reducing the density of defects, which can deteriorate breakdown voltages and increase leakage currents.

What's more, the vertical device geometry offers: higher voltages and forward currents, without sacrificing chip area; better scalability and heat dissipation; and freedom from the effects of surface states.

This approach may raise a few eyebrows, given the high cost of GaN substrates. However, volumes have been steadily growing over the years, large size substrates with diameters of up to 6 inch are starting to emerge, and the substrate price is expected to continue to decrease, due to further expansion of both the power electronic market and that for GaN optoelectronic devices, such as laser diodes.

Vertical GaN power devices can be divided into four regions: the buffer layer, the drift layer, the channel layer and the edge-termination region (see Figure 1). We have strategies for improving each of these, leading to a boost in device performance. For the channel layer we are pursuing selective-area doping, an ongoing hot topic.

Doping challenges

Selective-area doping remains a huge hurdle for realising the full potential of GaN power electronics. The purpose of this form of doping is to create laterally patterned *p-n* junctions (see Figure 2(a)). This type of junction is needed for the fabrication of various GaN power devices, including: junction barrier Schottky diodes or merged *p-n*/Schottky diodes (see Figure 2(b)); and vertical junction FETs (see Figure 2(c)). These structures have been produced in silicon and SiC by ion-implantation, but not in GaN.

There are two reasons why it is very challenging to realise ion-implantation in GaN, especially for the production of *p*-type material. One issue is related to the subsequent thermal annealing process, needed to activate implanted atoms and recover crystal damage caused by ion-bombardment. To anneal, often the temperature has to exceed 1200 °C, but GaN begins to decompose at only 900 °C.

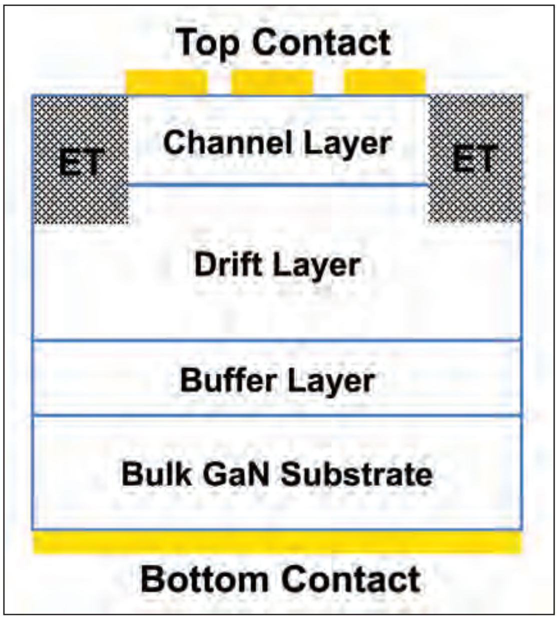


Figure 1. A cross-sectional diagram of the simplified structure of vertical GaN power devices on heavily doped bulk GaN substrates. ET indicates edge terminations

The second concern relates to the success of approaches to overcome this decomposition. To alleviate GaN decomposition at high temperatures, researchers have turned to capping layers such as AlN, multi-cycle rapid thermal annealing, and ultra-high pressure, but in all cases the conductivity of the implanted *p*-GaN is still very low – and judged from the perspective of power devices, it is far from satisfactory.

To overcome this particular hurdle, we have developed a re-growth method that realises selectively doped *p-n* junctions. With our approach, we can produce high conductivity *p*-GaN without having to worry about high annealing temperatures and associated GaN decomposition. This process currently remains one of the most important and promising methods for selective-area doping.

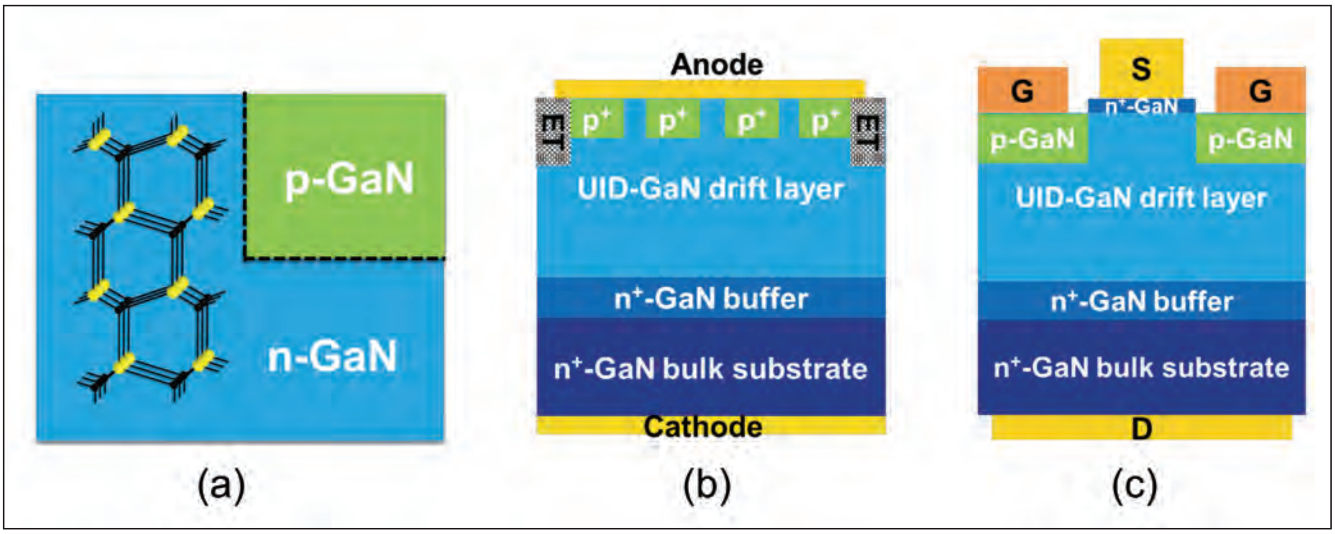


Figure 2. a) schematics of selectively doped *p-n* junctions. (b) JBS diodes or MPS diodes. (c) VJFETs.

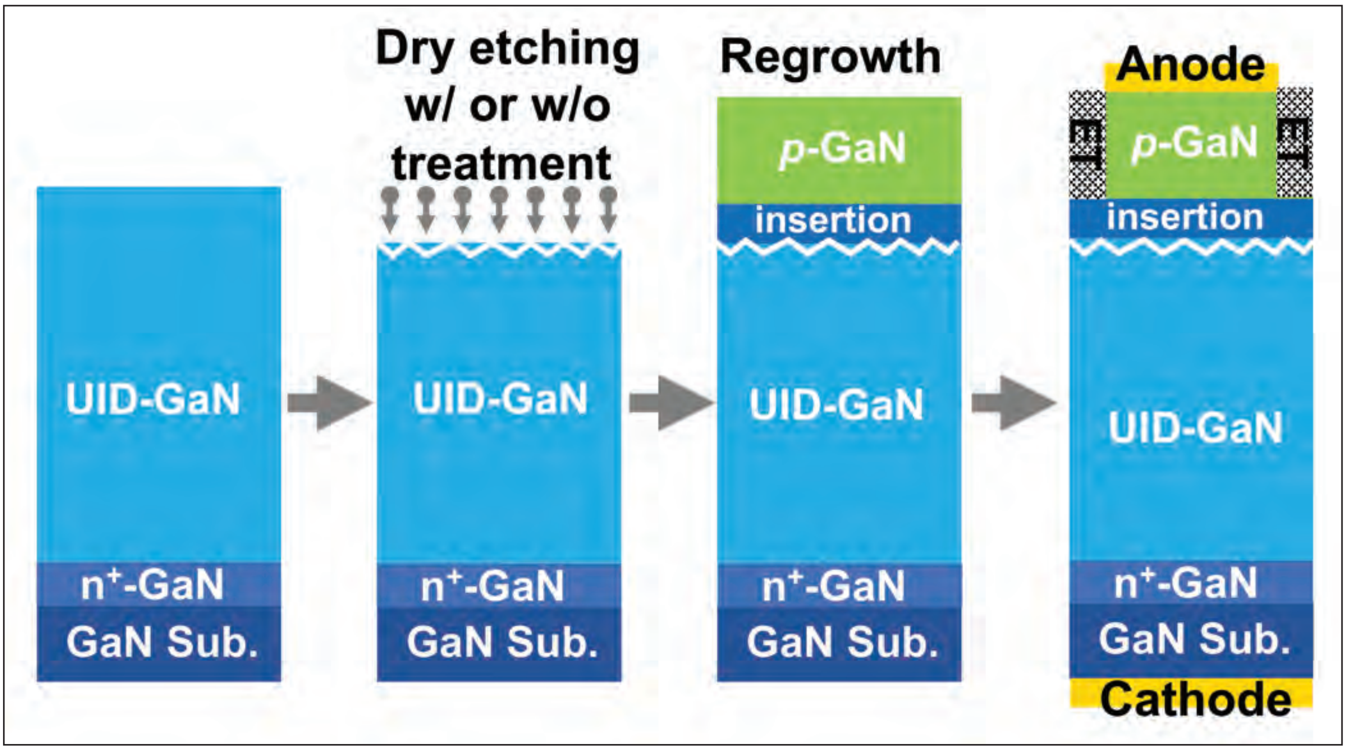


Figure 3. The growth and fabrication process of regrown *p-n* junctions formed by MOCVD. The structure is homoepitaxially grown on (0001) bulk GaN substrates. It is formed by the growth of an n^+-GaN buffer layer and an unintentionally doped (UID) GaN drift layer, before undertaking ICP dry etching and surface treatments, followed by the regrowth of a thin insertion layer and *p*-GaN. Diode fabrication includes the deposition of metal stacks for anodes and cathodes, mesa isolation and edge termination.

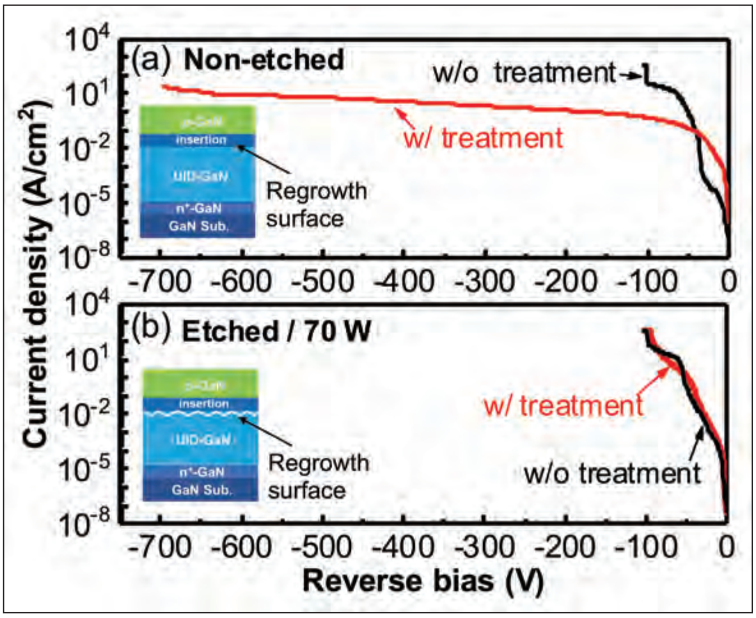


Figure 4. Reverse current-voltage characteristics of (a) non-etched and (b) etched samples with and without surface treatments. The non-etched sample was not subject to ICP plasma etching before regrowth. The etched sample was subject to ICP plasma etching, using a power of 70 W. Etching proceeds at around 200-300 nm/min, a reasonable rate for most device fabrication processes. A high etching power results in stronger ion-bombardment and more severe etching damage.

When we undertake our regrowth process, it is essential to ensure that the subsequent devices are not impaired by large reverse leakage currents, which can limit the ultimate breakdown voltage and increase power conversion losses in power electronics. Our research has uncovered two contributors to large leakage currents: surface contaminations at the regrowth interface, caused by impurities such as silicon, oxygen and carbon, all identified by secondary ion mass spectrometry; and etching damage, often caused by inductively coupled plasma etching, which is a widely used dry etching technique during GaN device fabrication.

To obtain selectively doped *p-n* junctions (as shown in Figure 2(a)), we could selectively remove part of *n*-GaN by inductively coupled plasma etching. This step would form trenches for subsequent *p*-GaN regrowth. However, this process would complicate experiments and analysis, because when two interfaces are exposed there is the possibility that leakage currents will flow in two directions. What's more, this approach is time-consuming.

