POWER ELECTRONICS WORLD

CONNECTING THE GLOBAL COMMUNITY

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The rise of GaN-based power systems

Design considerations for GaN success

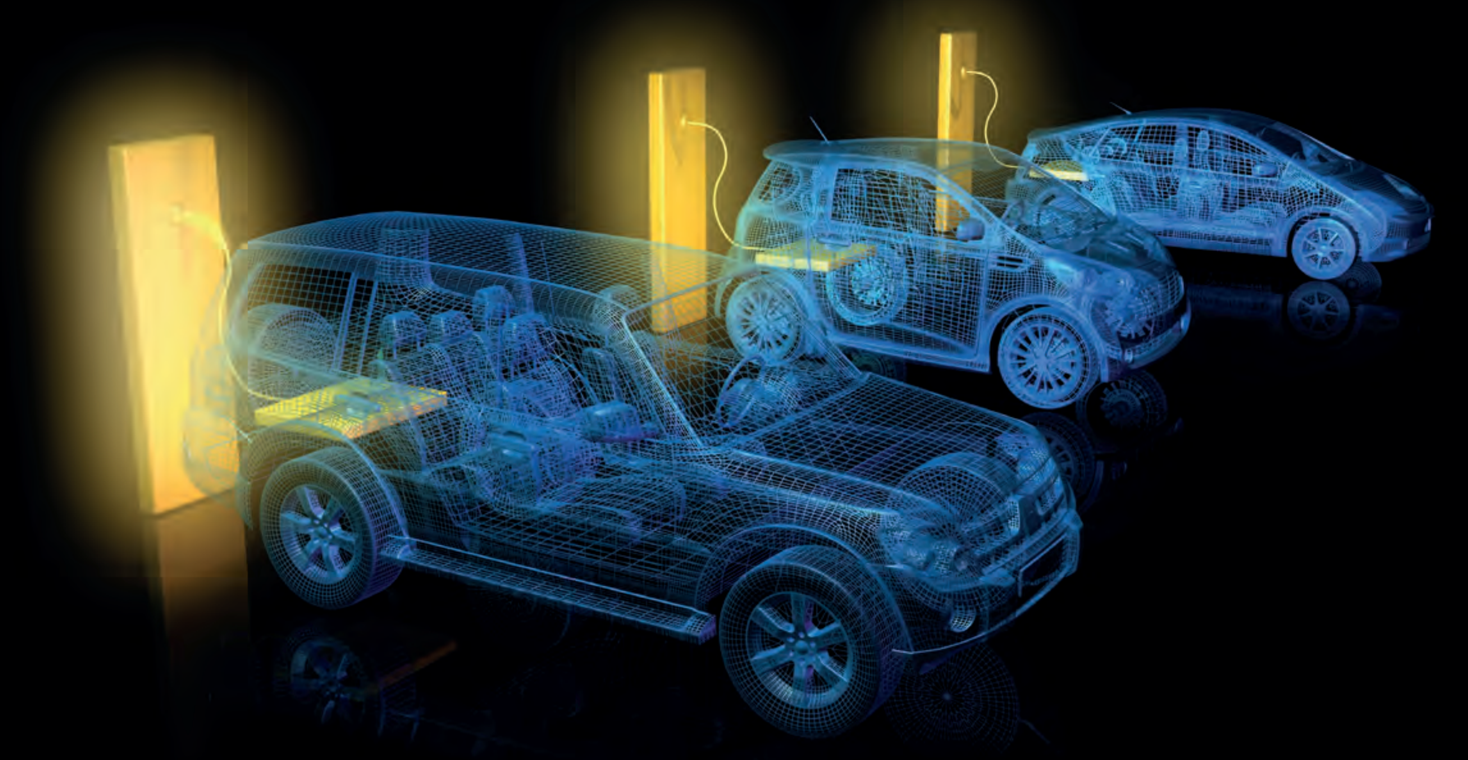
Sometimes it pays to go Solo!

Key components in PV bankability

Cree to set up SiC corridor

Power density, high-efficiency

GaN power switching topologies



editor'sview

By Mark Andrews, Technical Editor

Power Devices Central to CS International 2020

WHILE POWER ELECTRONICS is the heart of this magazine, power technologies also play increasingly major roles in the Compound Semiconductor International Conference, 31 March-1 April 2020 in Brussels. Silicon Carbide and Gallium Nitride will dominate power discussions as world renowned technology manufacturers and researchers examine best practices for ramping higher GaN and SiC volumes.
CS International is the place to be for insights into this exciting growth market.

Additions to the CS International programme occur daily. The focus on power device opportunities and challenges is sponsored by Class One Technology, a leader in refurbished and new wafer processing equipment.

Presenters at the CS International Conference will consider opportunities within SiC led off by Wolfspeed and Evatec, with support from such key supply chain members as Disco and Bruker. Companies making strides with GaN-based devices will share their insights and findings including presentations from Infineon and Exagan. IHS Markit will dive deeply into global power device opportunities.

This edition of Power Electronics World examines multiple technology and application areas. GaN Systems, a frequent contributor and market leader, completed its in-depth 'Designing with GaN' series earlier this year. We have brought all three parts together in this edition so that designers, product developers and engineers wanting a 'one-stop-shop' approach to GaN design basics can have just that. We also take an intriguing look into the possibilities of transmitting energy via photons in a feature article from the University of Ottawa (Canada). The researchers are seeking a way to enable high-voltage photonic power at telecom wavelengths. If their work supports manufacturable products this could grow opportunities for power-over-fiber systems because data and energy could be transmitted over the same line. We also delve into ion implantation techniques for power transistors and other exciting developments that are transforming power and the future of power electronics.

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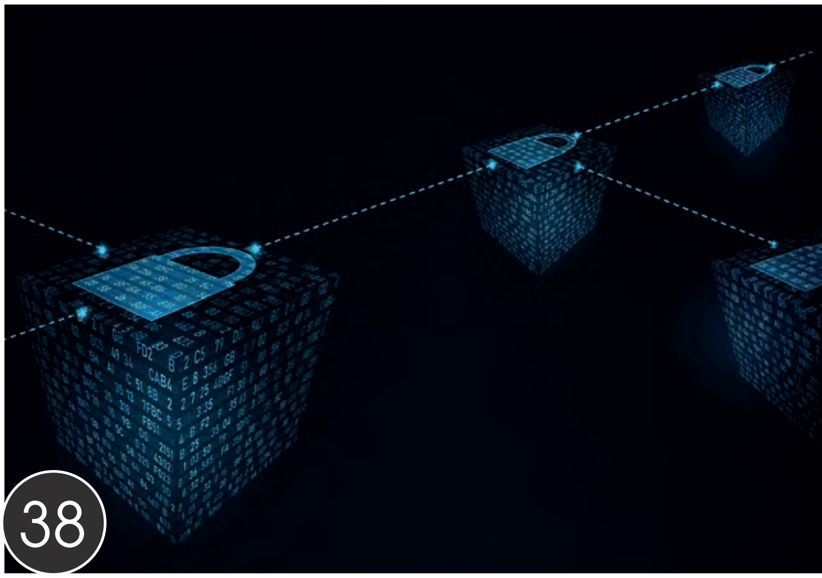

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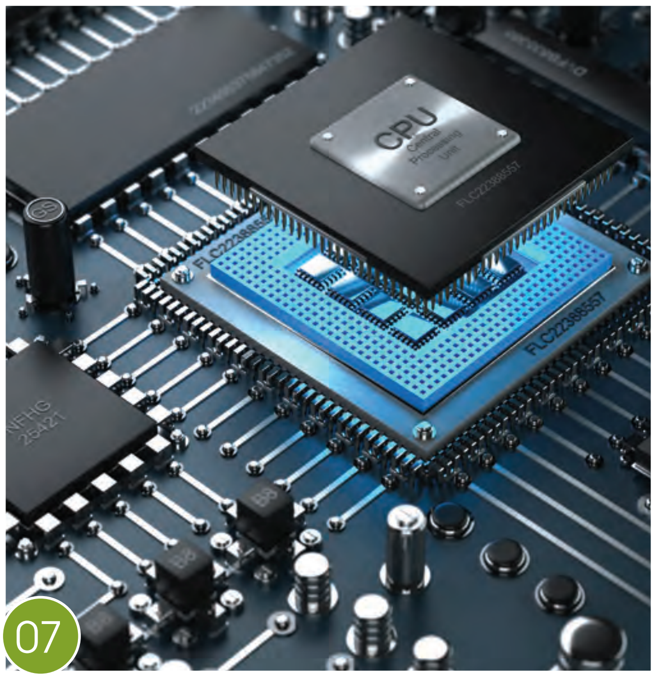


GaN and SiC power to reach $3 billion by 2025

The GaN and SiC Power Semiconductor Market is set to grow from its current market value of more than $400 million to over $3 billion by 2025; as reported in the latest study by Global Market Insights, Inc.

The expanding prominence of EVs can be aptly credited for the proliferation of GaN and SiC power semiconductor market trends. Even though automakers are introducing electric vehicles (EVs), their short driving range has dented their growth prospects, commanding the requirement of enhanced power devices.

GaN and SiC Power Semiconductor Market

Comprising mainly of gallium nitride (GaN) and silicon carbide (SiC), wide bandgap semiconductor (WBG) addresses high-end power density requirements. In consequence, players in GaN & SiC power semiconductor market have been vying with one another to provide higher switching frequencies, lower losses, high breakdown voltages and robustness in hostile environments, thereby leading to surge in the industry share.

With higher voltage and higher efficiency, automakers are saving on cost, maintenance and weight, while enhancing reliability. As such, GaN and SiC components are highly sought-after over semiconductor technologies such as silicone (Si) metal-oxide semiconductor field-effect transistors (MOSFETs) and insulated-gate bipolar transistors. Using SiC devices ultimately results in cost savings from reduced space requirements, lower battery costs, and simpler cooling measures, despite the additional upfront cost.

With myriad power supply operations demanding GaN & SiC components, adoption of the devices in sectors such rail traction, electric vehicles, and automotive electronic has increased, instilling confidence among players in GaN and SiC power semiconductor market.

When it comes to embracing IoT and connected devices, affluent countries such as the U.S. are leaving no stone unturned. Telecommunication sector—5G technology – tends to influence power semiconductor industry. With the U.S. at the helm, Japan, South Korea and China are taking audacious steps toward embracing 5G technology.

Companies across the aforementioned countries are looking forward to expand their 5G capabilities, which is bound to provide a lucrative boost to the regional GaN and SiC power semiconductor industry outlook.

For example, SK Telecom in South Korea acquired spectrums of 3.5 GHz and 28 GHz frequencies for the deployment of 5G network. Further, China Academy of Information and Communications Technology expects number of 5G connections in China to surpass 400 million by 2025.

PV inverters play an indispensable role in converting sunlight into electricity as the SiC embedded PV inverters propels the system efficiency and incurs lower switching losses. Experts opine that use of SiC devices for the PV inverter applications ameliorates the power density by reducing heat dissipation and size of passive components.

Sustained efforts by countries such as India and China to increase the use of renewable energy have instilled confidence among preeminent players in GaN and SiC power conductor market. The Government of India announced in September 2019 that India erected 195 solar panels on the terrace of UN. Meanwhile, according to the Ministry of New and Renewable Energy in India, the country of 1.3 billion population is gearing to have 175 GW solar energy in 2022.

These favorable initiatives undertaken by governments are expected to play an instrumental role in the uplifting of GaN & SiC power semiconductor industry landscape. With product diversification taking center stage, manufacturers are contemplating product portfolio expansion. Of late in May 2019, Infineon announced the roll out of its much anticipated 650 V CoolSiC MOSFET devices and are gearing to go into mass production.

On the other hand, Microsemi announced the roll out of new SiC products – 700 V Schottky Barrier Diode Devices & 1,200 V SiC MOSFET – which are expected to have positive influence in the growth of GaN and SiC power conductor market share.

Read More information: https://www.gminsights.com/industry-analysis/gan-and-sic-power-semiconductor-market.

Infineon adds 400V and 600V devices to CoolGaN

INFINEON TECHNOLOGIES AG of Munich, Germany has broadened its CoolGaN series with two new devices. The CoolGaN 400V device is tailored for premium HiFi audio systems where end users demand every detail of their high-resolution sound tracks.

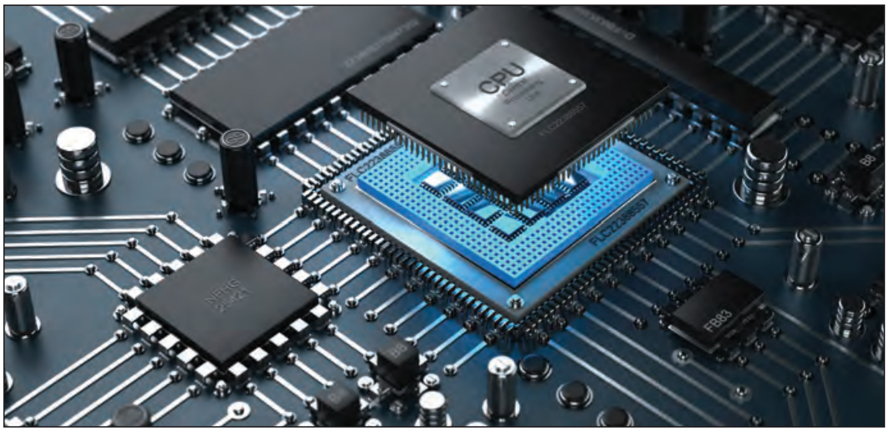
These have conventionally been addressed by bulky linear or tube amplifiers. Instead, audio designers can use the CoolGaN 400V switch as the class D output stage. The CoolGaN 600V industrial-grade device enables performance and cost optimization for low- and mid-power applications, such as in the area of low-power SMPS and telecom rectifiers. Every product in the CoolGaN family meets JEDEC standards.

Infineon says that the CoolGaN 400V switch enables smoother switching and more linear class D output stage by offering low/linear Coss, zero Qrr, and normally-off swich. Suitable class D audio amplifiers offer 0% distortion and 100% efficiency. What impairs the linearity and power loss is highly dependent on the switching characteristics of the device. Infineon says that CoolGaN introduces zero reverse recovery charge in the body diode and very small, linear input and output capacitances. The resulting benefit to the end users is more natural and wider soundstage audio. To further simplify the design, Infineon pairs the CoolGaN 400V device in an HSOF-8-3 (TO-leadless) package with a popular class D controller in an evaluation oard.

The CoolGaN 600V portfolio is now also extended with a new 190mΩ, industrial-grade high-electron-mobility transistor (HEMT), developed to fit any consumer and industrial application on an optimized cost with the aim to lower the technology entry barrier. Easy design-in is supported with a standardized DFN 8×8 packaging and the matching driver ICs from the GaN EiceDRIVER series.

POWI delivers one-millionth GaN-based InnoSwitch3 IC

POWER INTEGRATIONS (POWI), in high-voltage integrated circuits for energy-efficient power conversion, announced the delivery of its one-millionth InnoSwitch3 switcher IC featuring the company's PowiGaN gallium-nitride technology. In an event at the Shenzhen headquarters of Anker Innovations, Power Integrations CEO Balu Balakrishnan presented the one-millionth GaN-based IC to Anker CEO Steven Yang. Anker is a manufacturer of chargers and adapters, supplying retailers worldwide with powerful, compact USB PD adapters and a wide range of chargers and adapters for laptops, smart mobile devices, set-top boxes, displays, appliances, networking gear and gaming products.



"Anker is a world in compact charger design, and was the first high-volume customer for InnoSwitch3 products with PowiGaN. I'm pleased to recognize Anker's foresight and technical excellence, and to thank Mr. Yang for his critical contribution to the first successful mass-market deployment of high-voltage GaN technology."