To avoid these complications and speed turnaround, we begin by making planar regrown *p-n* junctions (see Figure 3). These junctions, regrown by MOCVD, have provided us with a test vehicle for obtaining fundamental knowledge on regrowth, such as the impact of inductively coupled plasma etching and surface treatments.

Evaluating etching damage

For our first set of experiments, we co-load two samples into the MOCVD reactor and regrow without any surface treatment. With this approach, we compared a non-etched sample and one etched with an inductively coupled plasma etching power of 70 W. Both samples suffer from large reverse leakage currents, highlighting the need to properly treat the surface prior to regrowth.

To realise this, we adopt a combination of UV-ozone and acid surface treatments. The former utilises powerful oxygen radicals to oxidize the surfaces and organic residue contaminants. The beauty of this treatment is that it is purely chemical, and thus free from plasma discharging. Note that with inductively coupled plasma etching, ion-bombardment takes place that can lead to charging damage and deterioration of the device's electrical characteristics. After the UV-ozone treatment, both samples are immersed in hydrofluoric acid and hydrochloric acid to remove oxidised materials and future clean the surface.

Electrical measurements reveal a massive reduction in the reverse leakage current in the non-etched sample. But that's not the case in the etched sample (see Figure 4). Our hypothesis for explaining this stark difference is that in the etched sample, etching damage is so severe that it cannot be repaired by surface treatments.

To put this theory to the test, we have carried out another set of experiments involving a lower etching power. This is reduced to just 5 W, a condition that slows the etching rate. We compare the reverse leakage currents in an as-grown sample with three samples that are first subjected to the aforementioned surface treatments. Two samples are etched with a power of 5 W, with an insertion layer thickness of 25 nm and 50 nm, respectively, and a third is etched at 70 W.

Results indicate that slow etching dramatically reduces the reverse leakage currents, and that an insertion layer helps to move the junction away from the regrowth interface, further reducing the reverse leakage current (see Figure 5). For the etched sample with an inductively coupled plasma etching power of 5 W and a 50 nm insertion layer, the reverse leakage current is lower than that in the non-etched sample and similar to the as-grown sample. The key conclusion from this experiment is that the combination of slow etching and proper surface treatments is very effective for regrowth.

Our findings prompt this question: What really drives the difference in reverse leakage currents between these samples? To find out, we have taken a closer look at the regrowth interface.

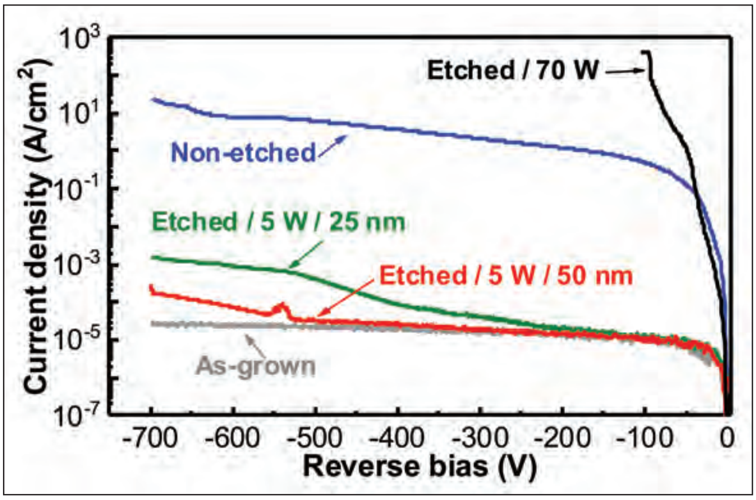


Figure 5. Reverse current-voltage characteristics of the non-etched sample and different etched samples. The power indicates the ICP etching power, and the thickness indicates the insertion layer thickness. An etching power of 5 W corresponds to an etching rate of around 20 nm/min.

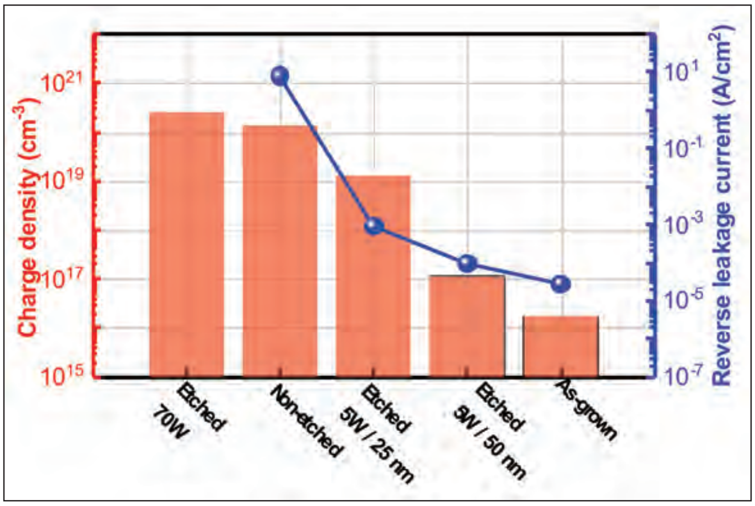


Figure 6. Charge density at the regrowth interface (histogram) and leakage current (line-shape) at −600 V for the five samples measured in Figure 5. The charge density is extracted from capacitance-voltage measurements.

One of its characteristics that can have a significant impact on the regrowth interface, and ultimately reverse leakage currents, is the charge density. Our measurements show that the higher the interface surface density, the larger the leakage current (see Figure 6). The as-grown sample has a low, constant charge distribution, on the order of 10^{16} cm^{-3}, while the regrown sample has a peak charge density at the regrowth interface in the range 10^{17}-10^{21} cm^{-3}. Measurements also show that a reduction in the etching power lowers the charge density at the regrowth interface, and trims the leakage current.

It is not surprising that a high density of surface charges has profound physical consequences. These charges will create a large electric field at the regrowth interface, and help carriers to tunnel through the potential barrier in the *p-n* junction and make a significant contribution to the leakage current.

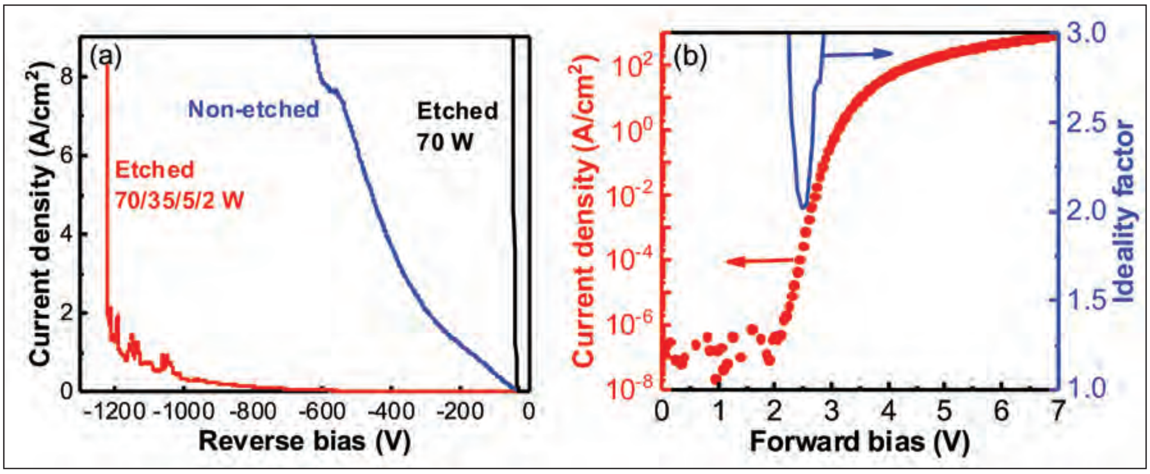
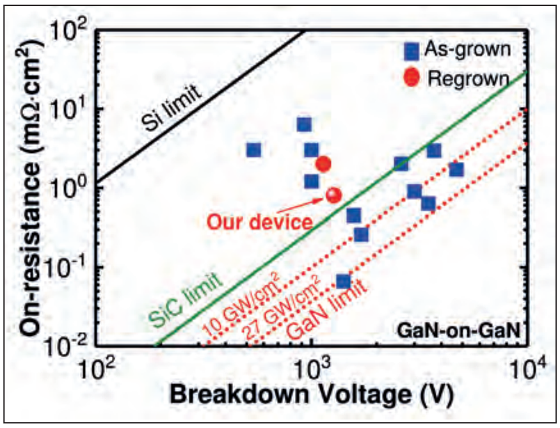


Figure 7. (a) Reverse current-voltage characteristics of the non-etched sample, the sample with the single-step etching, and the sample with the multi-step etching. All samples are subject to the aforementioned surface treatments. (b) Forward current-voltage characteristics and ideality of the sample with the multi-step etching.

Figure 8. Benchmark plot of on-resistance versus breakdown voltage for reported as-grown and regrown GaN-on-GaN *p-n* diodes.



Multi-step etching

Although slow etching delivers the best results, it's not always practical. It can be very time-consuming, a significant impediment for some device structures with deep trenches and mesas.

To address this concern, we have evaluated multi-step etching, decreasing the ICP power from 70 W to 35 W, and then down to 5 W and finally 2 W. The four-step etching process pays dividends, producing samples with significantly reduced reverse leakage currents and the highest breakdown voltage – it can be over 1.2 kV (see Figure 7(a)).

Another benefit of this multi-step etching process is that it produces a good regrowth surface. We have compared two etched samples, both subject to a 70 W etching power. Subsequent slow etching steps, using multi-step etching, produce significant improvements in surface quality. We postulate that during multi-step etching, slow etching probably plays a role in recovering the plasma etching damage caused by previous high-power etching steps. In other words, slow etching is more like healing than etching.

Before we can herald multi-step etching as a great success, we need to make sure that it doesn't degrade the forward characteristics of regrown *p-n* junctions. Our measurements are encouraging. Samples exhibits excellent forward rectifying behaviours, with an on-off ratio of around 10^{10} and an on-resistance of 0.8 mΩ cm^2. The ideality factor, which can be used to evaluate the performance of a *p-n* junction, is also promising. Its value is around 2.0, a figure that compares favourably with previously reported values for regrown *p-n* junctions, and is close to that of our as-grown samples – they are in the range 1.5-1.8.

Baliga's figure-of-merit provides another opportunity for us to benchmark our regrown *p-n* diodes. For these devices, it is 2.0 GW cm^{-2}. That's very close to the SiC limit, and even comparable to some values reported for as-grown *p-n* diodes. Given that this work is still in its infancy, we are very encouraged by this result. We anticipate improvements in inductively coupled plasma etching, surface treatments and device fabrications, spurring the performance of GaN regrown *p-n* junctions towards the GaN limit.

In short, our results show that it is possible to produce high performance regrown *p-n* junctions via epitaxial regrowth. Our next step is to apply the obtained fundamental knowledge on regrowth to selective area doping. When progress follows, it will make a significant contribution to improving the performance of advanced GaN power electronics, and helping this class of device to create a greener planet.

Further reading

K. Fu *et al.* Appl. Phys. Lett. **113** 233502 (2018)
K. Fu *et al.* IEEE Electron Device Lett. **40** 1728 (2019)
H. Fu *et al.* Appl. Phys. Express **11** 111003 (2018)
H. Fu *et al.* IEEE Electron Device Lett. **39** 1018 (2018)
H. Liu *et al.* Appl. Phys. Lett. **114** 082102 (2019)

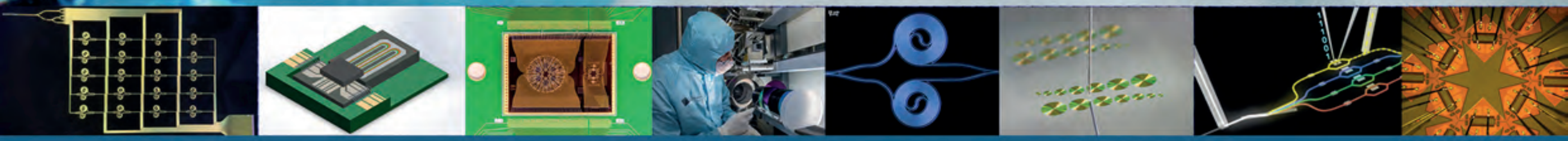
CORNERSTONE

www.cornerstone.sotonfab.co.uk

UK Silicon Photonics Fabrication Capability

PIC AWARDS WINNER 2019

CORNERSTONE is a rapid prototyping fabrication capability that can provide competitive prices for both active and passive silicon photonic devices, via an MPW service.