InnoSwitch3 offline CV/CC flyback switcher ICs with PowiGaN technology are up to 95% efficient across the load range. Very low switching and conduction losses of PowiGaN primary switch allows delivery of as much as 100 W from a space saving InSOP 24D surface mount package in enclosed adapter applications without requiring a heatsink. Quasi-resonant InnoSwitch3-CP, InnoSwitch3-EP and InnoSwitch3-Pro ICs combine the primary power switch, primary and secondary control with safety isolated high speed link (FluxLink™) in between, as well as the secondary SR driver and feedback circuits in a single surface-mounted package. The superior switching performance of PowiGaN technology results in substantially higher efficiency, enabling very compact adapter designs. Commented Mr. Balakrishnan: "Anker is a world in compact charger design, and was the first high-volume customer for InnoSwitch3 products with PowiGaN. I'm pleased to recognize Anker's foresight and technical excellence, and to thank Mr. Yang for his critical contribution to the first successful mass-market deployment of high-voltage GaN technology." Added Mr. Yang: "By using PowiGaN-based InnoSwitch3 ICs we are able to offer USB PD chargers that are compact, lightweight, and capable of delivering high power output. We are excited to use this innovative new technology to help us achieve our goal to charge everything faster. We are confident this advancement will help us keep gaining positive market feedback and customer response."

Power Integrations' new InnoSwitch3 ICs are available now, priced at $4/unit in 10,000-piece quantities. Technical information on PowiGaN-based products – along with five new reference designs describing USB PD chargers from 60 W to 100 W – are available on the Power Integrations website at: www.power.com/PowiGaN.

Connectors:
key components in PV bankability

The concept of bankability plays an important role in assessing the viability of new solar power projects. Selwyn Corns, managing director of Stäubli Electrical Connectors UK, discusses the effect PV connectors have on bankability and the importance of their reliability over a plant's expected 25+ year lifetime.

THE TERM BANKABILITY was coined during the credit crunch in the aftermath of the financial crisis in 2008 and is a measure of the willingness of financial institutions to finance a project. Banks often took a gatekeeper role in the project approval process and in their bankability assessments they developed a systematic approach to identifying the legal, technical and economic risks of projects.

For photovoltaic plants, bankability has become an established risk management tool covering the whole lifetime of the project and can be a deal breaker for investors in large projects. In recent years this emphasis on a PV project's overall efficiency has been heightened by the withdrawal of government subsidies for solar power in many countries.

The MC4-EVO2, whose voltage rating of up to 1500V dc means that solar power operators can benefit from longer cable strings when linking solar fields.

The key to long term efficiency

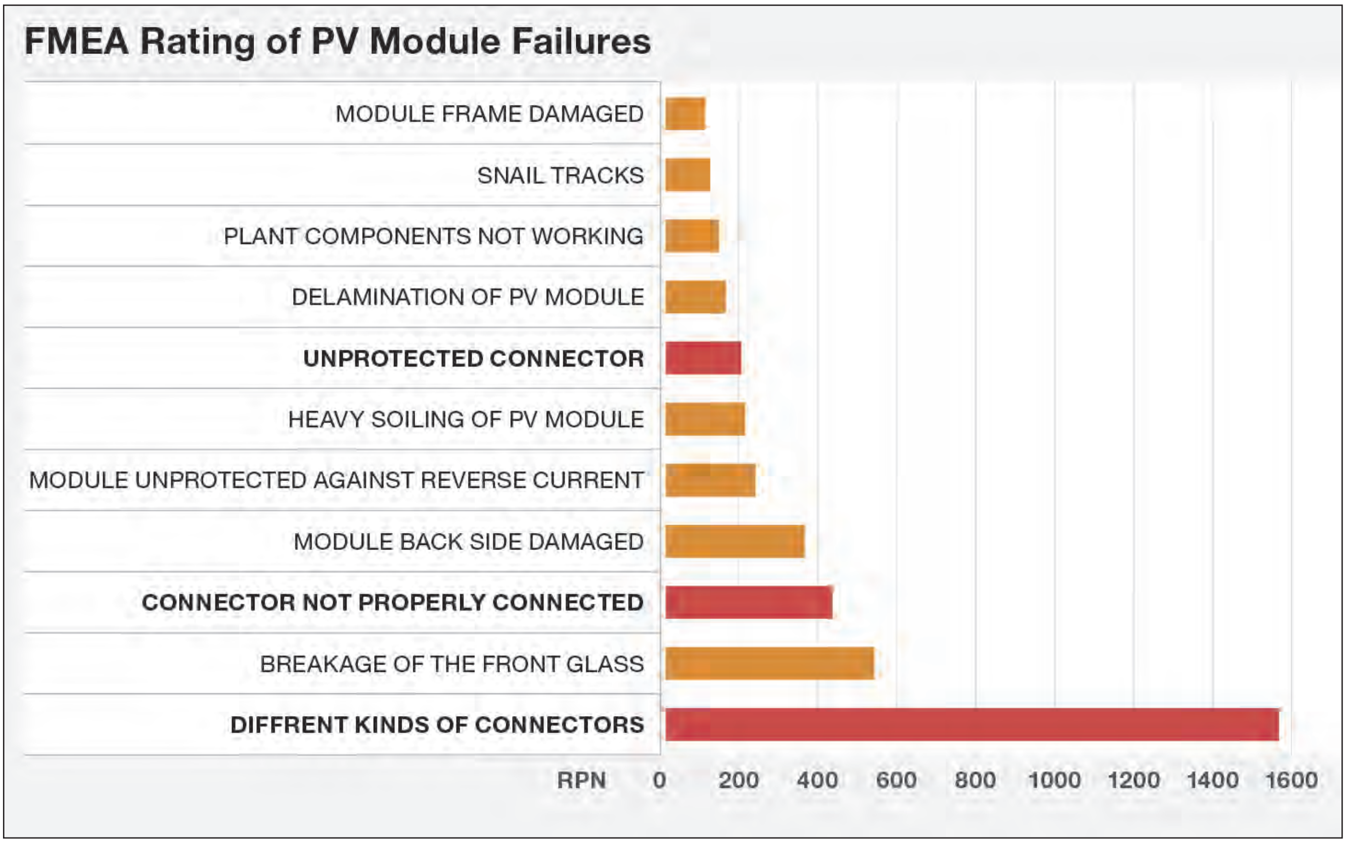
The guiding principle for bankability is to minimise risk while maximising return. This can only be achieved by ensuring efficiency over the long term through the use of high quality components.

During the project planning stage of a PV system, the main focus is understandably on the initial costs, predominantly on the two highest cost items: the solar panels and the power inverters. The components for cabling (connectors, junction boxes and cables) typically make up less than 1% of the total initial costs.

This is a reason not to consider cutting costs by using cheaper connectors, since any initial savings would only amount to a small proportion of the total capital expenditure. Any savings would be outweighed by the resulting higher failure rates over the project's 25 year or more lifespan that would lead to higher operating costs and a negative impact on return on investment.

Technical risks

The assessment of technical risks covers the whole project life cycle and involves all parties and associated contracts along



Failure Mode and Effects Analysis ratings of PV module failures

with the corresponding components and associated suppliers. Technical risks can arise from PV modules, inverters, connectors and other mechanical or electrical components, as well as from system engineering, energy prediction, installation and operation.

Technical risks very much depend on the individual framework conditions of the underlying PV system, i.e. system design and size, module technology and inverter configuration, site characteristics (whether ground or roof-top mounted), geographic and climatic conditions as well as international standards and local regulations.

These risks were a major consideration in the EU-funded Solar Bankability project, which ran from 2015 to 2017, and was set up to establish a common practice for professional risk assessment based on existing studies and statistical data of failures in PV plants.

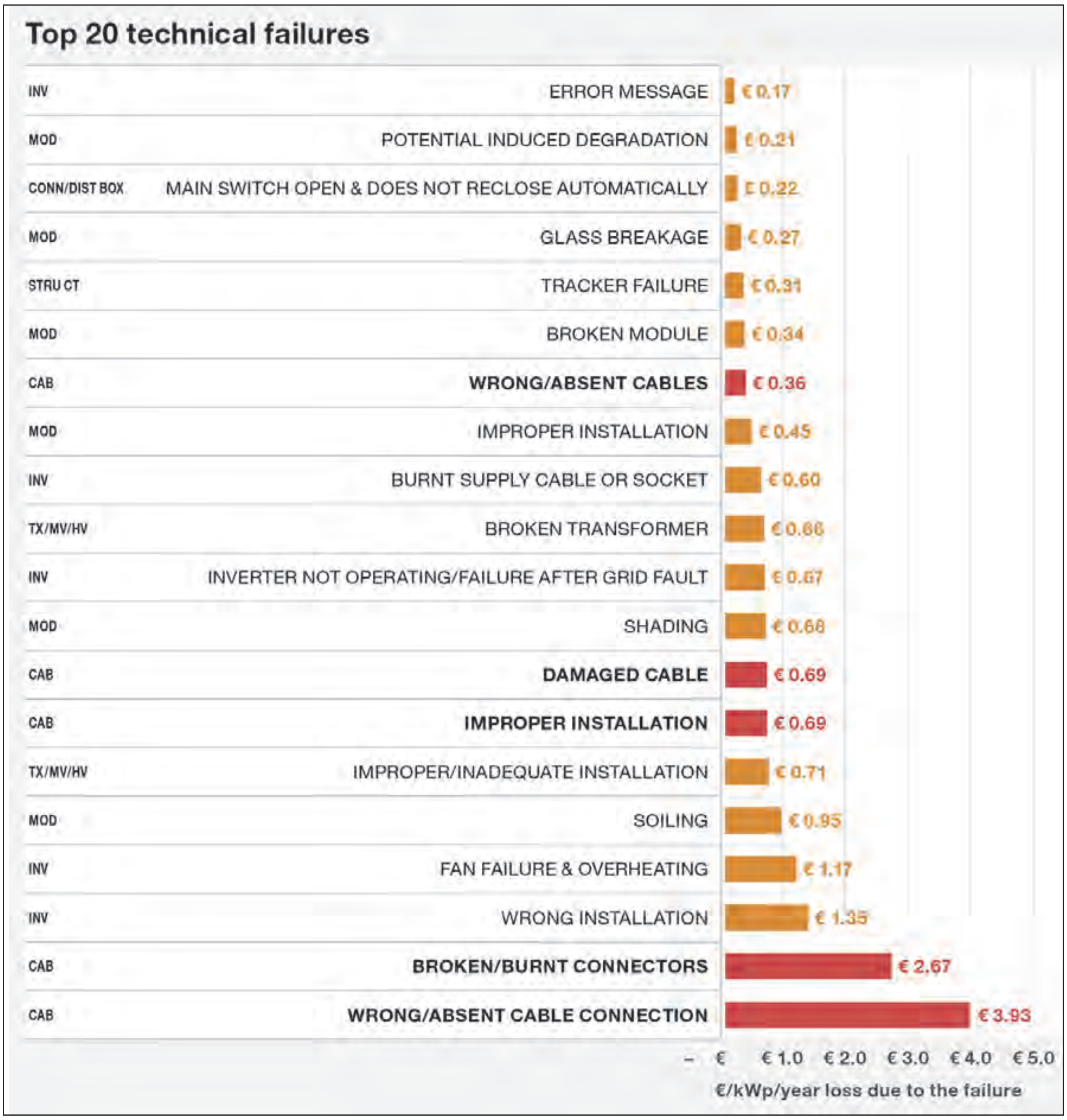
One of the reports it produced presents a cost-based Failure Mode and Effects Analysis (FMEA) for the estimation of economic losses due to planning failures, system downtime and replacement of components. High among the risk factors affecting downtime were those relating to connectors, with the use of mixed connectors from different manufacturers having by far the highest risk. Other causes of downtime were connectors not being correctly connected, and unprotected connectors. Connectors and cable problems were also prominent among the top 20 technical failures in terms of economic impact, taking into account downtime and cost of repairs. Wrong or absent cable connections caused the largest losses, followed by broken or burnt connections.

Connectors and bankability

One reason connectors have such a large impact on bankability is the large number of them required. For example, in a 5 MW ground-mounted plant, there could be 20 blocks of solar panel modules, each containing 18 strings of 45 modules. This amounts to about 32,000 connectors on the modules plus another 3000 for the field assembly, making 35,000 in all. The failure of one connector can cause the outage of a whole string of 45 modules.

Another factor is if operators try to cut corners by using cheaper connectors or mixing connectors from different manufacturers. It is important for connectors to have a very low electrical resistance as this maximises the current flow without generating significant amounts of heat.

For mismatched connectors or those not made to the highest specifications, there can be a vicious circle effect, with a higher contact resistance leading to component heating, which leads to a higher contact resistance and so on until the connector eventually fails or even causes a fire. Mixing connectors from different manufacturers can cause problems due



The top 20 most common technical failures

to differences in production processes and quality standards, loose fitting and insufficiently high contact forces, and chemical incompatibility of component materials. Cross-mating is specifically disallowed in the relevant standards as studies have shown that there is no compatibility between different brand connectors.

Long term reliability

Stäubli's PV connectors maximise bankability through their low contact resistance and long term reliability, which have helped to make the MC4 series the market leader. They use the company's proprietary MULTILAM contact technology, which has spring contact elements to produce multiple current-carrying contact points. Each spring forms an independent current bridge, so that the many parallel springs substantially reduce the overall contact resistance. This helps them to provide long term reliability, with a lifetime of 25 years and more.

Stäubli's expertise built up from over 20 years' experience of manufacturing PV connectors and accessories makes the company a bankable partner for the long term, helping to lower the risk of any PV project.

> Mixing connectors from different manufacturers can cause problems due to differences in production processes and quality standards, loose fitting and insufficiently high contact forces, and chemical incompatibility of component materials

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Molecular beam epitaxy at the University of Waterloo.

Extending the reach of photonic power

High-voltage photonic power converters designed for telecom wavelengths promise to extend the reach of power-over-fibre systems

BY MEGHAN BEATTIE AND KARIN HINZER FROM THE UNIVERSITY OF OTTAWA

WE LIVE IN an increasingly interconnected world, depending heavily on electronic devices such as sensing and communications equipment. Delivering reliable power to these devices as they are deployed in more remote and extreme environments can be challenging. The conventional approach is to provide power over copper wire, but this is highly sensitive to electromagnetic interference and prone to heating and sparking in hazardous conditions. An alternative solution to these challenges is photonic power transmission. This involves a light source and a photonic power converter, which converts the light back into electricity.

Merits of the optical approach include full electrical isolation and immunity from electromagnetic interference. In addition, fibre is lighter and cheaper than copper cabling; it is more tolerant of the environment; and there is the potential for simultaneous power and data transmission using existing telecommunications technology.

The superiority of optical fibre for data transfer is well known in the telecommunications industry; however, there are still roadblocks to widespread implementation of photonic power transmission. In particular, long distance transmission remains a challenge – one that we are addressing in our research at the University of Ottawa with a novel chip design, operating at telecom wavelengths, that will offer tremendous improvement in the reach of power-over-fibre systems.

The light source for a photonic power transmission system can be either a laser or an LED. After transmission, light is transformed back into electrical power by a photonic power converter, also known as an optical power converter, photovoltaic power converter, laser power converter, or phototransducer. Optical power can be transmitted through free space, but it is usually preferable to route it through an optical fibre, which guides the light and eliminates the need for line-of-sight trajectories.

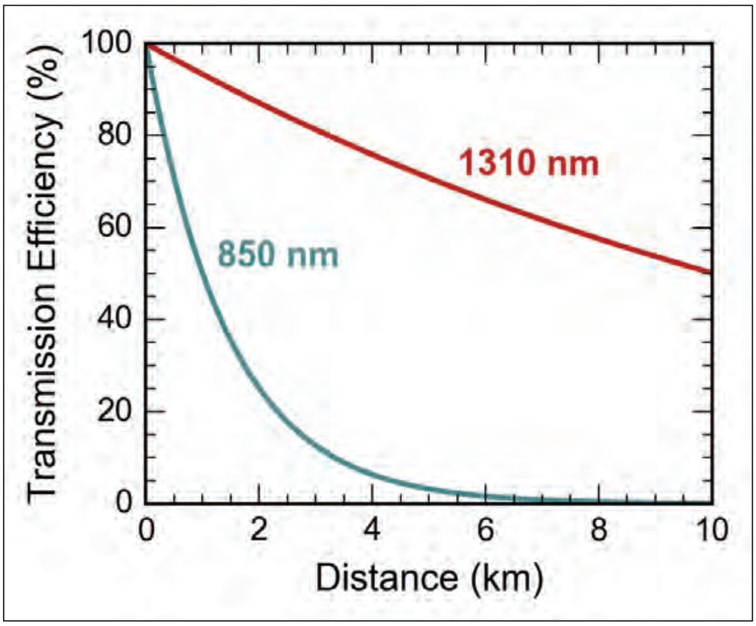


Figure 1. Optical fibre transmission efficiency as a function of distance for 850 nm and 1310 nm light. Attenuation coefficients are assumed to be 3 dB/km for 850 nm and 0.3 dB/km for 1310 nm.

Just like solar cells, photonic power converters generate electrical power from light through the photovoltaic effect. When light impinges on the device, photons are absorbed, generating a potential difference, or photovoltage, and an electric current. However, photonic power converters have a key difference to solar cells – rather than being designed to generate as much power as possible from the very broad solar spectrum, which spans the ultraviolet to the infrared, they operate within a very narrow energy range that corresponds to the output of a laser or LED. This distinction allows photonic power converters to operate at efficiencies of up to 70 percent, much higher than a solar cell.

Photonic power has already been adopted in niche applications, powering sensors for high-voltage transmission-line monitoring and deployed in magnetic resonance imaging machines where strong magnetic fields prevent the use of copper wires.

The use of photonic power transmission is sure to grow – budding applications are numerous and varied. It is a promising option for providing power to sensors and smart electronics in autonomous vehicles, which require isolation in an electrically noisy environment.

Opportunities also exist in emerging smart-grid infrastructures, which rely on vast arrays of sensors and inter-device communications, often operating in challenging environments with high voltages, electromagnetic interference and harsh weather. Other industries in which photonic power supply could make a positive impact are aerospace, avionics, defence, medicine, and telecommunications.

Wavelength	Material	Segmentation	Voltage	Efficiency	Source
850 nm	GaAs	Vertical	6 V	70%	Broadcom / uOttawa
850 nm	GaAs	Vertical	23 V	60%	
9XX nm	Si	Lateral*	3 V	41%	MH GoPower
9XX nm	Si	Lateral*	20 V	40%	

Table 1. Record segmented photonic power converter efficiencies at various wavelengths and operating voltages. *MH GoPower photonic power converters are multi-junction, but illuminated from the side so that they retain the same requirements for precise alignment and uniform illumination as standard lateral designs.

Increasing the distance

As the majority of photonic power converters are based on GaAs, their absorption lies in the 850 nm band. That's far from ideal, because at this wavelength the optical attenuation in the fibre is around 3 dB/km – or, put another way, power halves for every kilometre it travels through the fibre. This restricts GaAs-based photonic power converters to operate in either free-space configurations, or in scenarios involving short fibre links (see Figure 1).

A far better option for power transmission over long lengths of fibre is to shift to a wavelength where attenuation is minimised. Opportunities exist in the O-band and C-band, found at 1310 nm and 1550 nm, respectively (see Figure 1 to appreciate the extent of the improvement). However, to make this adjustment, there must be a move from a GaAs-based material system to one such as InP, on which smaller bandgap absorbers can be grown.

Our team at the University of Ottawa is adopting this approach. We are developing the first vertical-segmented InP-based photonic power converters for operation at 1310 nm. To produce these devices, we are collaborating with a team at the University of Waterloo that uses MBE to make our epistructures. Grown on an InP substrate, these heterostructures feature a lattice-matched InAlGaAs absorber.

The move to 1310 nm slashes the attenuation in the fibre to just 0.3 dB/km, or 7 percent per kilometre, opening the door to power transfer over several kilometres. There is also the tantalising prospect of using the longer wavelength C-band for data transfer, enabling a single fibre to simultaneously provide power transfer and communication.

Boosting the voltage

The operating voltage of a photonic power converter is limited by the bandgap of its light-absorbing region. GaAs-based devices, grown either by MBE or MOCVD, generate about 1.2 V, which is insufficient for most power applications. Conventional DC-to-DC converters could boost this voltage. However, a far better option for ensuring immunity to electromagnetic interference is to scale the voltage within the device itself, using series connections.

One widely used option is to form laterally segmented, interconnected devices (see Figure 2(a)) to generate output voltages of up to 20 V. This voltage is high enough to ensure that devices can be powered directly from the photonic power converter. However, this approach requires complex fabrication, and the devices that result are impaired by the strict requirement for precise alignment and uniform illumination across all segments. If one segment receives less illumination, it produces less photocurrent, limiting the current of the entire device and reducing its output power. Practical efficiencies for this type of device are typically 30 percent to 35 percent, although efficiencies under ideal conditions have hit the mid-50 percent range.

Due to these drawbacks, state-of-the-art photonic power converters rely on vertical interconnections, similar to multi-junction solar cell technology (see Figure 2(b)). The absorbing material is portioned into optically thin segments, series-connected with

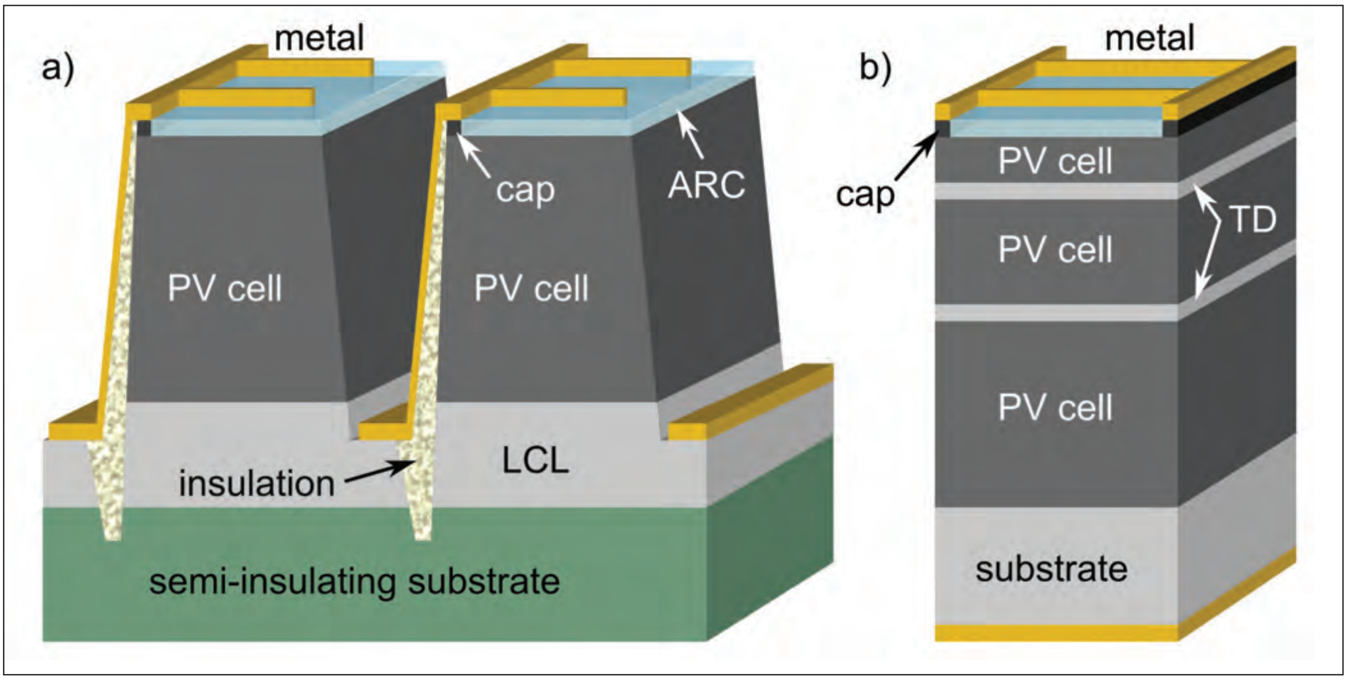


Figure 2. Typical design for a (a) lateral- and (b) vertical-segmented photonic power converter. ARC: antireflection coating, LCL: lateral conduction layer, PV: photovoltaic, TD: tunnel diode.

tunnel diodes. With this type of architecture, high output voltages are combined with high efficiencies. For example, a 20-junction GaAs device made by Broadcom Semiconductors ULC (formerly Azastra Opto) can produce an output voltage of 23 V. Fabrication is straightforward, and devices have good tolerance to non-uniform illumination, enabling efficiencies in excess of 60 percent. The record for efficiency, realised by Broadcom in partnership with our team, is as high as 70 percent for a five-junction device (see Table 1 for a brief overview of record efficiencies for segmented photonic power converters).

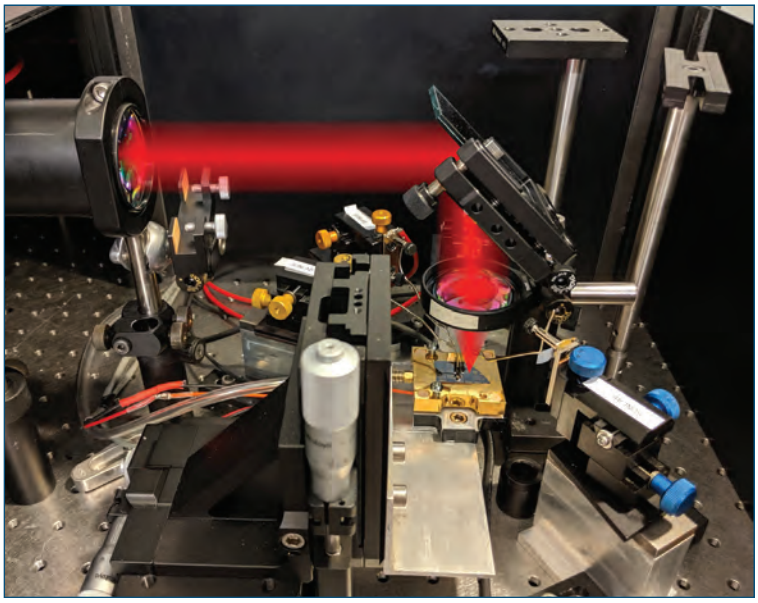
To boost the voltage of our 1310 nm photonic power converters, we employ this state-of-the-art, vertical-segmented, multi-junction design. The InAlGaAs absorbing region with a bandgap of 0.864 eV is partitioned into semi-transparent photovoltaic sub-cells. By precisely tuning the thickness of each layer, we ensure that each vertical segment generates the same current. This is accomplished with the thinnest layer at the top and the thickest at the bottom. The total thickness of the absorbing layers is almost 5 μm, ensuring at least 98 percent absorbance of incoming light. By shifting the composition of the quaternary, we can produce transparent lattice-matched tunnel diodes between each sub-cell. Ultimately, high-quality, vertical-segmented photonic power converters will be achieved.

We have produced a range of single-junction photonic power converters to determine the relationship between thickness of the absorber and quantum efficiency (see Figure 3). For these test devices, we have selected layers with thicknesses that would be used in a multi-junction structure. As expected, thicker layers increase absorbance, and by extension, quantum efficiency. One of our current activities is to establish an in-house fabrication process for device testing (see Figure 4 for a partially fabricated, single-junction photonic power converter wafer). Development of a complete multi-junction structure is also underway.

To benchmark the performance of our devices, we use the detailed balance limit. This represents the theoretical limiting efficiency of the device, and assumes that every absorbed photon generates a single electron-hole pair, completely separated and perfectly conducted. Calculations are carried out in the radiative limit, so excited charges can only relax by radiating light that may be reabsorbed in the device. These calculations offer an upper limit on what can be realised, as real devices are impaired by imperfect absorption and conduction, as well as non-radiative forms of charge relaxation. As we improve material quality, the performance of our devices gets closer to the limiting efficiency.

For our design, the theoretical voltage per junction is 0.63 V, in the radiative limit for an input power density of 10 W cm^{-2}. Based on these results, an ideal 10-junction photonic power converter of our design could achieve an output voltage over 6 V, and a limiting efficiency of 65 percent. For realistic material, a 10-junction photonic power converter should power a 5 V device with an efficiency of between 50 percent and 60 percent. Cranking up the input power, the current will increase linearly and voltage logarithmically. These changes would push the limiting efficiency to over 70 percent in the radiative limit for 100 W cm^{-2}.

Further improvements in the voltage and the efficiency will result from moving to a slightly larger bandgap for the absorbing region, aligning the absorption edge to



Experimental setup to measure current-voltage characteristics for photonic power converters with overlay of beam path.

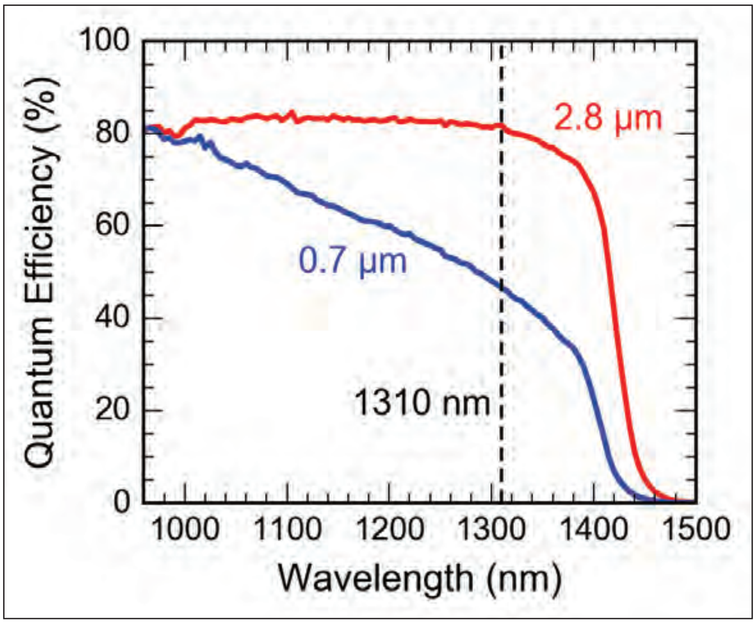


Figure 3. Quantum efficiency of optically thin, 1310 nm single-junction photonic power converters of varying thickness, designed to be incorporated into a multi-junction stack.

Wavelength	Material	Distance	Transmission Efficiency	Combined Fiber-PPC Efficiency*
850 nm	GaAs	1 km	50%	30%
		10 km	0.1%	0.06%
1310 nm	InAlGaAs/InP	1 km	93%	56%
		10 km	50%	30%

Table 2. Estimated efficiencies for power-over-fibre systems assuming 60 percent photonic power converter efficiency. *Does not account for efficiency of the light source (laser or LED).

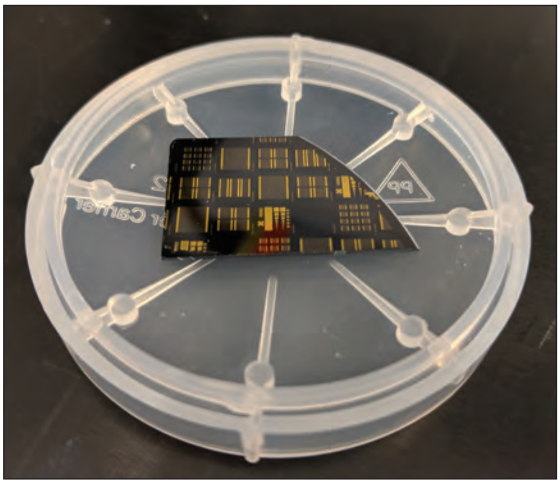


Figure 4. Single-junction photonic power converter chips for O-band operation.

the incoming light at 1310 nm – which corresponds to a photon energy of 0.95 eV – and thereby reducing the amount of energy lost to heat. Note that maintaining absorbance at 98 percent requires the use of a thicker absorber.