UNIVERSITY OF Southampton

University of Glasgow

UNIVERSITY OF SURREY

EPSRC Engineering and Physical Sciences Research Council

GaN set to move deeply into power applications

PEW Technical Editor Mark Andrews spoke with Power Integrations' Director of Training, Andrew Smith, about the company's expanding portfolio of GaN devices for mobile electronics, automotive and renewable energy applications. The PI experts say that GaN is available and cost-effective, giving incumbent power technologies new competition in global markets.

Q WHEN GaN STARTED to branch out from defence/security/High-Rel applications into consumer markets, it was frequently touted as THE technology enabling ultra-small, universal laptop power converters & rechargers – But these super-small converters haven't materialized, at least not in general consumer product lines. Given PI's focus on recharging and power conversation apps amongst its many products, where does the company see the industry at present when it comes to bringing GaN technology to market in this application area?

Power Integrations' InnoSwitch technology is designed for small form factor applications including miniaturized laptop, tablet and smartphone chargers.

A Actually, GaN is here! We announced our PowiGaN™ technology in July of this year. We have been shipping to customers for more than a year and recently shipped our 1 millionth device. We developed the PowiGaN technology specifically for offline power conversion to harness some of the performance benefits promised by wide band-gap technology and put it inside our highly integrated InnoSwitch-3 and LYTSwitch-6 power conversion ICs. Integration allowed us to solve the challenges associated with the very fast switching of GaN devices, such as noise suppression, EMI and protection while allowing us to reduce heat generated by more than 30%. The improvement in efficiency means that heatsinks are not required for power adapters and chargers up to 100 W and has enabled a wave of new converter designs that are just beginning to enter the market.

Q What are the most prevalent applications of GaN technology within consumer and industrial market segments?

A Rapid charging and USB PD for tablets and smart-phones has benefited from a new generation of configurable conversion technologies such as our InnoSwitch™3-Pro family. New designs are entering the market at a rapid rate as the technology coalesces around stable power delivery protocols. The increase in power capability enabled by PowiGaN technology in easy-to-use familiar conversion devices as well as the increase in efficiency means that this market segment will continue to grow and dominate the initial use of GaN. Other industries such as industrial and appliance markets, Home-Business Automation (HBA) and solid-state lighting tend to move more slowly, but all are embracing the benefits of the new technology. This is especially true with respect to the small-size it can enable for reliable power conversion.

Q What differentiates Power Integrations' GaN-based solutions from competing technologies, especially in the areas of AC-DC conversion and industrial motor drives?

A PowiGaN was developed by Power Integrations for offline power conversion. For example the high VDS(MAX) rating reflects industry requirements for a robust power switch. We package our PowiGaN technology inside our existing families of power conversion ICs. In doing this we eliminate the challenges of driving GaN seen with discrete devices, and use Lossless current sensing to eliminate the discrete sense resistors that can contribute more series impedance (and power loss) than the GaN switch itself. This allows our customers to confidently and quickly adopt PowiGaN technology and quickly bring the benefits to the consumer.

Q Cost differentials and concerns over long-term performance have dogged gallium nitride technology's evolution in commercial/consumer markets as we have seen with earlier wide bandgap technologies (GaAs, SiC, etc.). Challenges have largely been overcome in many areas while others remain. What could be holding back the further growth of GaN in consumer / industrial / commercial applications?

A Our approach has been to position PowiGaN as simply a better power switch. Wide band-gap technology has promised a lot and there have been a several predictions about performance in advance of any real data. Discrete implementations of the new technology required a lot of external components to implement successfully which led to solutions that failed the cost-vs-performance challenge and slowed adoption beyond niche markets. We have followed a more cautious approach in introducing our technology, developing manufacturing processes and test protocols that ensure long term performance and reliability before bringing products to the market. This has enabled a smooth and accelerating adoption ramp with our customers. Optimized performance and employing appropriate integration techniques means that our technology provides the benefits of performance that can be cost-effectively achieved leading to widespread adoption of the technology for more mainstream applications and products.

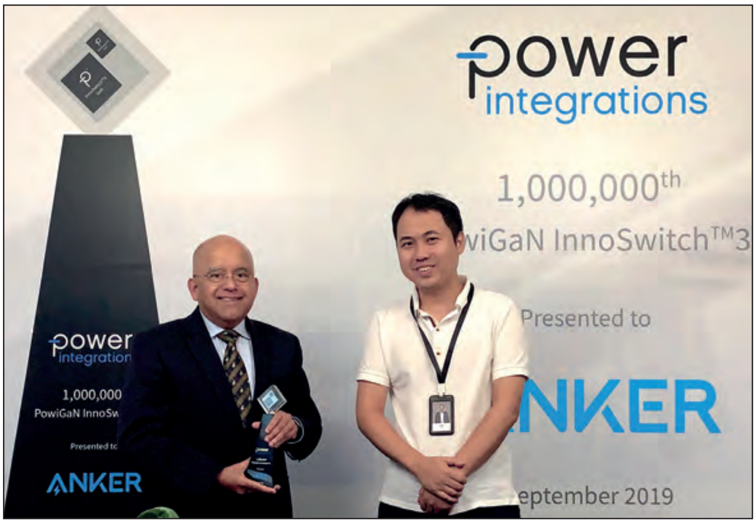
Q What is Power Integrations' view of the next big hurdle GaN technology needs to overcome in consumer, commercial or industrial applications in terms of engineering/technology or consumer preference?

A We believe that we have solved the application challenges of employing GaN technology which means our customers can exploit the smaller size and lighter weight that increased efficiency and less heat delivers. Customers already value these benefits and the industry is moving quickly to adopt the new technology in their next generation of products. The only obstacle that remains to be overcome is for manufacturers to dispel any lingering concerns about the "newness" GaN and embrace the technology.

The new Power Integrations LYTSwitch-6 provides faster switch energy conversions at higher voltage and frequency; its small size makes it ideal for applications across many OEM products.

Q Is there anything we haven't touched upon that you would like to explore?

A These are good questions and cover a lot of areas. One of the ongoing myths about GaN is that it is a high frequency technology that must employ planar magnetics for optimum performance. Power supply design is about balancing all areas of operation to create the best possible design for an application. High frequency designs sacrifice some of the efficiency benefits of GaN switches to provide a smaller power transformer. The penalty for higher switching frequency is EMI and circuit noise which both increase the size of the EMI filter and create design challenges for the engineer. We believe that power supply size is a thermal challenge, and is not driven by component size. We have therefore adopted a lower frequency switching approach to maximize efficiency and simplify filtering. This approach has led to balanced designs which are easy to implement, use conventional transformers and still achieve industry leading form-factors.



Power Integrations CEO, Balu Balakrishnan, presents Anker with an award following the company's receipt of Power Integrations' one millionth GaN chip.

Trade disputes

fuel supply chain worries, opportunities

Long-smoldering trade disputes between the United States and China have impacted many sectors of global economies with semiconductor manufacturers amongst those hardest hit. Recent headlines in Washington, DC and Beijing have signaled a compromise may be coming, but long-term consequences could persist for years. Silicon Semiconductor asked experts at the Chartered Institute of Procurement and Supply (CIPS) to examine today's issues and how these may affect business in 2020 and beyond.

REPLIES FROM: BILL MICHELS, VP OPERATIONS, CIPS AMERICAS

Q Trade disputes between the US and China were ratcheted up this summer when US President Donald Trump announced additional sanctions. What has the 'tit for tat' done to affect business and supply chain conditions for semiconductor manufacturers?

Bill Michels: The recent developments in the US-China trade conflict are pushing organizations to accelerate reassessment of their supply chains. For many companies, the cost savings of sourcing from China have been diminishing for some time, while risks have been increasing, so changes were in the works before the trade war began. As the tit for tat between the two governments' ebbs and flows, it has not brought a resolution of the conflict into focus. Instead, uncertainties are growing, forcing the hand of risk-averse organizations to 'reshore' or move their sources to other new origins not subject to tariffs.

Companies that can raise the capital to invest in automation or other manufacturing innovations are finding that those investments can offset the benefits of low-cost country sourcing. Black and Decker is an example of that, as it has announced it will build a highly automated, $90 million dollar facility to produce Craftsman hand tools.

However, we can't expect a huge migration back to the US. Technology companies that have made huge investments in equipment and training a workforce are not likely to move back quickly. In fact, A.T. Kearney's 6th annual Reshoring Index confirms that growth in manufactured goods imported into the United States from the 14 largest low-cost country (LCC) trading partners in Asia rose by $66 billion or 9 percent for the year, the largest annual increase since the beginning of the economic recovery. US gross manufacturing output, by comparison, grew only 6 percent year-over-year in 2018.

Another response to changing world markets is to build smaller, autonomous plants close to the markets they serve. In that scenario production may stay in China, but primarily to serve Asian markets. The notion of one location distributing to the world is diminishing, based on the changing political, social, and environmental conditions of the global economy.

President Trump has asserted that China needs a US trade deal because Chinese companies are more adversely affected by tariffs than American corporations. But global economists have argued that China's current growth is not much slower than expected and that China is using the dispute to grow internal demand and supply sources that bypass the US – what's your view?

Bill Michels: The worst unintended consequence of the dispute could be a downturn in the global economy. According to IHS Markit, the Future Output Index in the J.P. Morgan Global Composite PMI hit a seven-year low in July. Panelists surveyed cited the US-China trade war as one of the factors lowering their forecasts. The rising uncertainties from the dispute also appear to be affecting the US stock market – sending it up or down depending on what signal comes out of Beijing or Washington.

Have US-China supply chains been rerouted because of the dispute?

Bill Michels: Categories with low complexity can easily be moved to Vietnam, Malaysia, Thailand, the Philippines, and other countries not subject to the tariffs. No doubt the trade issues are forcing the reengineering of supply chains and creating a redistribution of products.

Some of the rerouting going on now predated this particular dispute. Samsung, for instance, reportedly has moved a significant amount of its production from China to Vietnam. Apple may be considering a similar move, and a continuing dispute could accelerate their decision.

Have you seen evidence that Chinese manufacturers are developing alternative resources either from within China or other regions?

Bill Michels: I have not seen specific evidence of Chinese manufacturers developing alternative sources from within their own country or other, less hostile countries; however it could be that the Chinese government is holding its position so firmly because it feels that companies there can find alternative sources. I have also seen some Chinese investment in the US. The sale of the GE appliance business to Haier is a great example

Have key members of the US/China supply chain learned from this experience to the point that they are factoring how-to-operate amidst a trade war into present day operations and/or future planning?

Bill Michels: It seems clear that many of the firms we have mentioned, Samsung, Apple, Black & Decker, as well as others have been taking a lot of factors besides labor costs into their sourcing decisions for some time. For those forward-looking companies, the risks of a trade war are simply one more factor to go into a complex decision. They have likely been looking at logistics issues and the risks of intellectual property or data theft as other potential costs of sourcing from China.

President Trump may have delayed tariffs on many popular consumer products, and there may be a more comprehensive deal reached eventually, but the well has been poisoned for now and it will likely bring long-term changes. The lesson here is that supply chain professionals have an obligation to continually manage innovation and geopolitical risk. They can't wait for a crisis, they must prepare for whatever might come. The application for exemptions to tariffs has benefited some firms. Applie got 10 exemptions and some of my clients were successful.

Within the US, media coverage has focused on how tariffs have hurt general manufacturing and farmers due to reductions in sales to Chinese markets, higher costs of component goods and other consumer-centric impacts. Will trade to return to 'normal' once the dispute ends?

Bill Michels: The electronics industry has capitalized its industry and workforce in Asia, and it would take a very long time and a great deal of money to change and recapitalize the industry. In addition, they would have to find and train a new workforce. Asia is also a huge market for electronics products, so even as companies might build new facilities outside China, there is still a good reason to keep production

in that country to serve the region. The “new normal” for many companies will keep them in China, but not simply to export to US customers.

The agricultural industry is a bit different as its products are true commodities, subject to supply and demand sensitivity. When disputes are resolved it may take one or two seasons or growing cycles to re-establish “normal” levels of imports and exports; however, nothing is guaranteed. Other countries may be able to carve out market share while US exports to China are restricted. Subsidies to farmers can mitigate the hardships here in the short term only, they could worsen the situation if, for instance, farmers cannot start moving their products again, so they decrease future planting. Even if farmers get subsidies the crop stays and compounds the following year when new crop comes in. At some point the supply must balance with demand

Has the impact been felt by manufacturers producing solar (PV) energy components, cells or modules?

Bill Michels: The domestic suppliers of solar panels have capacity, innovations, and quality and are priced to compete with imported panels. Unfortunately, without competition from Asia, the pricing for domestic components will rise to match the levels of imported panels with tariffs. While increasing the margins for US producers while the tariffs continue, customers will be seeing higher prices.