Possibilities and challenges

With our design of photonic power converter, we expect to transmit 1310 nm photonic power over a 1 km length of optical fibre with a 56 percent efficiency. That's nearly a two-fold increase over a comparable GaAs-based 850 nm system. The performance provided by our 1310 nm link paves the way to powering 5G devices within the internet-of-things. Even for distances as long as 10 km, we expect 30 percent efficiency, a tremendous improvement over GaAs-based devices, which can only realise a 0.06 percent efficiency (see Table 2 for a summary of estimated efficiencies).

Within a full power-over-fiber system, the overall electrical-optical-electrical efficiency is not just determined by the efficiency of the photonic power converter and the extent of fibre attenuation, but also by the efficiency of the light source. For high-power lasers operating at 1310 nm, efficiencies can reach the mid-30 percent range. Assume an electrical-optical conversion efficiency of 35 percent, and a photonic power converter efficiency of 60 percent, and the electrical-optical-electrical efficiency can be as high as 21 percent through free space. Add in 1 km and 10 km lengths of fibre, and the total efficiency will drop to 20 percent and 11 percent, respectively, assuming perfect optical coupling.

These efficiencies indicate that fully optical power-over-fibre systems could be deployed over distances up to 10 km, delivering reasonable performance and enabling reliable, fully isolated power supply to hazardous environments. Crucially, this power transfer technology could be added to existing fibre networks, previously reserved for data transfer, by introducing a 1310 nm light source and a photonic power converter.

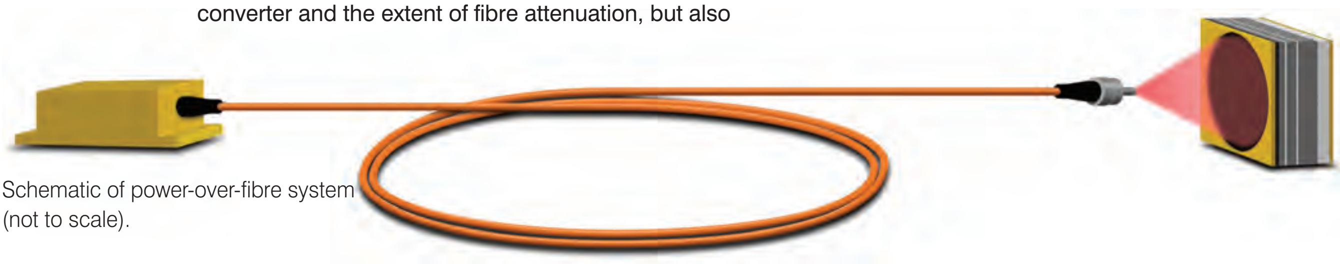
Our efforts, and those of our peers, are expanding the versatility of power-over-fibre systems. As the reach of photonic power extends, the catalogue of applications will continue to grow. There is no doubt that this technology has a very bright future.

Further reading

D. Xia *et al*. "Opportunities for High Efficiency Monochromatic Photovoltaic Power Conversion at 1310 nm," 46th IEEE PVSC, June 2019

M. Wilkins *et al.* IEEE Trans. Power Electron. **34** 1054 (2019)

S. Fafard *et al.* Appl. Phys. Lett. **108** 071101 (2016)



Schematic of power-over-fibre system (not to scale).

Cree to set up SiC corridor

As Cree forges ahead with its $1 billion SiC capacity expansion, company chief executive, Gregg Lowe, recently revealed a detour from the original plan. By Rebecca Pool.

FOLLOWING a mighty $500 million grant from the state of New York, Cree will now build a new automotive-qualified 200mm power and RF wafer fabrication plant in Marcy, New York.

The company had set out to convert an existing facility into such a fab, in Durham, North Carolina. But as Lowe points out: "We got this tremendous offer from New York state which has allowed us to get a substantially bigger fab for substantially less money." According to Lowe, Cree was to spend some $450 million on retrofitting an existing structure at Durham to expand wafer capacity by thirty times. However, the company will now invest around $170 million in building a new facility with nearly forty times more capacity.

Crystal growth and materials expansion will continue at Durham, to the tune of $500 million. And as Lowe says: "[The New York state investment] is a pretty good deal for us."

"We're creating this East silicon carbide corridor from New York to North Carolina and we reckon this is going to be very powerful," he adds. "Customers see us continuing to invest in silicon carbide capacity and expansion, and everyone is super-excited."
The new facility in Marcy, New York, is expected to bring in more than 600 new jobs by the end of this decade. Meanwhile the expansion of SiC crystal growth and epitaxy at Durham, North Carolina, will see a shift from lower-paid operator positions to higher-paid technician posts.

"We have partnered with local colleges in Durham to develop our own workforce, so our operators will be taking the necessary courses and associated degrees ready for this transition," says Lowe. "Also, up-state New York has a great collection of universities that are deep into materials and electronic engineering; having a highly qualified workforce is going to be key to get this really moving."

Proposed 200mm power and RF wafer fabrication facility, known as the "North Fab," was to be built in Durham (pictured), but will now reside at a new location in New York state.

Right now, the site in New York is ready for development while materials capacity expansion is already taking place in North Carolina. Come 2022, and with materials production in place, Cree expects to ramp 150 mm wafer production at New York and then transition to 200 mm wafer sizes around two years later.

The timings coincide with Cree's recent contract with US-based automotive propulsion system developer, Delphi Technologies. Here, the company is to manufacture SiC MOSFETs for use in Delphi's 800 V inverters, with production scheduled to ramp during 2022.

"These inverters are for a global, European [car] manufacturer, and our increases in capacity will work nicely with the ramp of this product," says Lowe. "We're quite certain that come this time our silicon carbide wafer fab will be the largest on the planet."

Importantly, the Cree chief executive also reckons industry SiC capacity constraints are easing. He highlights how Cree is steadily increasing SiC crystal growth capacity every week while also increasing epitaxy capability. "I also think the customer shift on electric vehicles from silicon to silicon carbide has really happened too," he adds. "Our customers are leaning very heavily towards silicon carbide right now."

China changes

But right now, how is Cree weathering ongoing US-China tensions? Earlier this year, the US Bureau of Industry and Security added Huawei to its 'Entity List' banning the beleaguered China-based business from buying components from US companies, such as Cree.

According to Lowe, Cree's LEDs business is "still bouncing around a bit" which hasn't been helped by trade friction and the economic situation in China. But, as he highlights: "The enthusiasm for silicon carbide power devices as well as electric vehicles and solar power systems will be the growth engine for Cree going forwards."

And while demand for electric vehicles has softened in China, following cuts in the nation's generous government subsidies, Lowe is unfazed, pointing out how subsidies are now aimed at cars with a relatively large driving range.

"The short-term has put a pause on the growth rate of the Chinese car market and car manufacturers are adjusting to these subsidy changes," he says. "But silicon carbide enables cars to go further with the same battery-size so in the long-term this is good for us."

But right now, how is Cree weathering ongoing US-China tensions? Earlier this year, the US Bureau of Industry and Security added Huawei to its 'Entity List' banning the beleaguered China-based business from buying components from US companies, such as Cree

Supercharging the HEMT

Cranking up the aluminium content in the AlGaN channel promises to create high-power HEMTs for extreme operating conditions.

BY PATRICK CAREY, FAN REN AND STEPHEN PEARTON FROM THE UNIVERSITY OF FLORIDA AND ALBERT BACA, BRIANNA KLEIN, ANDREW ARMSTRONG ANDREW ALLERMAN AND ROBERT KAPLAR FROM SANDIA NATIONAL LABORATORIES

POWER ELECTRONICS are ubiquitous. They are deployed in satellites, unmanned autonomous vehicles, electric cars, photovoltaic systems, and power transmission on the utility grid.

Silicon is still the dominant material for making these power devices, but in the last decade or so there has been an increasing use of wider bandgap materials, such as SiC and GaN. This move has much merit: it opens the door to higher switching frequencies and superior thermal management; and it slashes the size and weight of the power converter, by allowing the use of smaller, lighter passive elements while simplifying thermal management.

The introduction of SiC and GaN devices is not going to be the end of the story, but the beginning of a journey to materials with even wider bandgaps. Under development right now are devices made from ultra-wide bandgap semiconductors, such as diamond, Ga_2O_3 , BN and high-aluminium-content AlGaN. This class of materials promises to propel device performance to a new level.

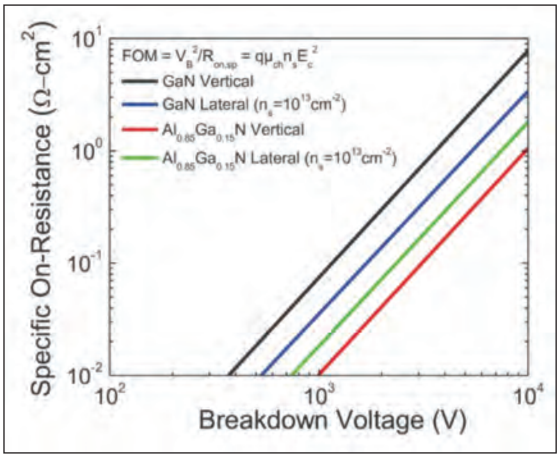


Figure 1. Specific on-resistance versus breakdown voltage for high-aluminium-content devices compared with GaN.

In applications where devices are deployed in an extreme environment, high powers have to go hand-in-hand with greater robustness. These attributes may be required in avionics, automotive, nuclear, defence, and extra-terrestrial applications.

For example, in exploratory missions to the surface of Venus, devices must withstand temperatures of 500 °C, while maintaining their performance in corrosive sulfuric acid clouds. In addition, there can be the need to provide continuous operation when bombarded by radiation. The Galileo orbiter, which probed Jupiter for many years, withstood an irradiation dose above 600 krad before it plunged to its planned demise as the effects of radiation damage became unrecoverable.

Traditionally, it has been the wide bandgap materials SiC and GaN, working in conjunction with other technologies, that have provided a reasonably successful approach to extending device lifetimes in these high-power applications operating in extreme environments. But these materials are beginning to reach maturity, so obvious questions arise. Two that top the list are: What is the next material system for power electronics? And what will be the next innovation?

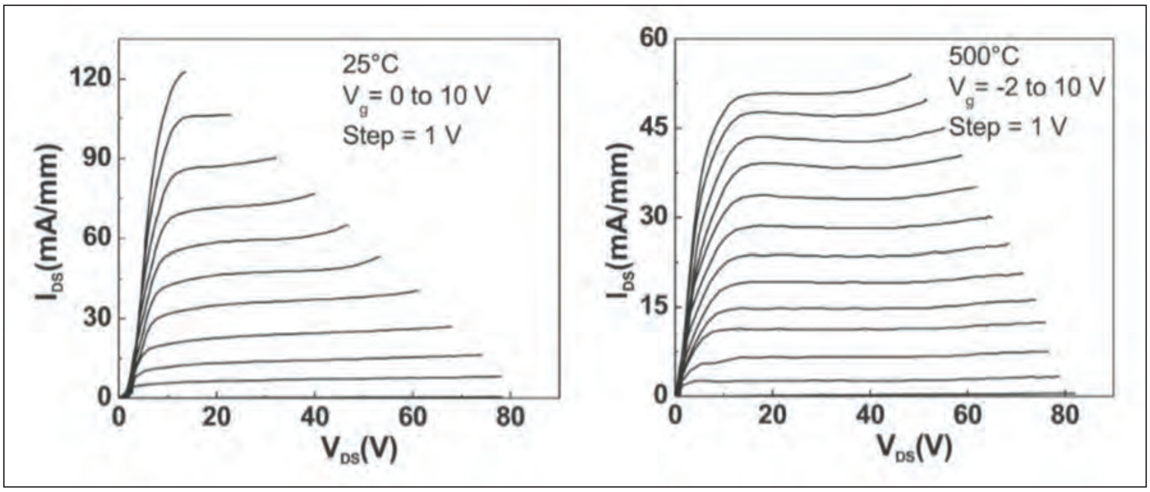


Figure 2. Typical current-voltage characteristics at 25 °C and 500 °C.

Every ultra-wide bandgap semiconductor has its pros and cons. Often there are concerns related to cost, substrate availability, and existence of controlled doping and contact schemes. For example, while Ga_2O_3 has made some progress in vertical diodes with bulk growth technology, its low thermal conductivity, lack of native p-type doping, and low electron mobility are drawbacks for its use in power electronics.

An attractive option is to build on the success of previous efforts. That's possible with GaN, a material that has benefitted from more than thirty years of exploration and investment. Its performance can be improved by increasing the aluminium content in the AlGaN channel of the HEMT. That's the approach trailblazed by our team, a partnership between the University of Florida and Sandia National Laboratories.

One of the greatest strengths of AlGaN is its ultra-wide bandgap, which leads to a very high critical breakdown field, E_c. The exact relationship between the critical field and the bandgap, E_g, is a focus of active research, but it is essentially a power law, with E_c proportional to $E_g^{2.5}$. Due to this relationship, when the aluminium content increases to 70 percent or more, the bandgap widens to 5.4 eV, and the breakdown voltage increases – it should hit 13.4 MV/cm (see Figure 1 for a comparison of aluminium-rich devices and those with pure GaN, illustrating the potential for devices that combine an ultra-low specific on-resistance with a high breakdown).

Like other ultra-wide-bandgap materials, alloys of aluminium-rich AlGaN hamper the production of low-resistance ohmic contacts. In addition, with this ternary it is challenging to realise meaningful carrier concentrations and high mobilities. However, excellent progress has been made to date in all these areas.

Encouragingly, initial irradiation studies on HEMTs with high-aluminium-content AlGaN-channels show that bombardment with 2.5 MeV protons has little effect on this device. However, research prototypes show a reduced single-event burnout tolerance in simulated space environments.

These results indicate that there is an improvement in total dose irradiation hardness when moving from a GaN-channel device to an AlGaN HEMT. This is to be expected, given the strength of the atomic bonds. For GaN, it is 8.92 eV/atom, while for AlN, it is 11.52 eV/atom – to put those figures in context, values for silicon and GaAs are just 2.34 eV/atom and 2.17 eV/atom, respectively.

Growing AlN

For every compound semiconductor, it is ideal to grow the epilayer on a native substrate. So, for AlN HEMTs, the perfect platform is high-quality, single-crystal AlN. This foundation has a bandgap of 6.2 eV, a high thermal conductivity of 285 W m^{-1} K^{-1}, and it provides a nearly lattice-matched substrate for aluminium-rich AlGaN epilayers, greatly reducing strain and threading dislocation density in this ternary.

Producing high-quality AlN substrates is very challenging. The most promising method for preparation, physical vapor transport, produces material with dislocation densities below 103 cm^{-2}. However, commercialising substrates with this

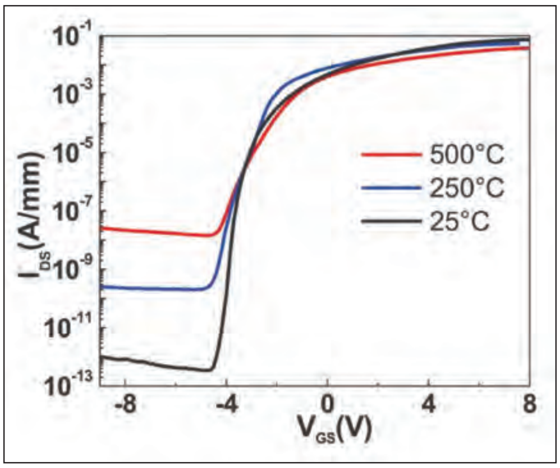


Figure 3. Id-Vgs curves at select temperatures from 25 °C to 500 °C.

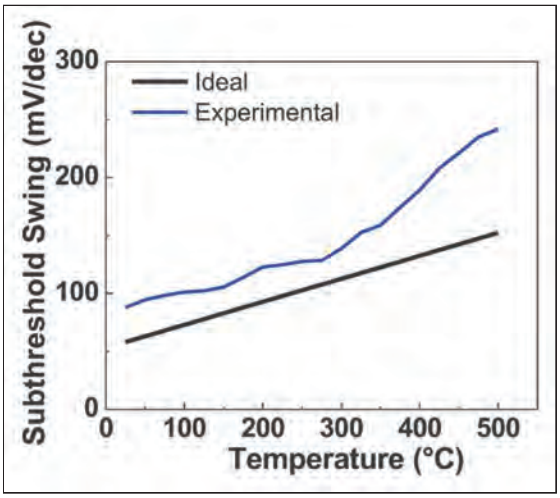


Figure 4. Experimental and ideal subthreshold swing as a function of temperature.

technique is far from easy, as it is tricky to combine a sufficient size with a low defect density.

Due to the high cost of AlN substrates, the majority of efforts directed at developing AlGaN are undertaken with sapphire or SiC substrates. They provide a template for growing a layer of AlN, which provides the foundation for AlGaN devices.

Growing AlN on sapphire is not straightforward. Two of the greatest issues are the large lattice and thermal conductivity mismatches. Failure to take sufficient care leads to cracks developing in AlN grown on sapphire after the critical thickness has been reached, due to tensile stress from the coalescence process.

Much effort has been devoted to avoiding this, and after 15 years of detailed study of the epi-growth of AlN epilayers on sapphire, there are now several reports that detail different growth processes for producing device-quality AlN epilayers.

When AlGaN epilayers are grown on AlN-on-sapphire templates, it is the composition of the AlGaN that determines epilayer, lattice and thermal mismatch. These mismatches can be exacerbated between the AlGaN and AlN. To reduce the stress and the density of defects in AlGaN epilayers, engineers can turn to compositionally-graded layers or superlattices, or begin by intentionally inducing three-dimensional growth modes, before switching to two-dimensional growth for planarization.

Processing challenges

Our team has used MOCVD to produce aluminium-rich AlGaN HEMTs on sapphire. The typical composition for these structures is a 85 percent aluminium barrier layer and a 70 percent aluminium channel layer. We refer to this structure as 85/70. With these compositions, the epilayers can behave as insulator-like materials, hampering the formation of ohmic contacts. Regardless of metallisation and annealing temperature, it is difficult to achieve linear, low-resistivity contacts without employing more advanced techniques. Our simple planar contacts have realised a contact resistivity of 2×10^{-2} Ω-cm^2. While this resistivity is still far higher than 10^{-6} or less, a typical range of values that are easily achieved in GaN devices, we believe that it is quite reasonable for an early attempt with our new aluminium-rich materials.

One established process for the AlGaN HEMT is plasma etching, a technique that is widely used with GaN. It is relatively easy to etch tens of nanometres per minute, a rate that optimises the control of the recessed gates. There is a danger that surface roughness can arise from micro-masking of the surface of Al_2O_3. However, this can be prevented with an appropriate gas chemistry to produce surfaces with a root-mean-square roughness below a nanometre. We have found that a small addition of BCl_3 assists in the removal of Al_2O_3, to yield a better surface than that realised with a pure Cl_2/Ar environment.

Trumping GaN

We have evaluated the performance of our 85/70 transistor from room temperature up to 500 °C. Measurements of the forward current as a function of voltage reveal full gate modulation across the entire temperature range (see Figure 2). A great attribute of these devices is that they produce full pinch-off up to these temperatures. In sharp contrast, GaN HEMTs fail to provide full pinch-off above 300 °C – and they are plagued by a poor current on/off ratio, which is typically around 10^4.

One characteristic of SiC and GaN devices is a current-voltage curve with an upward slope in the saturation regime at elevated temperatures. This behaviour is not ideal – the slope should be horizontal – and it indicates a low output resistance, which hinders high-temperature performance. The is not an affliction for our 85/70 devices, which have

Growing AlN on sapphire is not straightforward. Two of the greatest issues are the large lattice and thermal conductivity mismatches. Failure to take sufficient care leads to cracks developing in AlN grown on sapphire after the critical thickness has been reached, due to tensile stress from the coalescence process

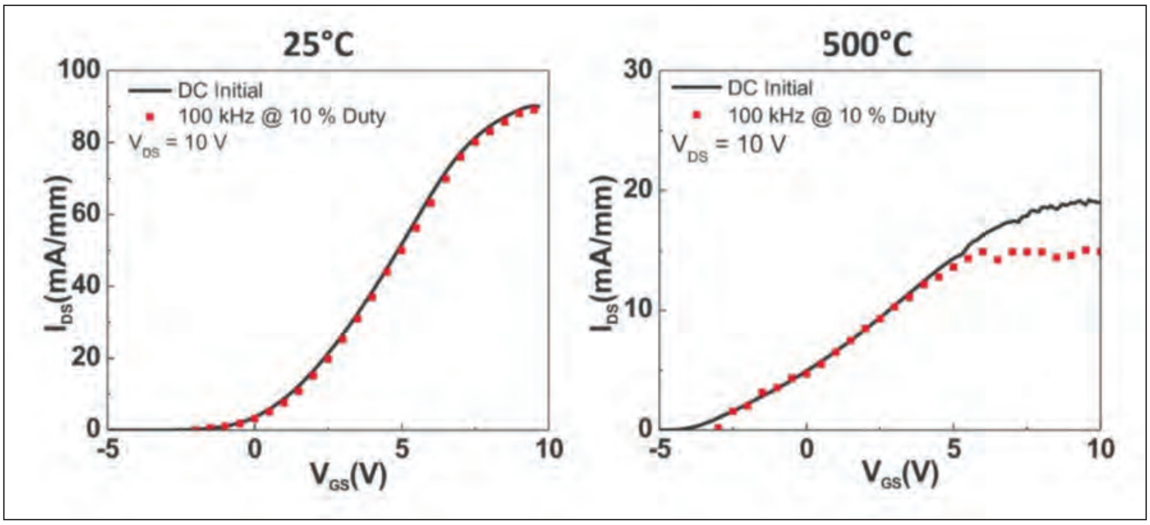


Figure 5. Gate lag at 25 °C and 500 °C performed at 100 kHz, 10 percent duty, and a drain-source voltage of 10 V.

a reasonably horizontal current-voltage slope in the saturation regime at 500 °C. This unique performance provides a significant improvement over traditional GaN-channel HEMTs.

At very high temperatures, the quality of the gate dictates channel modulation characteristics. We have undertaken initial studies with a Ni/Au gate. At room temperature, the Schottky barrier height is a moderate 1.2 eV, a value comparable to that of a GaN HEMT at room temperature. Raise the temperature, however, and device performances diverge. For our 85/70 device, the barrier height of the gate appears to be entirely unpinned, with a magnitude increasing to 3.3 eV at 500 °C. The lack of pinning is highly desirable, as it implies that the electrons on the gate gain thermal energy under heating, while in tandem the barrier height increases in magnitude, preventing an excessive leakage current at high temperatures. Another advantage of the high Schottky barrier is that it allows AlGaN devices to be driven at higher current densities and at higher drain voltages than GaN equivalents. The level of superiority is particularly acute at elevated temperatures.

It is worth noting that the unpinned behaviour may not hold true for other gate metal stacks. We are investigating this as we explore different designs to further improve device performance.

A significant benefit that stems from turning to high-aluminium-content AlGaN is the increase in breakdown performance. Efforts by our team reveal that AlGaN HEMTs are capable of withstanding electric fields up to 2.5 MV/cm, a figure that is approaching the SiC limit. Far higher values may be possible, as we are yet to employ techniques to improve performance, such as a source field plate, and it is still early in the development of this material system. For example, we have not yet begun to explore better dielectrics to match the breakdown field of AlGaN. Our hope is that as the growth, the device design, and the processing are optimised over the coming years, fabricated devices will move closer to the theoretical limit of 13.4 MV/cm.

Better breakdown characteristics are very valuable, as they drive down the power loss of the device that is associated with the reverse leakage current. For our devices, the current is as low as 10^{-12} A/mm at room temperature, rising to just 10^{-8} A/mm at 500 °C (see Figure 3).

These plots of reverse leakage at different temperatures can be used to determine an activation energy, and ultimately the mechanism behind the drain leakage current. Using an Arrhenius plot, we have determined an activation energy of 0.63 eV for temperatures below 350 °C, and an activation energy of 0.076 eV above 350 °C. An activation energy of 0.63 eV is consistent with Poole-Frenkel emission, while that at 0.076 eV is associated with band-to-band tunnelling. This can take place at this low energy due to significant bending within the conduction and valence bands.

The other key metric that can be extracted from these current-voltage plots is the sub-threshold swing. At room temperature, our devices have a value of 80 mV/dec, not far from the ideal 60 mV/dec (see Figure 4). From these graphs of sub-threshold swing we are able to extract the interfacial trap density. It is clear that there are two distinct linear regions: one from 25 °C to 300 °C, associated with trap densities of 2×10^{11} cm^{-2}; and the other from 300-500 °C, for trap densities of 3×10^{12} cm^{-2}. These values are very encouraging, suggesting that the interface in our devices might even be better than that in AlGaN/GaN, which has a typical trap density on the order of 10^{12} cm^{-2} at room temperature.

One envisioned use for our aluminium-rich AlGaN HEMT is high-power switching. To investigate its potential, we have undertaken gate switching at 100 kHz and a 10 percent duty cycle, using a constant drain bias of 10 V. These measurements reveal a

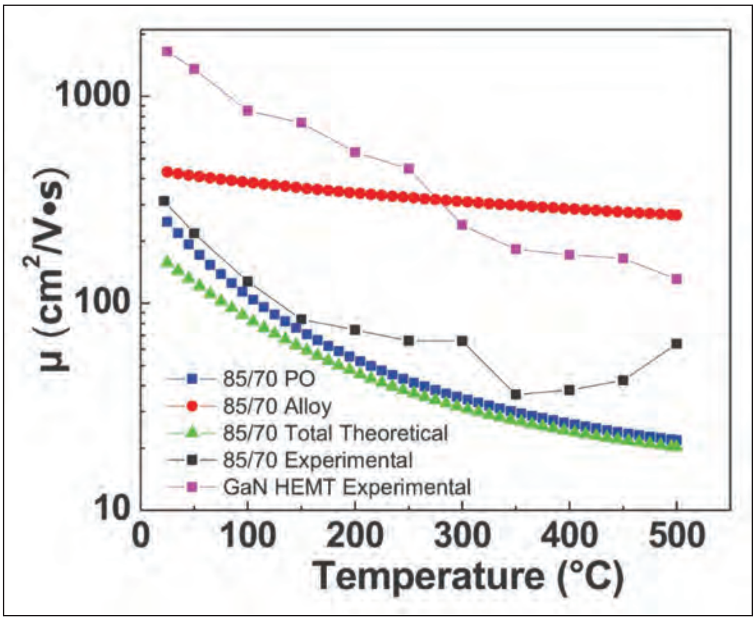


Figure 6. Modeled and experimental electron mobility as a function of temperature for the 85/70 HEMT, compared with a traditional GaN HEMT.

near-ideal pulsed current across the entire temperature range (see Figure 5).

We have also examined whether there is any evidence for the formation of a virtual gate. This is not wanted, as it could lead to current collapse under pulsing. The good news is that there is only a very slight reduction in pulsed current at high gate voltages, indicating that a virtual gate is clearly not forming.

Given the success of GaN devices in the RF domain, it is natural to wonder whether our transistors could have an impact there. But before diving into this, it is essential to consider the electron mobility in the AlGaN HEMT. The concern is that moving to a channel with a ternary alloy will result in a large increase in alloy scattering. This could be particularly significant in aluminium-rich AlGaN, as polar optical phonon scattering effects will become stronger, because the Al-N bond has a greater difference in electronegativities than the Ga-N bond. At low and moderate temperatures, alloy scattering will be the limiting factor, but it will be overtaken by polar optical phonon scattering at elevated temperatures.

We have modelled these two key effects and compared them with experimental values for mobility (see Figure 6). At room temperature, the channel mobility of the 85/70 device is just 3^{10} cm^2 V^{-1} s^{-1}. This value, much lower than a GaN HEMT, results from the combination of alloy scattering and polar optical phonon scattering.

History attests to a lag between success in the DC domain and that in the RF. After the demonstration of the first ever GaN device in 1993, it took another three years to realise the first RF performance. With AlGaN channel HEMTs, the wait has been even longer – a HEMT with an AlGaN channel was first demonstrated in 2007, only within the last year have several RF results been published, including the efforts of our team.

Initial results produced by our 85/70 devices include an f_t of 28.4 GHz and an f_{max} of 18.5 GHz. Large-signal RF testing, performed at 3 GHz using a drain-source bias of 20 V and gate-source voltage of 3.75 V, reveals a peak output power of 15.8 dBm at a power-added efficiency of 11 percent.

Don't be surprised that these results are nowhere near those of today's GaN RF devices. After all, advanced techniques for RF device processing have not been used. It's also important to note that RF solutions for extreme environments do not exist today for GaN or SiC RF devices.

We would expect that as an awareness of the capability of the AlGaN HEMTs grows, and more reports emerge, there will be further development and additional improvements. In turn, more groups will get involved, collective knowledge will increase, and this will lead to additional breakthroughs.

Even in its infancy, it is clear that the AlGaN HEMT has the potential to complement its GaN cousin. Intrinsic mobility limitations will impact some applications in power switching, but there are new opportunities for this material system in extreme environments. Unlike other ultra-wide bandgap materials, developers of AlGaN HEMTs can draw on the breakthroughs made with a similar material system – the successes that have been accomplished during thirty years of investigating GaN – and accelerate the development and commercialisation of this very promising transistor.

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia National Laboratories is a multi-program laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC (NTESS), a wholly owned subsidiary of Honeywell Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The views expressed in the article do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Further reading

M. J. Martinez et al. IEEE Trans Nucl. Sci 66 344 (2019)

P. H. Carey et al. IEEE JEDS 7 (2019)

A. G. Baca et al. ECS J. Solid State Sci. Technol. 6 Q161-Q165 (2017)

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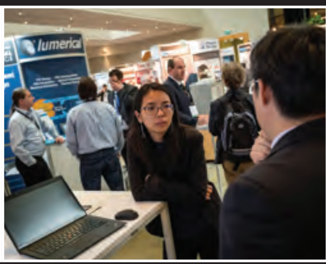



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The rise of GaN-based power systems

Power Electronics World invited the gallium nitride (GaN) transistor experts at GaN Systems to provide an introduction to the capabilities of high power density, wide bandgap semiconductors for designers who have worked primarily in silicon technologies. This article is the first in a three-part series.

BY PAUL WIENER, VP STRATEGIC MARKETING, GaN SYSTEMS

HIGHER-EFFICIENCY power conversion is critically essential to meet the needs of systems in areas of increasing reliance such as data centers, electric vehicles, renewable energy, industrial motors, and consumer electronics that are consuming ever more power. For example, industrial motors use 30 percent of the world's electrical energy. Data centers are forecasted to consume 5-10 percent of our energy resources. And with the growing number of IoT applications and devices and the arrival of 5G, the resources required to power them are adding more demand every day. The significant benefits that Gallium Nitride (GaN) technology was expected to bring to the power electronics market are now being realized, especially in the industries mentioned above.

This article, Part 1 of a multi-part series, describes the growth of the GaN power sector and the main application areas being affected. It gives a brief overview of the fundamentals of GaN technology and describes the similarities and advantages of GaN E-HEMTs compared to traditional silicon MOSFETs. It also provides examples of advanced E-HEMTs that are facilitating the rapid adoption of GaN designs in applications that require the highest possible efficiency.