While much attention has focused on China-US disputes, Japan and Korea had their own tussle recently over complex materials critical to high-tech manufacturing. Are global trade tensions growing? Don’t most companies dig deeply on supply chain details only when this is trouble?

Bill Michels: If you have not mapped your supply chain upstream all the way back to raw materials, you are asking for trouble from a potential tariff, single-source supplier, natural disaster or logistics snafu that you knew nothing about. Once you know where everything is coming from you can systematically assess every link in your chain to see if every supplier in every step is adding sufficient value to make it a worthwhile partner. Supply managers must look beyond cost to see how every supplier adds value to the overall benefit of the organization. That means analyzing changing market demand, economic conditions and risk as they choose suppliers.

And you are right – most companies only know all their supplies deeply when there is risk. Pharma companies, for instance, operate under fairly rigorous chain of custody rules for their supply chains, so they are well mapped. Going to chain of custody documentation is a step beyond simply knowing who your suppliers are. Rigorous chain of custody can identify which boat and day of the catch went into a can of tuna, what section of the field in the farm grew a box of strawberries, what day and what mine extracted the lithium in a battery and so on. There are industry associations that are trying to create systems to generate that granular data as part of their certifications of sustainability, but the efforts vary in their scope and effectiveness.

And yes, there are consultants who work with companies to develop supply chain maps because it can be a difficult process. Suppliers generally find it a burden at best, and an intrusion into their business at worst. It sometimes takes a contract renegotiation and a significant amount of trust to get suppliers to reveal their own supply chains.

In spite of those obstacles, the rising global pressures for corporate social responsibility make it imperative for companies to better map their supply chains and educate their suppliers to maintain ethical standards. A few countries have already established severe penalties for forced labor in the supply chain, putting new responsibilities on procurement and supply chain managers. The reputation risk is very high for companies that do not develop supplier training and audit capabilities to manage supply chain ethical, environmental and employment practices. A revelation of bad behavior deep in the supply chain could have catastrophic effects for buyers.

Do trade tensions in Asia and the US create opportunities for other regions, and if so, what are these regions and why might they benefit?

Bill Michels: Places that have infrastructure and labor advantages can benefit from the current trade difficulties. A recent Boston Consulting Group study highlighted the cost advantages of Mexico, Thailand and Indonesia over China – even before tariffs.

Vietnam is also aggressively courting manufacturing companies and has the success of attracting Samsung as sales message. The country is struggling a bit to develop its workforce, but even so, it might have a leg up on other low-cost countries that want to build silicon chips or solar panels. Ironically, some of the infrastructure improvements that China is making in Africa could help position African countries as low-cost competitors to China itself. The opportunities for Africa are largely in low-technology categories for the foreseeable future, simply because it’s easier to move simple parts than complex assemblies that require precision tools and a highly skilled workforce.

Finally, the trade war with China was started in order to benefit the US, and it may, in fact, do that – to the extent that tariffs help offset companies’ investments in automation or other innovations. Once robots are in place they never get tired or sick and they produce consistent quality.


Bill Michels,
VP Operations,
CIPS Americas

Empowering power electronics with PowerAmerica

PowerAmerica targets the primary obstacles to widespread adoption of wide bandgap power electronics: high costs, concerns with reliability and ruggedness, and a lack of expertise in the workforce

BY VICTOR VELIADIS FROM POWERAMERICA

THERE ARE SEVERAL REASONS behind silicon's dominance of the power electronics market. Silicon is renowned for its excellent starting material quality, its ease of processing, the opportunity for low-cost mass production, and proven reliability. However, despite significant progress, silicon devices are now approaching their operational limits. They are held back by their relatively low bandgap and low critical electric field, traits that result in high conduction and switching losses and a substandard high-temperature performance.

To address these shortcomings, much effort is being directed at increasing the competitiveness of commercial SiC and GaN power devices. Transistors and diodes made with these wider bandgap semiconductors have superior material properties, enabling the production of highly efficient power devices with a smaller form factor and reduced cooling requirements.

Helping to exploit the potential for energy saving and technological innovation are several initiatives promoting the adoption of these wide bandgap power devices. In the US, a number of government programmes have already played a major role in supporting early work to develop advanced crystal growth of SiC and GaN, wafer fabrication and device processing technologies. As far back as the late 1980s, organizations such as the Air Force Research Laboratory, the Army Research Laboratory, the Office of Naval Research, the Missile Defense Agency, and the Defense Advanced Research Projects Agency provided hundreds of millions of dollars to fund what has been decades of work at universities, industry, and government laboratories. Efforts initially focused on developing critical enabling technologies such as high-quality substrates and epitaxy; and unit process steps such as ion-implantation, implant activation and gate oxidation. Success ensured a domestic source for the US Department of Defense Wide Bandgap systems.

More recently, the Advanced Manufacturing Office of the US Department of Energy and North Carolina State University have formed PowerAmerica, a National

Left: Many of the students trained in hands-on PowerAmerica projects will go on to staff Universities or enter the industrial workforce. This will accelerate wide bandgap technology innovation.

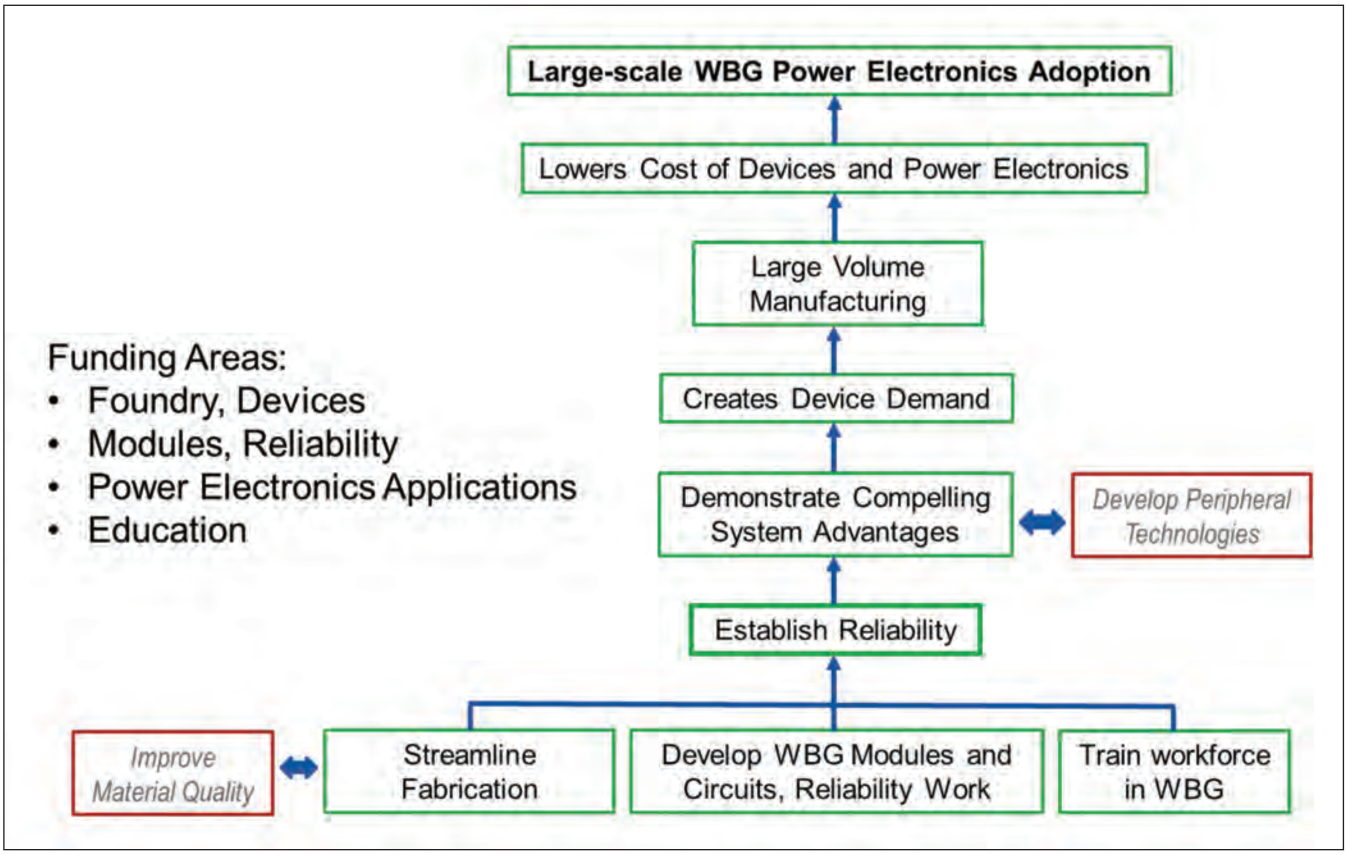


Figure 1. PowerAmerica funds projects in areas that synergistically culminate in large-scale wide bandgap power electronics adoption (green boxes). The red boxes represent key technology areas that are presently outside the Department of Energy PowerAmerica mission.

Network for Manufacturing Innovation Institute. This initiative, which commenced in 2015 and has a five-year budget of $150 million, is directed at improving cost-effective, large-scale production of wide bandgap power electronics. Efforts are aimed at addressing manufacturing gaps in wide bandgap power technology. Success will enable high-tech job creation, technological innovation, and a hike in the energy efficiency associated with many different applications.

Overcoming barriers to adoption

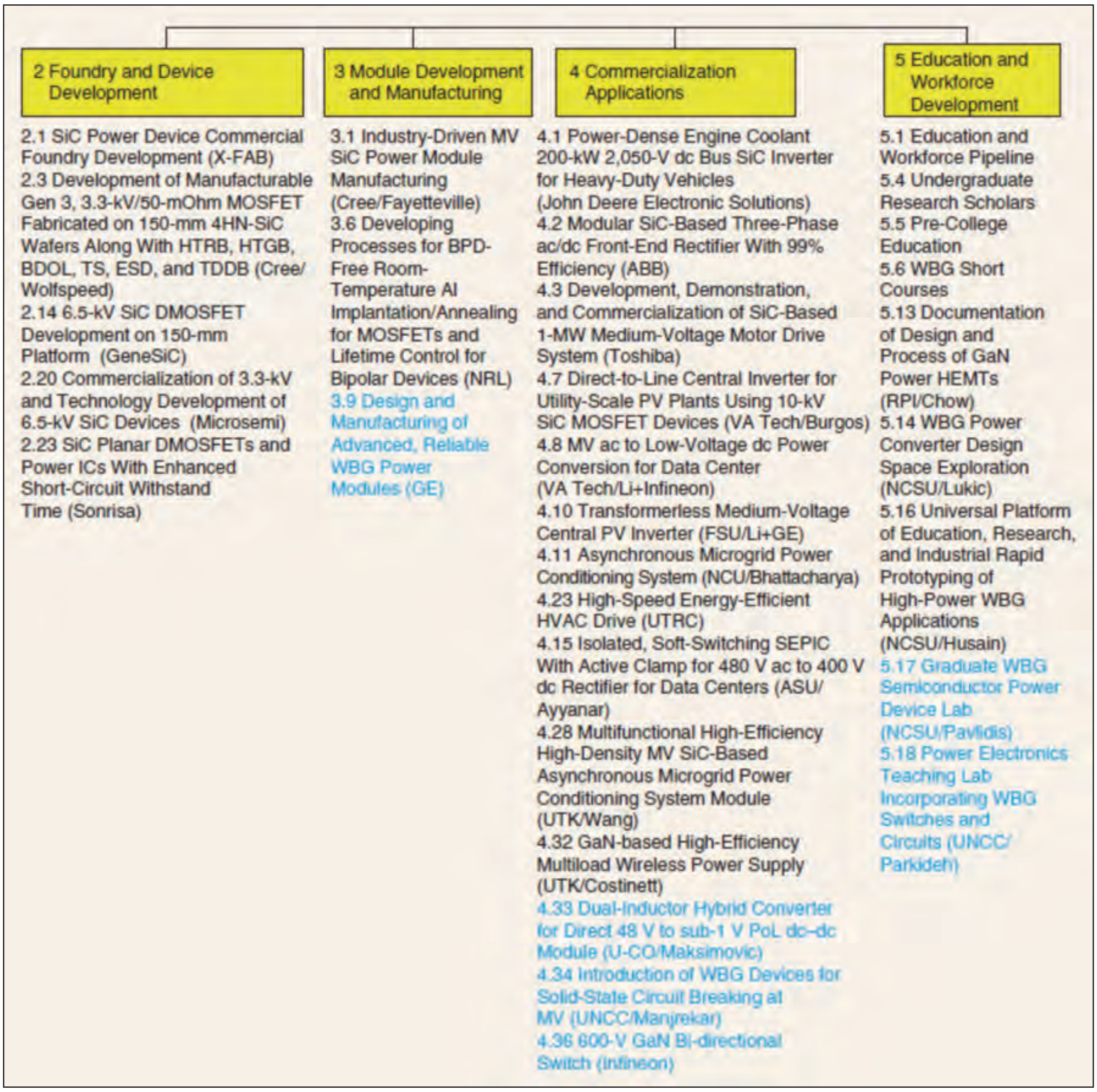
Today there is no question that wide bandgap devices are well beyond the stage of proof-of-concept. For example, it's been nearly two decades since Infineon launched the world's first commercial SiC Schottky diode. However, commercial progress has been slow, primarily due to three factors. One is that costs are far higher than those for mass-produced silicon, chiefly because manufacturing volumes are low and the dedicated foundries used for GaN and SiC production are not fully loaded. A second significant issue is that there are ruggedness and long-term reliability concerns. And the third issue is that the workforce lacks expertise in integrating wide bandgap technologies into systems – like many industries, the power electronics industry is traditionally slow to change and adapt to new technologies.