GaN market overview

A report from Yole Développement projects the power GaN market to grow at a 79 percent CAGR over the next five years, and by 2020 to reach (USD) $460 million in revenue. According to the analyst firm, the most significant volume will come from the AC/DC and DC/DC power supply market (a predicted $250 million sub-market by 2020), with a significant portion addressing data center power.

Other key areas for GaN adoption are electric and hybrid electric vehicles and wireless power. Additional markets, including solar (PV), industrial motor drives, Class D Audio, UPS systems and consumer electronics, are also driving forces behind this growth (Figure 1).

As these market areas would suggest, GaN devices offer significant efficiency gains for power electronics designs that surpass traditional approaches.

Fundamentals of E-Mode GaN HEMTs

In their native form, GaN HEMTs power transistors are depletion mode (normally ON) devices. In power switching applications, d-mode devices typically utilize a cascode configuration to effect normally OFF operation. The complexity of cascode implementation of GaN transistors, essentially multi-chip modules, has limited the market acceptance of this type of product.

E-mode (enhancement-mode) HEMTs on the other hand, are conceptually similar to normally OFF silicon MOSFETs. They consist of three terminal devices with gate, drain, and source nodes. Similar to silicon MOSFETs, a positive voltage between gate and source on the HEMTs enables a high-electron-mobility path between the drain and source terminals (Figure 2).

When the gate is held at or below source potential, the high-electron-mobility path is interrupted and no current flows between drain and source. Additionally, a GaN device's Qg, or gate capacitance, is lower by an order of magnitude or more compared to a silicon MOSFET device, which makes driving an E-HEMT device much easier.

The same circuit techniques used to drive traditional silicon MOSFETS can also be used with e-mode GaN HEMTs. In other words, the GaN device works much like a silicon MOSFET, only with much better switching and circuit performance. Additionally, GaN E-HEMT devices are closer to the "ideal switch" in power electronics applications because they do not have an intrinsic parasitic body diode as do silicon MOSFETS. Thus, there is no need for anti-parallel diodes.

Advances in E-Mode GaN

The desire for benefits arising from e-mode GaN devices has yielded advancements in e-mode GaN HEMT technology, and can be seen in GaN Systems E-Mode product line. The benefits of these

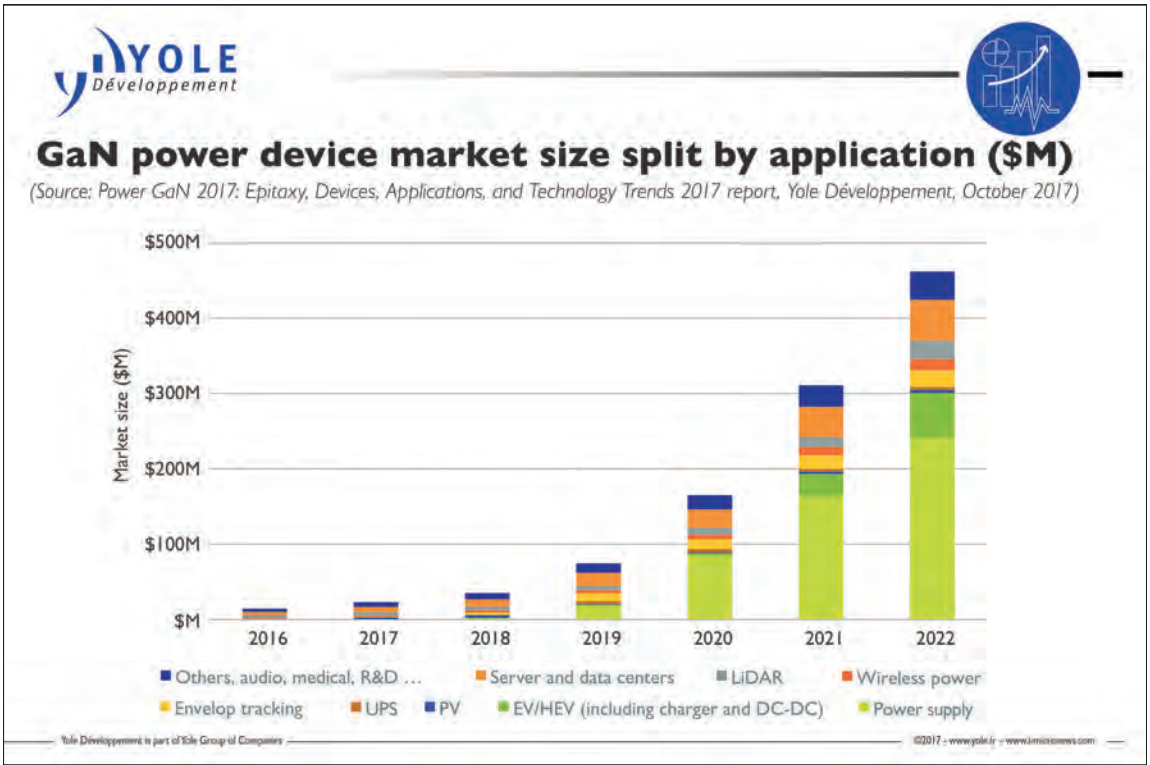


Figure 1. Yole projection of GaN adoption growth by various markets by year

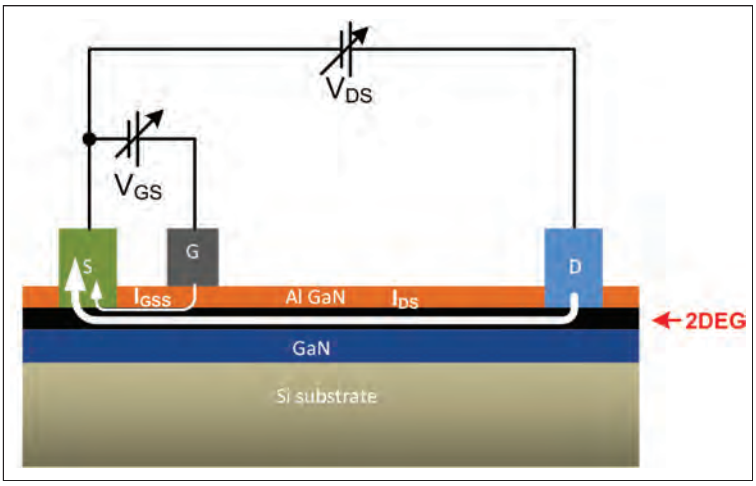
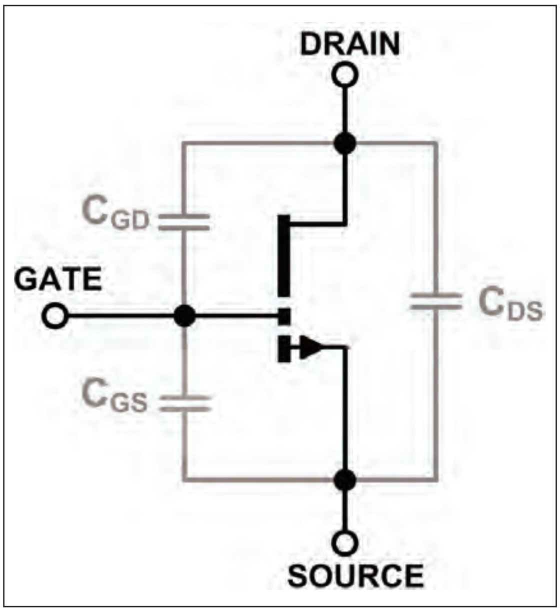


Figure 2. Topology for e-mode GaN devices is conceptually similar to silicon MOSFETs.



advanced devices include a more robust gate structure than similar devices, no DC holding current, and no complex gate diode PN junction. They switch on average four times faster and turn off at least two times faster than comparable devices on the market. By spending less time in the linear region, efficiency is greatly improved. Also, their lower gate capacitance means less energy is consumed driving the gate. The resulting energy savings applies right to the bottom line of increased power converter efficiency.

Not only can E-HEMT GaN devices upgrade many existing topologies, they enable new applications that were not possible with traditional options. For example, E-HEMTs can replace IGBTs in half-bridge hard-switching power converter circuits with drastic improvements in circuit performance. Moreover, E-HEMT GaN devices enable innovative topologies not possible with MOSFET devices such as the bridgeless totem pole topology (Figure 3). Silicon MOSFETs could never be used for these applications due to the limitations of QRR.

Benefits for power system design

As has often been observed, semiconductor advances are either the result of improvements in process or packaging. In the case of the GaN Systems E-Mode devices, both areas are evident. The work being done to increase the benefits of E-HEMT GaN devices include embedded die and advanced packaging and co-packaging of drivers and the GaN switches to minimize parasitic interconnections – offering functional modules and more.

The resulting benefits of using this are many:

- The need for heat sinking is reduced -- with opportunity to use the PCB as the heat sink – thus decreasing weight, volume, cost, size and assembly cost, and complexity of the device
- Increasing output power and/or switching frequency results in reducing the size of the magnetics, making them smaller and lighter
- Faster switching speeds and slew rates means the switching devices themselves spend less time in the linear region, thus lower switching
- Also, higher operating temperatures are possible due to the wide bandgap construction and larger potential barrier structures
- Low parasitics, overall, and much lower capacitances, including gate capacitance, means that it is much easier to drive and lower gate drive losses
- Higher breakdown voltages (due to the overall wide bandgap construction) and higher current (due to higher carrier density and increased electron mobility) are possible
- Eliminating the parasitic diode means better circuit operation and fewer external components needed in addition to zero recovery charge in circuit operation

These device attributes translate to reduced size and weight benefits; devices can be a quarter that of a silicon designs, which leads to lower system cost and increased efficiency, all of which results in lower total cost of ownership for the end user.

Industry roadmap and market trends

Reducing size and weight, while increasing performance (including power density), is now a requirement for power system applications. In the transportation sector, for instance, some automakers have announced that they will discontinue internal combustion engines within the next several years. This means that the infrastructure for electric transportation systems will need to be rapidly built-out. Moreover, electric vehicle rapid-recharging stations will need extremely efficient power electronics as will the on-board power electronic systems in vehicles themselves.

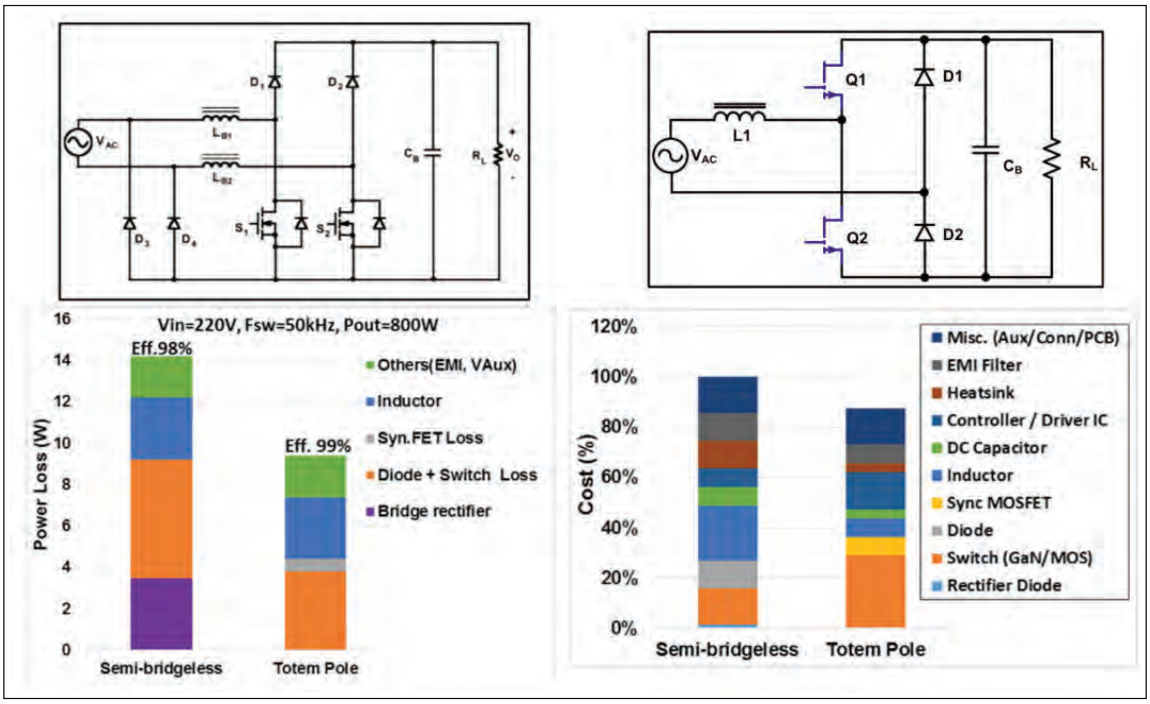


Figure 3. The Totem-pole topology possible with E-HEMT GaN delivers dramatic improvements in efficiency and size.

Also, one of the biggest needs for efficiency will be in server farms and data centers, which are being built out at a tremendous rate to serve the insatiable need for communications and storage for big data, IoT, and general internet traffic. In addition to saving energy, any increases in power density and efficiency are especially coveted since they translate directly into lower utility costs.

It's clear that the needs of the power electronics market aligns with the demonstrated benefits of GaN devices when incorporated into power electronics systems.

In Part 2, we will further explore the technical details of applying e-mode GaN devices to effect innovative and highly efficient power conversion topologies.

Power conversion is critically essential to meet the needs of systems in areas such as electric vehicles

The rise of GaN-based power systems – **Part II**

Part 1 of this series exploring gallium nitride (GaN) power devices provided a brief overview of GaN technology fundamentals, describing the growth of GaN power and its main application areas. This second part explores the technical details of applying GaN devices to implement innovative and highly efficient power conversion topologies.

BY PAUL WIENER, VP STRATEGIC MARKETING, GaN SYSTEMS

OBTAINING the optimum performance advantages of a GaN E-mode (enhancement-mode) high electron mobility transistor (E-HEMT) requires special design considerations, especially under dynamic conditions.

GaN has both lower switching and conduction losses, and its thermal performance provides many high-density power conversion possibilities. Unlike silicon (Si) MOSFETs, a GaN E-HEMT with no body diode has zero reverse recovery losses and exhibits high dv/dt ruggedness. This makes the technology an ideal fit for half-bridge hard switching designs. Meanwhile, both lower gate charge (Q_g) and output capacitance (C_{oss}) of GaN HEMTs make the performance of GaN-based soft-switching converters even better.

However, because of fast switching, circuit and layout techniques to minimize noise coupling and the Miller effect are more important than ever. With dv/dt> 100V/ns, GaN E-HEMTS switch faster than Si and silicon carbide (SiC) MOSFETs. GaN has four times faster turn-on and approximately two times faster turn-off time than a state-of-the-art SiC MOSFET with similar $R_{DS(on)}$. As a result, controlling noise coupling from the power to gate drive loop should be the first priority in circuit design. Also, high dv/dt and di/dt combined with low C_{ISS} and $V_{G(th)}$ require limiting gate spikes from going above the threshold or maximum rating under the Miller effect for safe operation since any added impedance that modifies the amplifier input impedance can cause problems.

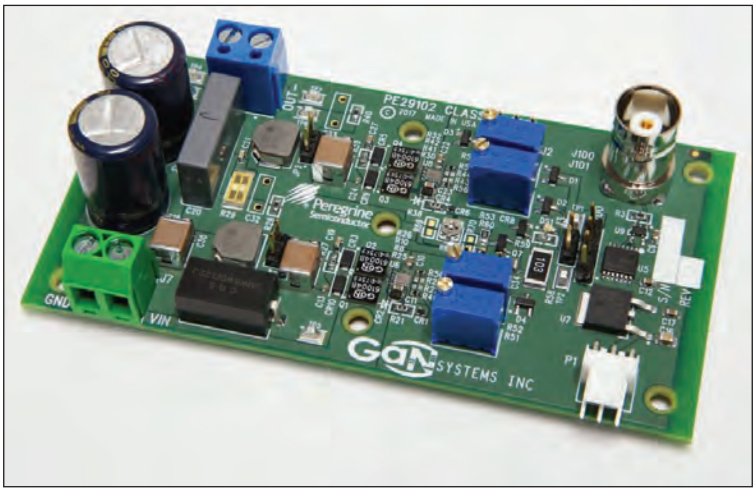


Image 1. The 100 V GaN E-HEMT FB EVB (GS61004B-EVBCD) optimized for Class D amplifiers.

Without proper design considerations, gate ringing or sustained oscillation may occur that can lead to device failure. This is more critical for 650 V hard switching half bridge applications since very high dv/dt spikes could occur at a hard turn-on. A single-ended topology is of less concern for the Miller effect. In addition, the design requirements on dv/dt and di/dt are relaxed for resonant zero voltage switching (ZVS) topology.

To minimize the Miller effect lowering the gate drive impedance (R_g and L_g) is critical, especially at turn-off. The basic rule is the gate needs to be held down as strong as possible with minimum impedance. The Miller effect is more prominent for 650 V-based than 100 V-based designs since the dv/dt is higher for the higher voltage design than in a lower voltage design. In addition, different design techniques are recommended for positive vs. negative dv/dt.

Positive dv/dt

- Prevent false turn-on
- Strong pull-down (low R_G/R_{OL})
- Low L_G to avoid ringing

- Use of negative gate bias at turn-off, -2 to -3V, helps

Negative dv/dt
- Occurs at turn-on of the complementary switch in half bridge
- Keep V_{GS-_pk} within -10 V
- Strong pull-down (low R_G/R_{OL}) and low LG for lower ringing
- V_{GS} may bounce back >0V (LC ringing), so ensure $V_{GS+\_p}k< V_{G(TH)}$ to avoid false turn-on or gate oscillation

GaN E-HEMT speed can be easily controlled by gate resistors. A separate RG for turn-on and turn-off is recommended. For controlling the Miller effect, an $R_{G(ON)/RG(OFF)}$) ratio ≥ 5 to 10 is recommended.
For more details, please refer to the application guide "Design with GaN Enhancement mode HEMT" [1].

PCB layout

With their fast switching time, GaN E-HEMTs require the usual layout considerations to avoid gate ringing and oscillation. Suggested best layout practices for gate drives include:
- Physically separating the power loop and the drive loop areas to minimize noise coupling
- Minimizing the pull-down loop by locating the gate driver close to the ground capacitor
- Minimizing the turn-on (pull-up) loop by locating the VDD capacitor close to the driver
- Isolating and avoiding overlap between gate drive and drain copper pad
- Isolating and avoiding overlap from Drain/Source to control grounds

Several low (80-100 V) and high (650 V) voltage half/full bridges and gate driver/controller ICs from different suppliers have been verified to work with GaN E-HEMTs and simplify the implementation of best practices. Image 1 shows the GS61004B-EVBCD with a 60 V half-bridge GaN driver optimized for high frequency applications that include DC/DC conversion and wireless power charging.

Paralleling techniques for GaN

GaN technology's $R_{DS(on)}$ and transfer characteristics, including transconductance that decreases with temperature, provide negative feedback to self-balance and compensate devices and overcome circuit mismatches. In addition to reducing the total gate drive loop in paralleling designs, a dual-gate drive makes it easier to have a symmetric gate drive layout and reduce the total layout footprint area. Image 2 shows the parallel layout for two GS66516T GaNPX packaged devices. The gate drive requirements for GaN are five to 10 times less than an equivalent Si MOSFET and have 50 times or greater lower gate drive losses at MHz-level switching.

Critical parasitic parameters can have a high impact on GaN paralleling. For that reason a star connection is recommended to equalize the gate/source inductances. Also, common source inductances should be minimized as much as possible. For high current parallel designs, a small negative gate drive turn-off bias (from -3V to -5V, synchronized) is recommended for lower turn-off losses and a more robust gate drive. The layout should have high frequency current flows occurring in opposite directions on two PCB layers for magnetic flux cancellation to lower parasitic inductances.

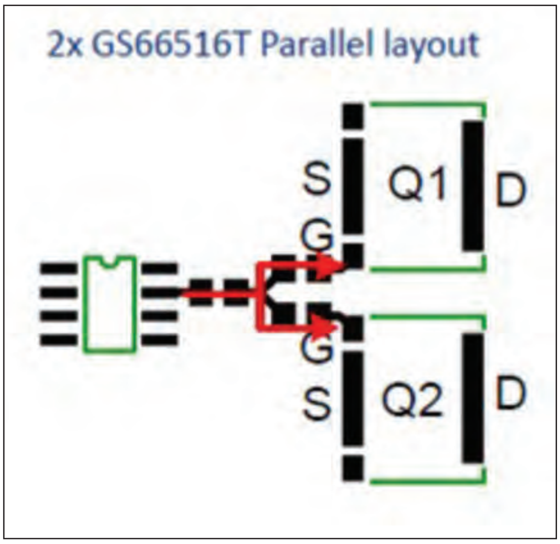


Image 2. Symmetry of dual gate drive in parallel design reduces PCB space.

A high-power, GaN-based IMS platform

An insulated metal substrate (IMS) evaluation platform, the GSP65RxxHB-EVB, demonstrates the implementation of the design considerations discussed so far as well as others to achieve increased power density and reduce system cost with GaN power devices. The metal core/aluminum printed circuit board (PCB) with heatsink is shown in Image

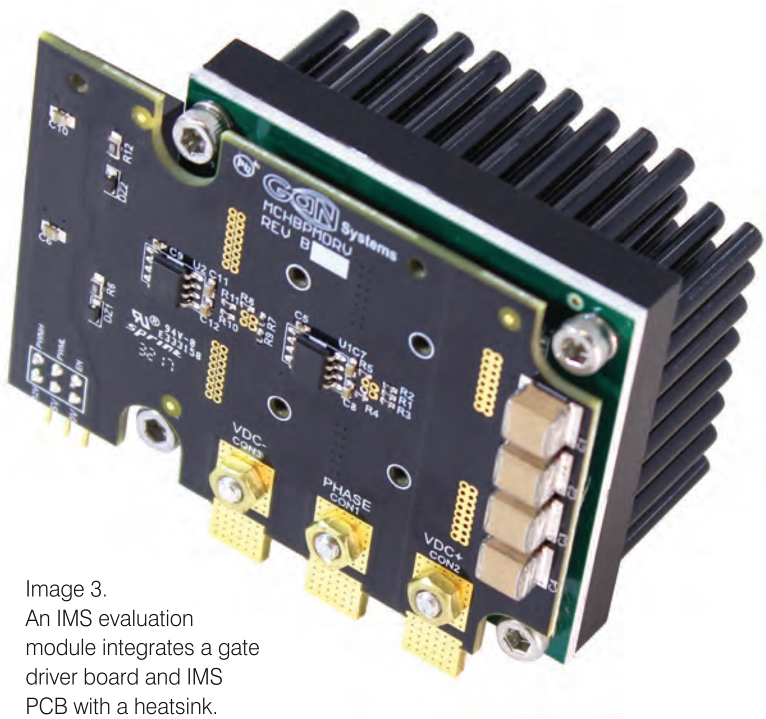


Image 3. An IMS evaluation module integrates a gate driver board and IMS PCB with a heatsink.

	FR4 PCB Cooling with Vias	FR4 PCB with Cu inlay	IMS PCB
Thermal resistance	Good	Better	Best
Electrical Insulation	No, additional TIM needed	No, additional TIM needed	Yes
Cost	Lowest	High	Low
Advantages	• Standard process • Lowest cost • Layout flexibility	• Layout flexibility • Improved thermal compared to thermal vias	• Lowest thermal resistance • Electrically isolated
Design challenges	• High PCB thermal resistance	• Cu-inlay surface coplanarity • High TIM thermal resistance	• Layout limited to 1 layer • Parasitic inductance • Coupling capacitances to the metal substrate

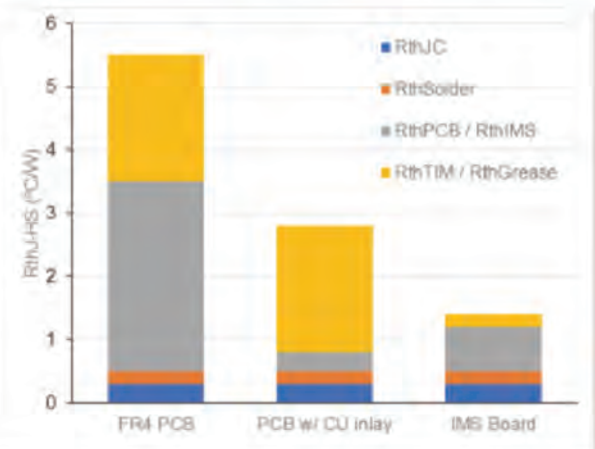


Image 4. Comparison of several design parameters including junction to heatsink thermal resistance (R_{thJ-HS}) for FR4 PCB with cooling vias and FR4 PCB with Cu inlay to an insulated metal substrate (IMS) board. Thermal results are estimated based on the GS66516B GaN E-HEMT.

levels. The IMS module design approach has been used in automotive, industrial, server/datacenter, and consumer applications. Automotive applications include on-board chargers, DC/DC converters, three-phase inverters and high power wireless chargers. For industrial applications, the modules have been used in 3-7 kW photovoltaic inverters as well as energy storage systems (ESS) and motor drives, including variable frequency drives. Servers/datacenters have employed a 3 kW AC/DC power supply. Finally, IMS modules have been used in consumer/residential energy storage systems.

In contrast to thermal cooling for surface mount technology (SMT) packages that often use cooling vias or a copper (Cu) inlay, the IMS board provides several advantages as summarized in

Switching transient and loss analysis of GaN

The hard-switching turn-on transition for GaN HEMTs is shown in Image 5. Compared to Si MOSFETs, the absence of reverse recovery loss means a relatively clean channel current Id waveform. A capacitive E_{qoss} loss is part of the hard-switching losses. For GaN HEMTs, the absence of the QRR makes the Q_{oss} noticeable although the value of the Q_{oss} for GaN HEMTs is still the smallest among both Si and SiC MOSFETs. The E_{oss} loss is introduced by the capacitance self-discharging current of the switch device itself and Eqoss loss is introduced by the capacitance charging current from the opposite switch device. Image 6 shows the difference between hard switching-on loss distribution in Si MOSFETs vs. GaN E-HEMTs.

Eon/Eoff scaling method for GaN

The E_{on} of GaN E-HEMTs depends on the junction temperature (T_j). Also, the devices from GaN Systems are highly scalable. As a result, an Eon/Eoff scaling method for GaN can be used to obtain the E_{on}/E_{off} at other operating conditions (different Vds, T_j, and R_g), by scaling the data from the initial operating conditions. Image 7 shows the step-by-step E_{on}/E_{off} scaling procedure.

This approach mainly requires three steps for both E_{on} and E_{off} scaling. For E_{on}, the first step is R_g scaling. Next is the E_{qoss} calculation and V_{ds} scaling. The third step is T_j scaling. For E_{OFF}, the first step is R_g and T_j scaling, next is the E_{oss} calculation, and third is V_{ds}

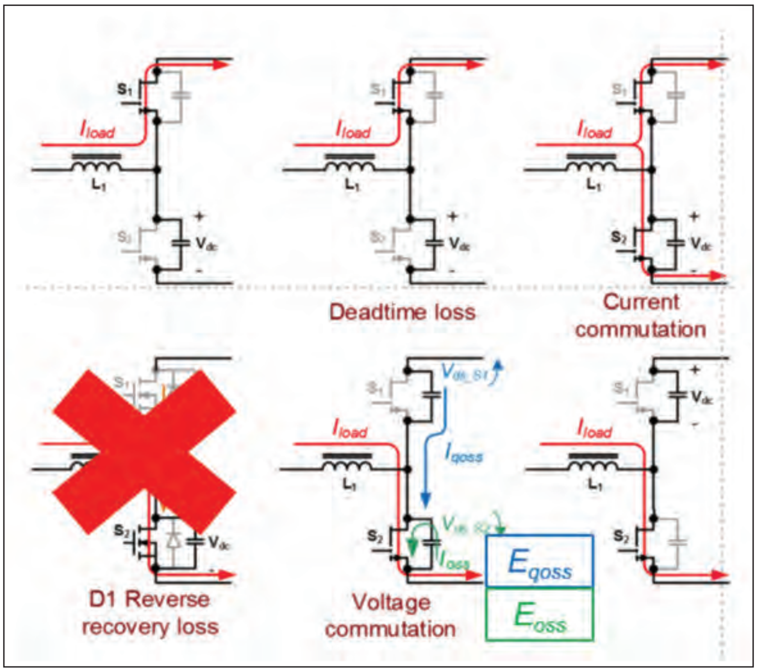


Image 5. Hard switch-on transition and switch commutation principle of a GaN HEMT.

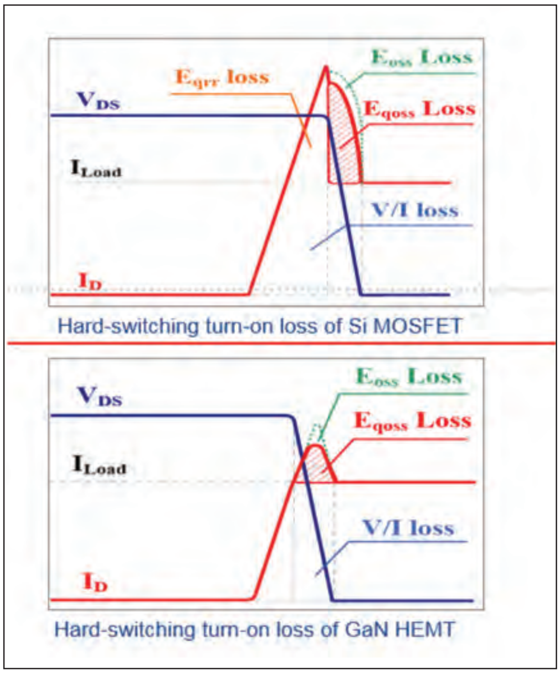


Image 6. No reverse recovery loss and lower capacitive loss mean lower E_{on} loss for GaN E-HEMTs.

scaling. In this analysis, the initial condition is defined as V_{ds}=400V, $R_{g_}$on=10Ω, $R_{g_}$off=2Ω, and T_j=25°C. Note that the initial condition can be revised with an accurately measured E_{on}/E_{off} curve.