To tackle all these three issues, PowerAmerica is running over 35 industrial, university, and national laboratory projects annually. Projects are scheduled to complete their scope of work in a single year. This programme of activities will enable US leadership in wide bandgap power electronics manufacturing, work force development, job creation, and energy savings.

Within this, my role as Executive Director and CTO of PowerAmerica is to strategically select these projects. This is a position that I have held since 2016, following 21 years in the semiconductor industry, where I undertook various roles involving wide bandgap devices. I have been active in SiC, with tasks that include the design, fabrication and testing of 1-12 kV SiC static induction transistors, JFETs, MOSFETs, thyristors, junction barrier Schottky diodes and PiN diodes. I have also helped to develop 150 mm GaN-on-silicon wafers for advanced radar systems, and taken responsibility for the financial and operations management of a commercial foundry. My approach for catalysing the manufacturing of low-cost SiC and GaN power electronics is outlined in Figure 1.

Cutting costs

The efforts of PowerAmerica are taking place against a backdrop of falling prices for wide bandgap power devices. During the last eight years, prices of commercially available SiC MOSFETs have plummeted by about 80 percent, thanks to a combination of an increase in manufacturing volume, technological innovation, and an a move to larger-area wafers – 150 mm is now the common diameter. However, the prices of wide bandgap devices are still about three-to-four times higher than those of similarly rated components made from silicon.



2 Foundry and Device Development

2.1 SiC Power Device Commercial Foundry Development (X-FAB)
2.3 Development of Manufacturable Gen 3, 3.3-kV/50-mOhm MOSFET Fabricated on 150-mm 4HN-SiC Wafers Along With HTRB, HTGB, BDOL, TS, ESD, and TDDB (Cree/Wolfspeed)
2.14 6.5-kV SiC DMOSFET Development on 150-mm Platform (GeneSiC)
2.20 Commercialization of 3.3-kV and Technology Development of 6.5-kV SiC Devices (Microsemi)
2.23 SiC Planar DMOSFETs and Power ICs With Enhanced Short-Circuit Withstand Time (Sonrisa)

3 Module Development and Manufacturing

3.1 Industry-Driven MV SiC Power Module Manufacturing (Cree/Fayetteville)
3.6 Developing Processes for BPD-Free Room-Temperature Al Implantation/Annealing for MOSFETs and Lifetime Control for Bipolar Devices (NRL)
3.9 Design and Manufacturing of Advanced, Reliable WBG Power Modules (GE)

4 Commercialization Applications

4.1 Power-Dense Engine Coolant 200-kW 2,050-V dc Bus SiC Inverter for Heavy-Duty Vehicles (John Deere Electronic Solutions)
4.2 Modular SiC-Based Three-Phase ac/dc Front-End Rectifier With 99% Efficiency (ABB)
4.3 Development, Demonstration, and Commercialization of SiC-Based 1-MW Medium-Voltage Motor Drive System (Toshiba)
4.7 Direct-to-Line Central Inverter for Utility-Scale PV Plants Using 10-kV SiC MOSFET Devices (VA Tech/Burgos)
4.8 MV ac to Low-Voltage dc Power Conversion for Data Center (VA Tech/Li+Infineon)
4.10 Transformerless Medium-Voltage Central PV Inverter (FSU/Li+GE)
4.11 Asynchronous Microgrid Power Conditioning System (NCU/Bhattacharya)
4.23 High-Speed Energy-Efficient HVAC Drive (UTRC)
4.15 Isolated, Soft-Switching SEPIC With Active Clamp for 480 V ac to 400 V dc Rectifier for Data Centers (ASU/Ayyanar)
4.28 Multifunctional High-Efficiency High-Density MV SiC-Based Asynchronous Microgrid Power Conditioning System Module (UTK/Wang)
4.32 GaN-based High-Efficiency Multiload Wireless Power Supply (UTK/Costinett)
4.33 Dual-Inductor Hybrid Converter for Direct 48 V to sub-1 V PoL dc–dc Module (U-CO/Maksimovic)
4.34 Introduction of WBG Devices for Solid-State Circuit Breaking at MV (UNCC/Manjrekar)
4.36 600-V GaN Bi-directional Switch (Infineon)

5 Education and Workforce Development

5.1 Education and Workforce Pipeline
5.4 Undergraduate Research Scholars
5.5 Pre-College Education
5.6 WBG Short Courses
5.13 Documentation of Design and Process of GaN Power HEMTs (RPI/Chow)
5.14 WBG Power Converter Design Space Exploration (NCSU/Lukic)
5.16 Universal Platform of Education, Research, and Industrial Rapid Prototyping of High-Power WBG Applications (NCSU/Husain)
5.17 Graduate WBG Semiconductor Power Device Lab (NCSU/Pavlidis)
5.18 Power Electronics Teaching Lab Incorporating WBG Switches and Circuits (UNCC/Parkideh)

Figure 2. Strategic PowerAmerica 2018-2019 budget period projects synergistically accelerate commercialization of wide bandgap power electronics. New member projects are shown in blue font.

One way to trim costs is to exploit economies of scale. This can be accomplished by repurposing 150 mm and 200 mm silicon foundries. If these foundries have not kept pace with the channel length reductions of the last two decades, this opportunity may have great appeal. That's because it allows the lines to manufacture legacy silicon parts while ramping up SiC fabrication, which requires relatively modest 0.5 μm design rules. Although investment will be needed to support fabrication steps that are unique to the production of wide bandgap devices, such as high-temperature implantation and annealing, contact formation, and backside processing, a capital investment of $12 million to $15 million should be sufficient.

Taking this approach lowers both material and process costs, so long as the foundry is loaded close to capacity with silicon and SiC wafers running on the same line – and that standard, high-yield SiC process blocks are offered for the majority of SiC fabrication, to ensure mass production. Note that today the latter is challenging, as SiC 'device' companies tend to compete on design as well as process integration, an area where many hold extensive IP portfolios.

Pioneering this approach is the collaboration between PowerAmerica and X-FAB, which is a facility that has 150 mm SiC wafers fully integrated within a high-volume, automotive-qualified silicon foundry. In X-FAB's lines, processing is dominated by fixed overhead costs, with the economy of scale of silicon fabrication brought to SiC manufacturing, slashing costs. Members of PowerAmerica that are fabricating at X-FAB include ABB, GeneSiC, Microchip, Monolith, UnitedSiC, Global Power, Sonrisa, The State University of New York, and North Carolina State University. In addition, several other companies are fabricating at X-FAB including many from Europe and Asia.

Costs should continue to fall with the introduction of 200 mm wafers. Thanks to this, it should be possible to produce devices for a cost that is just 50 percent more than it is for silicon, so long as the right approach is adopted in the foundry. Note that device cost is only one element of the system's bill of materials, and that the move to wide bandgap devices reduces the demands on other components, opening the door to the production of systems that are smaller, lighter and cheaper to make.

After wide bandgap chips are produced they need to be packaged and put into modules. There are no volume manufacturing efforts in these two critical tasks in the US, because, since as far back as 1970s, semiconductor assembly and packaging has been off-shored. Complicating matters, if a GaN or a SiC chip is housed in a standard silicon module, it will fail to reach its full potential.

But it's not all doom and gloom. The reality is that wide bandgap devices offer a unique opportunity for industrial growth, because they require modules with reduced parasitic inductance, a lower thermal impedance, higher-voltage isolation, and a higher-temperature capability. To usher in this era, PowerAmerica is funding the development of wide bandgap modules that will excel on all these fronts. They will feature specialised layouts that minimise parasitics; they will utilise new base-plate materials that will lower thermal impedance and allow for double-sided cooling; they will feature a low inductance; and they will employ new potting compounds for higher-temperature operation.

Ruggedness and reliability

The second criterion for ensuring widespread adoption, as well as improved performance, is to produce wide bandgap devices that are more reliable and rugged. Reliability can increase through improvements in material quality and fabrication. Many makers of SiC and GaN devices are now releasing their reliability data. Results indicate that performance is rivalling that of silicon. There is also a move towards greater rigour, with several industry-led semiconductor engineering trade organisations and standardisation bodies working towards the establishment of standards for these classes of power device.

Increasing the ruggedness of a power device is not easy. In practice, it requires careful consideration of design trade-offs. Ultimately, power electronics engineers have to define safe-operating-area requirements for particular applications. The chances of commercial success are much higher if the ruggedness of the wide bandgap device mimics that of silicon, since this holds the key to quick adoption.

Numerous device reliability and qualification projects have been funded by PowerAmerica (see Figure 2 for a list of projects carried out in the 2018-2019 budget period). This has led to several product releases in the marketplace. Device ruggedness projects have identified failure mechanisms and safe operating areas, and elucidated design trade-offs for optimising resistance for given ruggedness requirements.

PowerAmerica applications projects, like *Fast EV charger*, highlight the competitive advantages of SiC and GaN devices in power electronics systems spurring further development and growth.

Another important initiative by PowerAmerica is the funding of the establishment of an honest broker ruggedness/reliability testing centre. The work that is done there builds 'independent' confidence for the suitability of wide bandgap devices in power electronics systems.

The applications projects that are supported by PowerAmerica are highlighting the compelling advantages of SiC and GaN devices in power electronics systems, including a trimming of the weight of the unit, a reduction in its volume, a higher efficiency, and a reduced bill of materials. There has also been a great deal of technological innovation, including new circuit topologies, novel gate drivers for faster switching and protection, and printed circuit board layouts that minimise inductance and eliminate ringing. These advances help to build the value proposition provided by wide bandgap electronics in the likes of laptop adapters, photovoltaic inverters, uninterruptible power systems, data centres, electric vehicle fast chargers and on-board chargers, solid-state circuit breakers, microgrid power conditioning systems, medium-voltage variable speed drives, traction inverters, and auxiliary power converters. Thanks to these successes, those in upper management are left in no doubt of the competitive advantages of wide bandgap technology. This can unlock internal funding, leading to further development.

Educating the workforce

A highly skilled workforce is the third essential ingredient to creating a substantial demand for wide bandgap devices. To realise this, during the first four years of the PowerAmerica initiative, more than $24 million of funding was used to support

Member-only PowerAmerica meetings provide opportunities for networking and partnerships. They also allow members to deliver a collective, amplified voice on issues that affect the wide bandgap industry, influencing its direction and shaping its growth.

63 hands-on University projects. This has equipped over 300 students with real-world wide bandgap power electronics experience.

During the next few years, these efforts will start to bear much fruit. Some of these students will enter the industrial workforce and help to accelerate the insertion of wide bandgap technologies into products. For those making that transition, entering the workforce has been aided by the university-industry collaborative nature of these projects. There have been ample internship opportunities, with PowerAmerica university-affiliated students spending time at ABB, John Deere, GE, Lockheed Martin, Raytheon, Eaton, Schneider Electric, XFAB, UnitedSiC, and GeneSiC. In addition, there has been a steady flow of qualified personnel taking up highly specialised wide bandgap employment positions.

Other students involved in PowerAmerica will become faculty members at universities. This is also beneficial to the future of SiC and GaN, as it will help to train a new generation of students, and create a snowball effect in wide bandgap education.

To train the existing workforce, every year PowerAmerica organizes an industry-driven short course on wide bandgap semiconductors. Taught by experts from across the United States, it lasts two-and-a-half days. It is typically offered to sold-out audiences in the fall of each year. The programme is designed to provide diverse applied training, filling industry knowledge gaps, with content formulated by evaluating data from industry-wide polls asking the critical question: What training is needed to catalyse your wide bandgap growth and is not available in present educational settings? The content for this course continues to evolve, with improvements driven by attendee feedback.

Additional educational initiatives run by PowerAmerica include free, available-to-all monthly technical webinars, delivered by member experts. There are also: wide bandgap lectures, being added to power electronics courses across all 18 member universities; and tutorials offered at the winter and summer PowerAmerica member meetings, which provide an informal setting for learning and networking. Finally, to educate participants and promote the PowerAmerica wide bandgap ecosystem, I have recently delivered numerous, well-attended tutorials at mainstream trade conferences. They include the Applied Power Electronics Conference and Exposition, the International Symposium on Power Semiconductor Devices, both the International Conference on Silicon Carbide and Related Materials and its European counterpart, the Workshop on Wide Bandgap Power Devices and Applications, and the Energy Conversion Congress and Exposition. At all these gatherings there has been a recent surge in interest in wide bandgap devices.

PowerAmerica is clearly playing an important role in addressing the three key barriers to widespread angel tech

PIC INTERNATIONAL CONFERENCE

31 MARCH - 1 APRIL 2020
BRUSSELS, BELGIUM

Why should you choose to sponsor with PIC International?

- Are you looking to accelerate your growth and reach the major players in the integrated photonic circuits industry?
- Do you want to educate, influence and network with the industry?

If you have answered yes to any of the questions above, then PIC International 2020 is the perfect event for you. Here are but a few reasons why you must consider sponsorship.

Reasons to sponsor

1. Access and network with the leading players across the global photonic integrated circuits industry
   Going from strength-to strength, PIC International 2020 will allow you to engage with 400+ leading senior decision makers from the major companies across the integrated photonics industry in one dedicated exhibition hall, including over 30 international experts, who will speak at the conference.

2. Raise brand and company awareness
   We have an intensive and multi-faceted marketing program available and already underway, which includes email marketing, social media, conference partners, direct mail and live events in addition to promotion in the PIC Magazine digital portfolio Coupled with the marketing program, the support of our highly esteemed Conference association and media partners ensure your company, product and service will achieve maximum visibility within the industry for the next 7 months.

3. Thought leadership and credibility
   Aligning with the leading global photonic circuits industry conference will give you a great opportunity to be positioned as a thought leader in the industry. Engage in debate, share insights and expertise on industry challenges with your peers.

4. ROI and long-term partnerships
   Many of our sponsors repeatedly support the event year on year, demonstrating how the industry trusts the PIC International brand as the leading information and networking resource to deliver the best programme and ROI. Unparalleled networking opportunities enable you to both build existing and generate new relationships and demonstrate ROI by aligning with the conference brand.

5. Accessibility
   We have opportunities to suit all budgets.

6. Post-event exposure
   Even when the event is over, you will be included in off-season conference promotional activities, plus the PIC digital portfolio as well as the fortnightly email newsletter.

7. Expand your audience
   PIC International is part of AngelTech, a brand which uniquely delivers insightful, engaging and high-valued conferences that have tremendous synergy between audiences. The current line-up, attracting more than 700 delegates, consists of co-located Compound Semiconductor (CS) International, Photonic Integrated Circuits (PIC) International, and Sensor Solutions International (SSI). Delegates can choose between which sessions they want to participate in and the single exhibition hall layout enables exposure to 3 different but related audiences

Contact: sponsor@picinternational.net to discuss opportunities with the PIC International Conference and Exhibition team or by calling +44 (0)2476 718 970 today.

Sponsorship opportunities are limited.

commercialisation of wide bandgap power electronics: the high cost, the concerns over reliability, and the lack of expertise in systems integration of these devices. Thanks to the funding of building-block projects in device and foundry, reliability and modules, and commercial applications that synergistically culminate in large-scale wide bandgap adoption, sales of SiC and GaN devices are sure to climb over the next decade and beyond.

Victor Veliadis is greatly indebted to his team, and the Department of Energy Technical Manager Dr. Allen Hefner for his valuable technical contributions and generous support.

PowerAmerica: The benefits of membership

THERE ARE COMPELLING INCENTIVES for membership in PowerAmerica, a 49-member institute that includes those from all areas of the GaN and SiC supply chain. One of the benefits is assistance with device design and cost-effective manufacturing in high-volume foundries. To bolster confidence in the use of SiC and GaN devices and modules in power electronics applications, support is given to 'honest broker' third party reliability/ruggedness evaluation centres.

Another initiative of PowerAmerica has been the establishment of a device/module bank to increase the availability and timely accessibility of long lead-time, pre-production engineering samples for power application development. By turning to the device bank, just a few days are needed for members to procure long lead-time engineering samples. That's a great asset, as it speeds members' development of next-generation products, while producing valuable user performance feedback that can guide manufacturer device optimisation. One of the strengths of PowerAmerica is that it has the reach and depth to connect companies and practitioners across the wide bandgap supply chain. It provides its members with unparalleled opportunities to effortlessly make connections, create partnerships, advance technology innovation, grow their business, and build their brand. Members have complimentary access to online members-only business and technical content – including market research and presentations – and this provides powerful context and data for making sound technical and business decisions. By participating in regularly held member-only meetings, individual companies are able to deliver a collective, amplified voice on issues that affect the wide bandgap industry. This influences its direction and shapes its growth.

The work of PowerAmerica also includes the running of member-initiated, pre-competitive projects. These are selected by members and financed with membership funds. Working on projects of common interest and sharing generated IP is a cost-effective way to spur technological innovation and overcome barriers limiting industry growth.

Finally, there are PowerAmerica education and workforce benefits for the members. They include access to industry tailored short courses at reduced cost, specialised tutorials, opportunities for internships and talent recruitment, and interaction with experts across the wide bandgap supply chain.

PowerAmerica is a 49 Strong, member driven institute active in all areas of the power wide bandgap supply chain

Angel
BUSINESS COMMUNICATIONS

WEBINARS

Expertise: Moderators, Markets, 30 Years + Pedigree

Reach: Specialist vertical databases

Branding: Message delivery to high level influencers via various in house established magazines, web sites, events and social media

Specialists with 30 year+ pedigree and in-depth knowledge in these overlapping sectors:

Semiconductor (Silicon/Compound)
Publications include: Compound Semiconductor, Silicon Semiconductor, CS China, SiS China

Power Electronics
Publications include: Power Electronics World

Future Mobility
Publications include: TaaS Technology, TaaS News

Data Centres
Publications include: DCS Europe, DCS UK, SNS International

SmartSolar UK & Ireland
Publications include: Solar and Power Management, Solar UK and Ireland

Sensors
Publications include: Sensor Solutions Magazine, Sensor Solutions International

Digitalisation
Publications include: Digitalisation World, Information Security Solutions, Managed Services

Photonics
Publications include: PIC Magazine, PIC Conference

Expert Moderators

Dedicated technical and time-served experts/editors

Mark Andrews

Mark Andrews is technical editor of Silicon Semiconductor, PIC Magazine, Solar+Power Management, and Power Electronics World. His experience focuses on RF and photonic solutions for infrastructure, mobile device, aerospace, aviation and defence industries

Jackie Cannon

Director of Solar/IC Publishing, with over 15 years experience of Solar, Silicon and Power Electronics, Jackie can help moderate your webinar, field questions and make the overal experience very professional

Dr Richard Stevenson

Dr Richard Stevenson is a seasoned science and technology journalist with valuable experience in industry and academia. For almost a decade, he has been the editor of Compound Semiconductor magazine, as well as the programme manager for the Compound Semiconductor International conference

Phil Alsop

Journalist and editor in the business to business publishing sector for more than 30 years currently focusing on intelligent automation, DevOps, Big Data and analytics, alongside the IT staples of computing, networks and storage

For more information contact:

Jackie Cannon **T:** 01923 690205 **E:** jackie@angelwebinar.co.uk **W:** www.angelwebinar.co.uk

Angel
BUSINESS COMMUNICATIONS
6 Bow Court, Burnsall Road, Coventry, CV5 6SP
T: +44(0)2476 718 970 **E:** info@angelbc.com **w:** www.angelbc.com

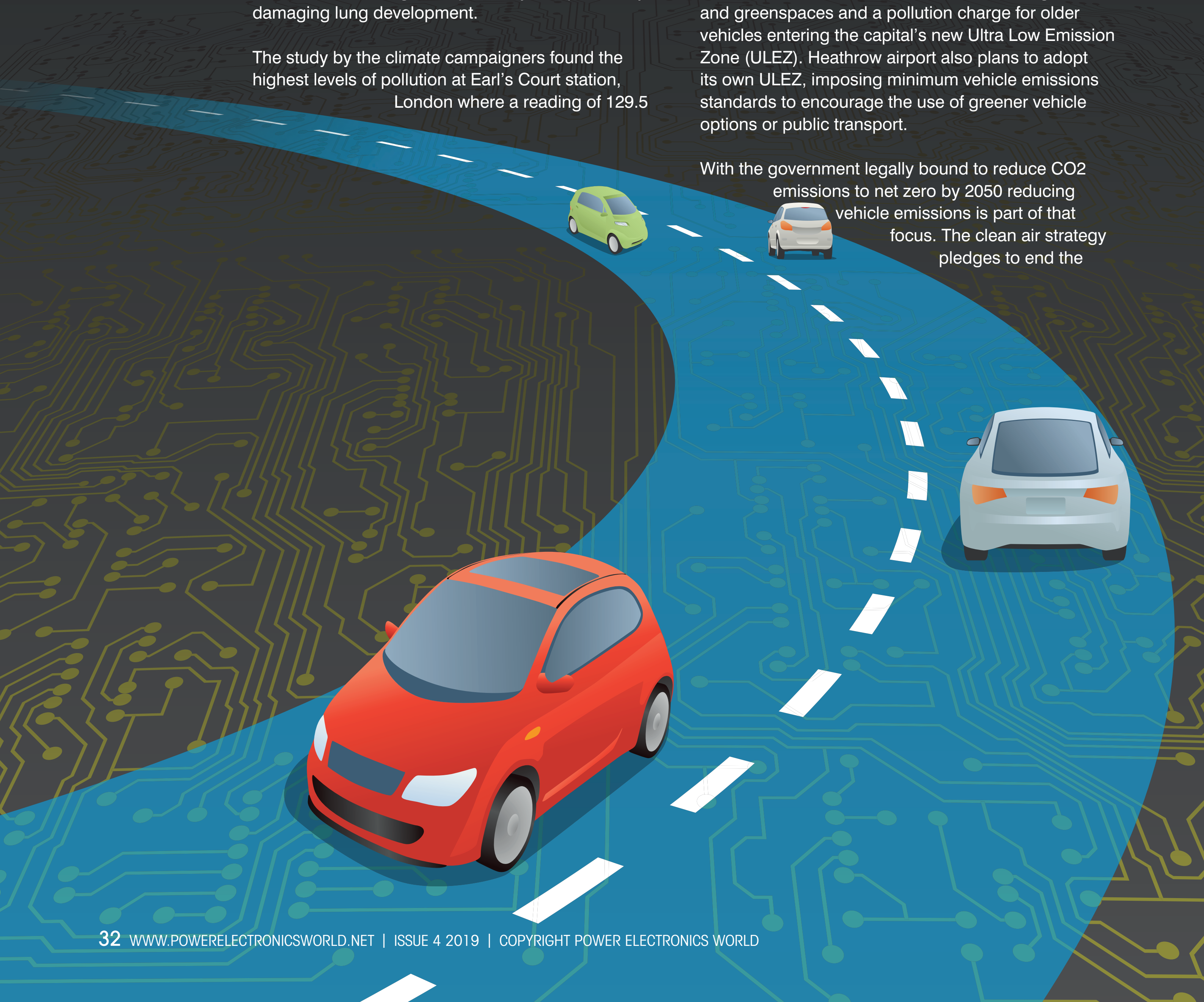
Will all roads eventually lead us to EVs?

Siemens Smart Infrastructure: concerns persist over the charging infrastructure and price of electric vehicles (EVs)

ALMOST 2,000 locations across England, Wales and Northern Ireland have levels of air pollution that exceed safety limits, says Friends of the Earth*. Road traffic emissions are a leading source of nitrogen dioxide (NO2) with the pollutants worsening chronic illnesses, shortening life expectancy and potentially damaging lung development.

The study by the climate campaigners found the highest levels of pollution at Earl's Court station, London where a reading of 129.5 micrograms per cubic metre was recorded, against the government air-quality limit of 40µg/m3. Greater London has introduced a number of measures to improve matters including: hybrid or zero emission buses, a £48m scrappage scheme to swap older cars and vans for cleaner alternatives, more grass and greenspaces and a pollution charge for older vehicles entering the capital's new Ultra Low Emission Zone (ULEZ). Heathrow airport also plans to adopt its own ULEZ, imposing minimum vehicle emissions standards to encourage the use of greener vehicle options or public transport.

With the government legally bound to reduce CO2 emissions to net zero by 2050 reducing vehicle emissions is part of that focus. The clean air strategy pledges to end the



sale of all new conventional petrol and diesel cars and vans by 2040.

The decarbonisation of transport: the road to Electric Vehicles (EV)

With the political will and clear and consistent policies to encourage take-up, optimism is high for the mass adoption of EVs. However, doubts linger over insufficient charging points, limitations with respect to connecting charging infrastructure to the power grid and high vehicle prices.

Bernard Magee, Director Siemens Future Grid commented: “The decarbonisation of transport will require the major expansion of today’s electric and low emission vehicle infrastructure but these barriers are not insurmountable. To date approximately 120,000 charge points [DfT] have been installed in the UK and more are needed, particularly in remote locations. There were also nearly 60,000 new EV and hybrid registrations last year. While the figure represents a relatively small percentage of overall vehicles sales the industry is confident the uptake will continue to drive investment at national and local levels.”

EV infrastructure today

According to Zap-Map, monitors of the UK charging-point map, there are now 8,471 EV charging sites in the UK with a total of 13,613 chargers, compared with 8,400 fuel stations**. The number of charging sites has surpassed that of fuel stations for the first time and has increased by 57 per cent in the last 12 months. Although an important milestone the UK is still said to need an additional 28,000 public charging points by 2030 - double the current number, to support an estimated fleet of seven million EVs by the end of the next decade according to research by Deloitte***.

The road ahead

Magee continued: “By leveraging existing infrastructure, these ‘electric avenues’ provide accessible, reliable, affordable and simple charging points to help accelerate the increase in privately-owned EVs. Charging your car is becoming as simple as charging your phone, they’re less expensive to run, nicer to drive and are much better for the environment”

Adequate infrastructure is also a primary concern for fleets that are exploring an electrification strategy. While sixteen of the UK’s largest van fleets have committed to zero tailpipe emissions from vans in cities by 2028**** fleet operators face numerous complexities including vehicle charging management, data usage, total cost of ownership (TCO) for vehicles and significant up-front capital costs. “New mobility providers such as car-sharing clubs and specialised rental companies covering shorter distances in urban spaces are the biggest operators of EV fleets today. And the appetite for them among larger operators will grow as the technology improves, prices come down and battery charging infrastructure improves,” Magee explained. “Heavy goods vehicles are further from electrification than light duty vehicles, so expect a mix of power sources to be part of the transport landscape for the foreseeable future.”

Looking ahead ultra-fast charging and improved battery technologies will address the range limitations. A rapid charger at 50kW charging rate can fully recharge a standard EV in approximately 40 minutes. Next generation chargers at 350kW will allow vehicles to reach full charge in under 10 minutes. As car manufacturers launch vehicles with more advanced larger capacity batteries, high power charging will allow motorist to recharge more quickly and travel greater distances in a day. New batteries currently under development will power cars for up to 600 miles.

On pricing, Magee added: “Better technology, improvements in energy density and more choices plus the economies of scale will drive prices down. We can expect EVs to reach cost-parity with conventional cars in a matter of years from now.”

As one of the world’s largest providers of sustainable traffic and transport solutions, Siemens offers a comprehensive turn-key solution for all EV charging infrastructure projects and has extensive experience of installing EV charging and traffic control equipment on highways, public sector and private land.
*https://friendsoftheearth.uk/clean-air/nearly-two-thousand-locations-across-england-wales-and-northern-ireland-breaching-air

For further information on Siemens Intelligent Infrastructure, please see https://new.siemens.com/uk/en/company/topic-areas/intelligent-infrastructure.html

Further reading
** https://www.zap-map.com/ev-charging-sites-outnumber-petrol-stations-for-first-time/
*** https://www2.deloitte.com/uk/en/pages/press-releases/articles/nearly-30000-new-public-electric-vehicle-charging-points-needed-in-next-ten-years.html
**** https://www.cleanairday.org.uk/news/launch-of-clean-van-commitment-to-kickstart-a-revolution-on-our-roads

Current sensing rises to the challenges of advanced embedded systems

The embedded electronics development community is currently experiencing the biggest changes in our industry since the creation of the integrated circuit

BY KHAGENDRA THAPA, VP OF BUSINESS DEVELOPMENT OF ACEINNA'S CURRENT SENSING BUSINESS

FROM NEW software-oriented solutions like Artificial Intelligence, to new hardware topologies, to new semiconductor materials, we are in the middle of a disruptive period of demanding growth.

Much of these advances are related to user functionality, like Cloud-based Internet of Things (IoT) solutions that rely on next-generation RF technologies. Other rapidly emerging current sensing applications include Electric Vehicles (EV) and their Advance Driver-Assistance Systems (ADAS) and Autonomous Driving needs, to wide-bandgap power switches based on Silicon Carbide (SiC) and/or Gallium Nitride (GaN) semiconductors. Some of the most important advances in these spaces have been in performance and efficiency, enabling the next generation of electronic solutions to address the challenges and demands of users and the marketplace.

The latest trends in personal electronics put a lot of pressure on the designers of embedded systems. When it comes to consumer and medical wearables, advanced personal electronics, and the internet of things, the smaller, more functional, and longer lasting, the better. Similarly, industrial and automotive applications are pushing boundaries to achieve smaller, more efficient, reliable, and robust solutions. Significant improvement in all of these include reducing parts count, simplifying circuitry, and increasing operational efficiency.

Current-sensing technologies are key to creating the small precision control and protection electronic circuits needed to make the devices of tomorrow serve applications in an efficient and cost-effective manner. There is no precision without feedback, and current sensing can provide the critical performance information an embedded intelligent system needs to manage itself. The size, accuracy and speed of your current-sensing solution will directly impact all of these aspects.

AMR current sensing

A single-chip solution, the ACEINNA Anisotropic Magnetoresistive (AMR) technology based, isolated current sensor does not require additional components other than a decoupling capacitor. Compared to the other methods of current sensing, an AMR sensor provides a compact and high-performance solution. For example, the problem with using a shunt resistor is that it is inherently not isolated. A current transformer is bulkier than an AMR based current sensor and it only works with AC. Compared to using a Hall-effect sensor, AMR technology offers a bandwidth of 1.5 megahertz, and has a lower offset and noise.

Delivering better performance than a shunt register or transformer, AMR technology can respond to both DC and AC bi-directional current, with a bandwidth of

Figure 1: Modern current sensing technologies are available for a wide range of applications – from EV cars and ADAS systems to home appliances, telecommunications and server farms.

1.5 megahertz and a lower offset and less noise than Hall-effect-based solutions. Offering better accuracy, higher bandwidth with lower phase shift, and a very fast output step response, an AMR based current sensor is an accurate and compact solution for very critical measurements to protect and control power systems.

Within the sensor, the current flows through a U-bend in the lead frame, where it generates a forward or reverse field measured by two current sensors in the device. By measuring the field from both current directions, the device cancels out the external fields and magnetic anomalies which might be present. This allows a horizontally-sensing AMR chip to ignore external fields generated from other nearby components on the board.

Electric Vehicles

There is a tremendous amount of attention being paid to EVs right now. Much of the focus is on improving the efficiency of the powertrain, motors and On-board/Off-board charging systems as well as the performance of the battery pack, as they are all directly related to vehicle range and charging efficiency. The proper application of current-sensing technology in these application areas can deliver significant advantages. Since the motors are where the power is being spent, any improvement there will cascade benefits throughout the system, from increasing EV range to reducing thermal management needs. When it comes to driving motors, the switching frequencies and control mechanisms are critical.

Effective motor control requires accurate performance measurement, and for that you need effective current sensors. For condition monitoring of motors for predictive maintenance, fast current sensors help to measure and monitor motor ripple currents to determine lifetime and performance parameters. On the protection side, the current sensor helps support safety by improving the control, accuracy, and reliability of a motor drive.

Many EV power electronics and charging systems are migrating to advanced wide-bandgap semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN), as the benefits provided include higher efficiency and the ability to increase the switching frequency. A significant benefit of faster switching is the ability

COMPARISON

Desired Feature	Aceinna AMR	Hall IC / Hall IC based Modules	Current Transformer	Sense Resistor
Accuracy	✓	✗	✓/✗*	✓/✗*
DC - >1MHz 3dB BW	✓	✗	✗	✓
Isolated	✓	✓	✓	✗
Small Size	✓	✓/✗**	✗	✗

*Current Transformer and Sense Resistor applications require design trade-offs regarding complexity and customization. Accuracy will depend upon the components selected and the quality of the design.

**Hall Effect IC based sensor modules (such as those with Ferrite cores) are not small.

Figure 2: Advantages of AMR based Current Sensing versus other types of current sensing technologies.

to shrink the size of the passives and magnetics in a circuit, with direct size and weight benefits. However, when a circuit is switching faster, the ability to measure the performance parameters must be able to keep up, demanding real-time information from a fast and accurate current sensor. Monitoring the circuit in real-time enables advanced functionality like dynamic control of the power switching and motor drive frequency, as well as reliable and fast fault detection.

In the related area of electric trains, industrial machines, traction and robotics, we are starting to see the use of reluctance motors, a winding-free design that generates torque through magnetic reluctance.

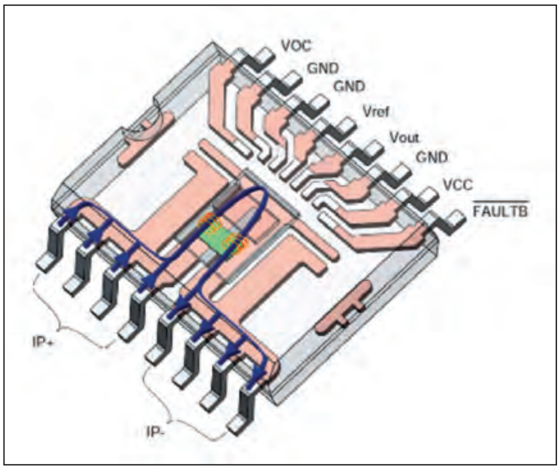


Figure 3: ACEINNA Current Sensors use a U-bend with two AMR sensors to cancel out. external fields

Available in synchronous, variable, switched and variable-stepping configurations, reluctance motors can deliver high power density at low cost. The problems with reluctance motors include high torque ripple at low speed, and the resulting noise. In addition, because of the extremely high temperatures involved, reluctance motors are usually deployed with a separate harness and control system. Advanced solutions using wide-bandgap SiC semiconductors and high bandwidth AMR sensors can take more heat, enabling size, weight, and complexity reductions of the overall system, providing cascading benefits.

Constructed without copper coils in the rotor, reluctance motors can be lighter than comparable electric motors. However, the required control system is very complex, because if you don't accurately control the current, which is related to torque, you'll get a torque ripple and that generates noise issues. Advanced fast current sensing improves control of the ripple current, which provides lower noise and a more reliable solution. It's important to bring up the protection side again because in high-power systems, you might want to switch the whole power stage off in 1.5 microseconds. If you look at that shutdown time budget, your step response needs to be less than 500 nanoseconds, and that's going to become more stringent as we migrate into higher power and frequency levels.

Power Factor Correction

Used to reduce the lagging power factor in inductive loads, Power Factor Correction (PFC) compensates for the phase difference between voltage and current, for when the power factor drops, the system becomes less efficient.

To get 1 kW of real power at a 0.2 power factor, 5 kVA of apparent power needs to be transferred (1 kW ÷ 0.2 = 5 kVA). This obviously can severely impact the performance in the case of inductive loads such as motors, refrigerators and HVAC systems, Inverters, uninterruptible power supplies (UPS), and similar application spaces.

Fast turn-on and -off time, fast reverse recovery and lower ON resistance of wide bandgap SiC and GaN based power switches are allowing effective use of Totem Pole architecture to improve efficiency of PFC and reduce the number of components used. These benefits help power systems to achieve higher efficiency 80+ Gold and Titanium certifications.

For example, when it comes to ripple currents in the PFC in a Totem Pole, to measure current cycle-by-cycle to calculate the pulse-width modulation (PWM) duty ratio, you need to have a high bandwidth for the ability to match the circuit's switching frequency. Let's say if your PFC switching frequency is being pushed to 65, 140, 200, 300 kilohertz, you ideally want 10 times the bandwidth of the switching frequency for the current sensor.

Smart manufacturing

When it comes to smart manufacturing and the smart factory, it's really about automation and data exchange. In a system where powered devices are connected to an intelligent infrastructure and the internet, you'll also need power conversion. Power monitoring and management are critical to the optimal operation of a smart assembly process, with everything being measured in real-time.

There are various locations in an automated system where an AMR current sensor can be deployed to take advantage of its accuracy, bandwidth, and step response. If you have a highly accurate sensor, then you can optimize your process and increase efficiency and productivity.

This performance advantage can be further leveraged by using AMR current sensing to determine how much the processor is being used, especially for applications involving AI, the Cloud, and data storage. AMR current sensors can also enable the use of power tracking for performance monitoring's sake, optimization of processor loading and thermal management.

Looking forward

Whether it is for advanced EVs, entire smart factories, UPS, inverters or motor drive, efficient and cost-effective power management is key to optimal performance. In applications from driving motors or powering 5G telecom, you want to be operating much faster and more effectively. Advanced current sensing enables a higher level of control, with a higher efficiency, at higher frequencies and temperatures.

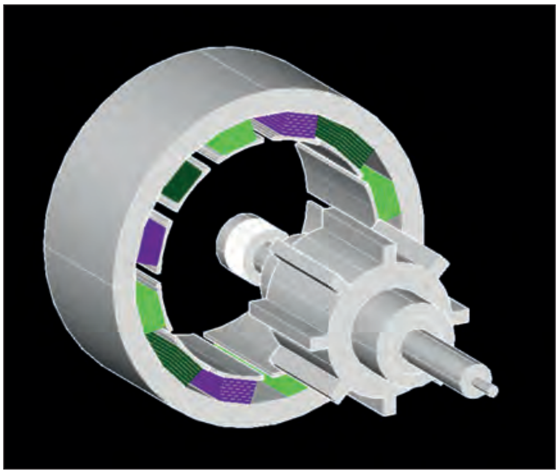


Figure 4: Variable switched reluctance motors can deliver high power density.

The next generation of embedded devices must be able to serve the latest application spaces in the most efficient and cost-effective manner. Using AMR-based current sensing solutions to ensure that the electronics are performing at their best will pay off in cascading benefits throughout the entire system.

There is no precision without feedback. Precise fast current feedback enables the highest levels of efficient and safe operation in an advanced powered circuit.

For more information about ACEINNA Current Sensing, please visit https://www.aceinna.com/current-sensors

About ACIENNA

ACEINNA Inc., is a leading provider of sensing solutions for automotive, industrial, telecom, datacenter and cloud infrastructure, consumer appliances, agricultural and construction markets.

ACEINNA's precise positioning solutions are MEMS based, open-source, inertial sensing systems that are leading the industry by enabling easy-to-use, centimeter-accurate navigation systems for the autonomous revolution. ACEINNA's isolated current sensor product family is based on an AMR technology that enables industry leading accuracy, bandwidth and step response in a simple, cost effective single-chip form factor. ACEINNA has R&D facilities in San Jose, CA; Andover, MA; and Chicago, IL; as well as manufacturing facilities in Wuxi, China.

FOR MORE INFORMATION

ACEINNA Inc., One Tech Drive, Suite 325, Andover, MA 01810
Tel: 978-965-3200
Fax: 978-965-3201
Email: info@aceinna.com
Web: https://www.aceinna.com

Reorganizing a computer chip:

Transistors can now both process and store information

Researchers have created a more feasible way to combine transistors and memory on a chip, potentially bringing faster computing.

BY VINCENT WALTER PERDUE UNIVERSITY

A COMPUTER CHIP processes and stores information using two different devices. If engineers could combine these devices into one or put them next to each other, then there would be more space on a chip, making it faster and more powerful.

Purdue University engineers have developed a way that the millions of tiny switches used to process information – called transistors – could also store that information as one device.

The method, detailed in a paper published in Nature Electronics, accomplishes this by solving another problem: combining a transistor with higher-performing memory technology than is used in most computers, called ferroelectric RAM.

Researchers have been trying for decades to integrate the two, but issues happen at the interface between a ferroelectric material and silicon, the semiconductor material that makes up transistors. Instead, ferroelectric RAM operates as a separate unit on-chip, limiting its potential to make computing much more efficient.

A team led by Peide Ye, the Richard J. and Mary Jo Schwartz Professor of Electrical and Computer Engineering at Purdue, discovered how to overcome the mortal enemy relationship between silicon and a ferroelectric material.

“We used a semiconductor that has ferroelectric properties. This way two materials become one material, and you don’t have to worry about the interface issues,” Ye said.

The result is a so-called ferroelectric semiconductor field-effect transistor, built in the same way as transistors currently used on computer chips. The material, alpha indium selenide, not only has ferroelectric properties, but also addresses the issue of a conventional ferroelectric material usually acting as an insulator rather than a semiconductor due to a so-called wide “band gap,” which means that electricity cannot pass through and no computing happens.

Alpha indium selenide has a much smaller band gap, making it possible for the material to be a semiconductor without losing ferroelectric properties. Mengwei Si, a Purdue postdoctoral researcher in electrical and computer engineering, built and tested the transistor, finding that its performance was comparable to existing ferroelectric field-effect transistors, and could exceed them with more optimization. Sumeet Gupta, a Purdue assistant professor of electrical and computer engineering, and Ph.D. candidate Atanu Saha provided modeling support.

Si and Ye’s team also worked with researchers at the Georgia Institute of Technology to build alpha indium selenide into a space on a chip, called a ferroelectric tunneling junction, which engineers could use to enhance a chip’s capabilities. The team presents this work on Dec. 9 at the 2019 IEEE International Electron Devices Meeting.

In the past, researchers hadn’t been able to build a high-performance ferroelectric tunneling junction because its wide band gap made the material too thick for electrical current to pass through. Since alpha indium selenide has a much smaller band gap, the material can be just 10 nanometers thick, allowing more current to flow through it.

In the past, researchers hadn’t been able to build a high-performance ferroelectric tunneling junction because its wide band gap made the material too thick for electrical current to pass through. Since alpha indium selenide has a much smaller band gap, the material can be just 10 nanometers thick, allowing more current to flow through it

More current allows a device area to scale down to several nanometers, making chips more dense and energy efficient, Ye said. A thinner material – even down to an atomic layer thick – also means that the electrodes on either side of a tunneling junction can be much smaller, which would be useful for building circuits that mimic networks in the human brain.

This research was performed in the Purdue Discovery Park Birck Nanotechnology Center and supported by the National Science Foundation, Air Force Office of Scientific Research, Semiconductor Research Corporation, Defense Advanced Research Projects Agency and the U.S. Office of Naval Research.

About Discovery Park

Discovery Park is a place where Purdue researchers move beyond traditional boundaries, collaborating across disciplines and with policymakers and business leaders to create solutions for a better world. Grand challenges of global health, global conflict and security, and those that lie at the nexus of sustainable energy, world food supply, water and the environment are the focus of researchers in Discovery Park. The translation of discovery to impact is integrated into the fabric of Discovery Park through entrepreneurship programs and partnerships.

Sigfox powers new IoT/IIoT connectivity

Internet of Things (IoT) devices and their industrial cousins in the IIoT are enabling 'smart' innovations including Industry 4.0 automation. Whilst RF connectivity networks are not always thought of as power efficiency tools, the experts at Sigfox point to the many ways that choosing the right network strategy can enable ultra-low power consumption and resiliency.

BY KEVIN MAHER, SIGFOX COUNTRY DIRECTOR, UK AND IRELAND

Q **The generic term 'unlicensed spectrum' is often applied to network strategies not confined to a portion of the electromagnet spectrum leased or made available by governmental regulatory bodies, but Sigfox prefers the term '0G' – Can you please explain the difference and what the term means for potential IoT innovators? Is 0G the same as unlicensed spectrum, or does the term point to advantages in this portion of the spectra that you wish to discuss?**

A Sigfox operates in the ISM band which, whilst unlicensed, is fully regulated. 0G is a proposed standard dedicated to the transfer of small messages in order to give us all access to a minimum communication service which would complement other communication protocols such as Wi-Fi, Bluetooth, Satellite, 3G, 4G, 5G, ADSL, Fibre etc. There are many advantages of having a back-up channel in case the main communication links fail or in cases where a network goes down after a natural disaster or malicious act.

Q **Does Sigfox see its capabilities as focused on network provisioning, equipment / IoT reference design maker, or something else? Could you please explain?**

A The growth of the IoT industry has historically been constrained by cost and energy issues. Small inexpensive objects simply do not have enough power to communicate with large mobile networks. Sigfox has, through its global 0G network and rich ecosystem of expert partners, pioneered low power device-to-cloud connectivity to complement high band-width solutions and allow solution providers to deliver out-of-the box, two-way, secured communication services to unlock the true potential of the IoT. We are the IoT enabler for chipset and device manufacturers, solution providers and customers.

Q **We have seen various IoT programmes roll out to varying degrees of success – Where does Sigfox see the industry today? What should we expect in the next 3 to 5 to 10 years?**

A There are many interesting and innovative projects currently being deployed that will fundamentally change the way humans interact with their environment. We are experiencing a huge demand for supply and logistics optimization (tracking of assets) that, until now, have not been cost effective to track. Going forward, we are seeing alignment with simplicity, low cost and ease of provisioning of solutions that will add value across a vast range of use cases in multiple verticals. I believe we will see exponential growth over the next five years and I expect to see tracking and tracing of assets ranging from containers, crates, and pallets to parcels, packages and goods that will provide an unprecedented level of visibility. IoT solutions will also monitor, maintain and alert to prevent unexpected failures and accidents from occurring.

Q **While the IoT is growing, its industrial cousin – the IIoT – is already transforming manufacturing and bringing higher degrees of safety and security to automated manufacturing. Is Sigfox a player in the IIoT and if not at this point, is there a plan to go after this portion of the market as well?**

A Sigfox is very much involved in the IIoT. We are providing the digital backbone for supply chain applications to dissolve traditional silos, provide end to end visibility of the complete chain and enable manufacturers to move from a linear to an integrated supply chain. Inbound and outbound logistics can now be fully integrated to improve decision making power and focus on operational efficiency. Supply and demand signals at every point of the network will now be available in real time, a key aspect for JIT (just-in-time) manufacturing. Digital transformation is at the heart of Sigfox's strategy.

Q **Security is always a concern within RF, whether a device is transmitting/receiving in lower or higher frequencies, Bluetooth, Wi-Fi, etc. How does Sigfox work with security protocols and does it provide device-level or network-level security?**

A Customers face three main types of threat in IoT: an unauthorized party taking control of devices, service disruption and theft of information. Sigfox has applied security by design principles in all the definition steps of its protocol and in the development of its infrastructure as well as all the components it offers to Sigfox users, Sigfox operators, device manufacturers and end-use customers. Devices are not directly connected to the Internet and do not communicate using the Internet protocol.

Whenever data is transmitted from a device, the message is picked up by several access stations, conveyed to the Sigfox Support System and delivered to a predefined destination. If the device requires a response, the IoT application has the opportunity, during a limited time window, to deliver the response to the device through the Sigfox Support System and base stations. This design means that devices never have the ability to send data to unknown entities via the Internet. They are therefore shielded from the Internet by a very strict firewall. Message authentication and encryption plus replay avoidance measures are also applied to ensure that devices cannot be taken control of or messages intercepted.

Q **Are there things about Sigfox that we have not discussed that you would like to explain or detail at this time?**

A We ran our annual event, Sigfox Connect https://sigfoxconnect.com/, in Singapore on November 20-21, 2019. This was an important worldwide event dedicated to IoT where all the ecosystem will meet to learn more about how 0G will drastically change the way we interact together in the near future. (Editor's note: At the time this article was published in December 2019, a 2020 event had not yet been scheduled; please check with Sigfox in 2020 for new event information.)

Q **How does Sigfox compare to other wireless networks and what are the key considerations for persons who might adopt the technology especially with regard to range, power consumption, security and other typical key concerns?**

A There is no single wireless technology for IoT devices. Each have their strengths and weakness and, in many cases, can complement each other. Sigfox is firmly positioned to address the challenges of low cost, simplicity and long battery life which addresses 80% of the market but there are use cases where a higher bandwidth may be required. This is where 5G can benefit from hybrid connectivity; for example, battery life extension on devices that only need to send small status messages until an event happens that triggers a 5G connection to transmit a higher volume of data such as video. Sigfox can also provide cellular anti-jamming protection for fixed devices or act as a backup, secondary (0G) connectivity in the event that the primary fails. It's about collaboration, not competition.