Dynamic R_{dson}

Trapping is a common problem in wide bandgap (WBG) semiconductors like GaN. It impacts the dynamic R_{DSon} (R_{dyn}) of GaN devices. While R_{dyn} reduces with higher junction temperatures due to the GaN E-HEMT's positive temperature coefficient, other factors that affect R_{dyn} include:

- Bias voltage
- Bias time
- Switching frequency
- Duty cycle

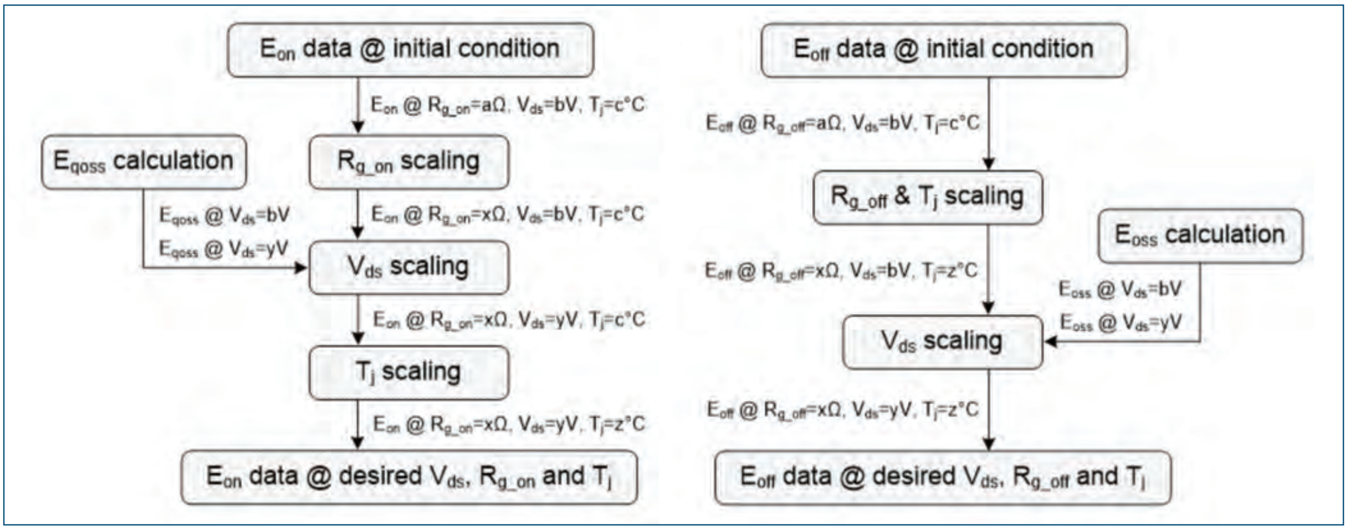
It should be noted that dynamic $R_{DS(on)}$ effects are negligible in steady state operation.

Moving to GaN

With proper design considerations, designing engineers can build power systems that have one-quarter of the power loss, size, and weight of Si-based solutions at a fraction of the cost. This second in a series GaN article, identified and discussed several key product characteristics and circuit aspects toward achieving those results.

Editor's Note: Part III of this series by GaN Systems will discuss topologies based on gallium nitride technology as well as specific applications including wireless power.

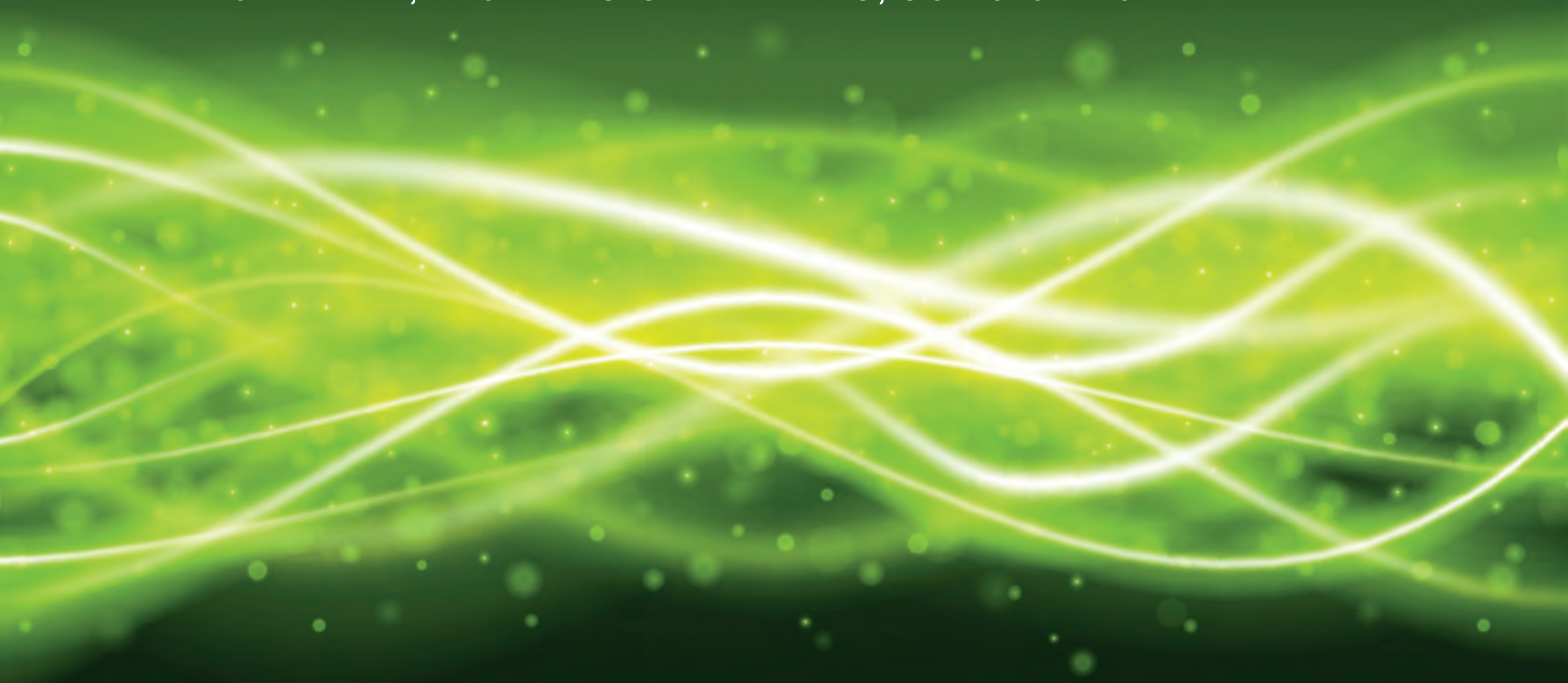
Image 7. E_{on}/E_{off} scaling procedure/ algorithm for GaN HEMTs.



Power density, high-efficiency
GaN power switching topologies

Power Electronics World invited the experts at GaN Systems to provide an inside look at design challenges and opportunities with this powerful high density, wide bandgap technology. This article is the third and final installment.

BY PAUL WIENER, VP STRATEGIC MARKETING, GaN SYSTEMS



MARKET DEMANDS call for major improvements in size, performance, and cost of electronic equipment. While Moore's law has continued to prove true for the "signal path," the "power path" has been slower to yield dramatic improvements. Thanks to the advances in Gallium Nitride (GaN) as a power transistor technology, power conversion has emerged as an enabling technology – making possible remarkable improvements in power efficiency, size, and cost. GaN power switching technology delivers higher levels of efficiency and enables new applications. The first two parts of this three-part article provided a brief overview of the fundamentals and discussed technical details of applying GaN devices. This final part presents four high-power-density high-efficiency/low power switching loss topologies based on GaN technology.

Bridgeless totem-pole power factor correction

GaN E-HEMT capabilities and performance advantages are applicable to both soft and hard-switching applications. Bridgeless totem-pole power factor correction (BTPPFC) is a good example of a hard-switching converter with the advantage of lower Eon/Eoff losses by using GaN technology.

In a conventional diode bridge power factor correction (PFC) circuit, it is a challenge to achieve higher than 98% efficiency due to the large diode losses in the bridge. A conventional 2-phase interleaved bridgeless PFC with Si-MOSFETs adds components and has low component utilization. In contrast, using GaN devices without the parasitic bipolar junction transistor (BJT) and integral body diode of the MOSFET there is no

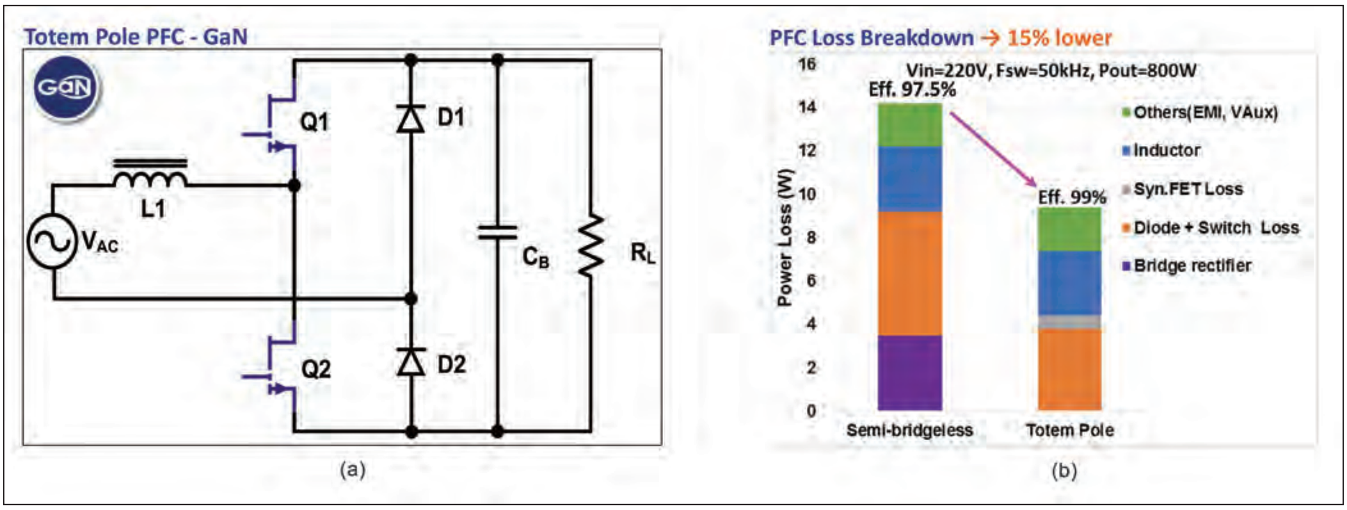


Figure 1: An 800-W CCM TPPFC GaN design (a) and resulting loss reduction (b).

reverse recovery and an anti-parallel diode is not required.

As a result, a GaN BTPPFC can easily meet the efficiency requirements for each 80 Plus certification level in 115 V and 230 V powered applications at 10%, 20%, 50% and 100% loads. For example, the PFC efficiency budget for the 80 Plus Titanium level at 50% requires 96% efficiency. With GaN devices this is:

$$\mathbf{Eff_{AC/DC} = Eff_{DC/DC} \times Eff_{PFC} = 99\% \times 99\% = 98\%}$$

Unlike a MOSFET-based bridgeless totem-pole PFC that has severe limitations in each type of switching mode design, GaN devices can address and reduce the challenges in each mode, including:

- Discontinuous-conduction mode (DCM) --> High inductor current ripple
- Critical conduction mode (CrCM) --> Complicated control
- Continuous-conduction mode (CCM) --> The challenge of reverse-recovery loss Qrr

Figure 1 (a) shows the GaN BTPPFC circuit. Using GaN devices, fewer and smaller parts are required. Since the Qoss is much smaller and there is no Qrr loss, the circuit has higher efficiency and since there is no Trr, the GaN design achieves higher switching frequencies too. Circuit operation at higher frequencies means smaller filters can be used and since it has lower losses smaller heatsinks can be used.

Figure 1(b) defines the elements that contribute to power loss in a standard MOSFET PFC circuit vs. a GaN-based Totem Pole topology. The combined power losses in the MOSFET design are significantly higher than in the GaN design. As shown in Figure 1 (b), the PFC loss is 15% lower with increased efficiency (from 97.5% to 99%) for a totem pole GaN PFC circuit compared to a Si-MOSFET design.
A 3-kW CCM BTPPFC evaluation board has been built with GaN HEMTs, achieving a 99.1% peak efficiency in the 50% power range and a power factor above 0.8 over a wide operating range.

Data center power is an exceptional application for the GaN BTPPFC topology. Typical power supplies employing silicon MOSFET technology have efficiencies of 94–96% and half the power losses occur in the supply's PFC stage. The significant efficiency improvements plus the lower component count of the BTP enables the design of smaller, higher density power supplies. And since is it has been estimated that 40% of the cost of operating a data center is energy costs, making the power supplies more efficient is a significant achievement.

Energy storage systems (ESS) and on-board bidirectional battery chargers (OBBC) in electric vehicles are also ideal applications of the GaN BTPPFC topology since it can handle the power flow in both directions in each application. In telecom applications, the topology can provide increased efficiency and reduce system size as well as reduce system bill of materials (BOM) cost.

Inverters

GaN E-HEMT switches can also be used in single-phase inverters. This is essentially an extension of the TPPFC application. GaN technology can provide two different design approaches.

In a unipolar mixed-frequency sinusoidal pulse width modulation (SPWM) single-phase inverter, GaN switches in the first two switches provide a high-frequency leg with Si MOSFETS providing the line-frequency phase leg as shown in Figure 2 (a). The goal of this topology is efficiency.

As shown in Figure 2 (b), a high-frequency single-phase unipolar SPWM inverter uses GaN E-HEMTs for all four switches, so both legs achieve high frequency.

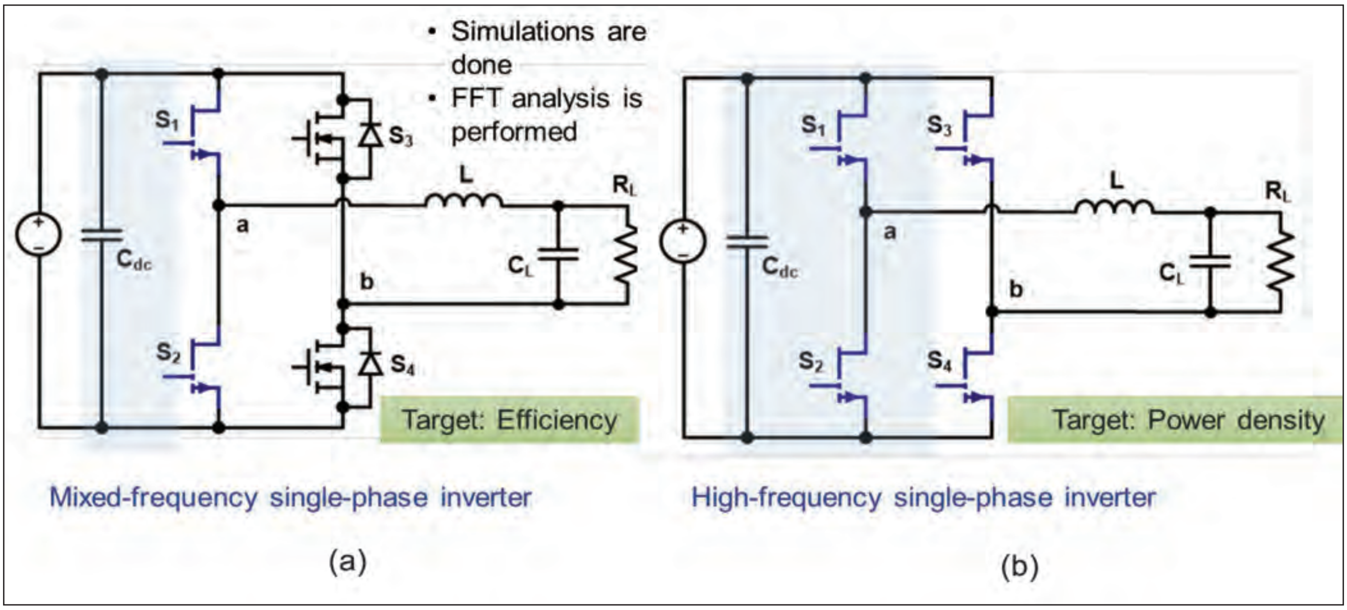


Figure 2: Single-phase inverters using GaN switches for a single (a) and both (b) legs have different design goals.

The goal of this topology is power density. Loss analysis and total harmonic distortion (THD) comparisons were performed using the same GaN devices in both mixed-frequency and high-frequency, single-phase 2-kW inverter simulations.

In switches S1 and S2 for the mixed-frequency inverter, deadtime loss was a small fraction of the total 6-W loss for each switch, with 2.7 W attributed to conduction losses and about 3.3 W for switching losses. Switches S3 and S4 only had conduction losses that were 1.5 W each. For this design, the resulting efficiency drop contributed by the switches was 0.76%.

For the high-frequency design, the losses of all four switches were identical (6 W each), with conduction losses of about 2.8 W, switching losses about 3.1 W and the remainder being deadtime losses. The efficiency drop contributed by the switches in this approach was 1.21%.

Fast Fourier Transform (FFT) analysis was performed on simulations of both designs. For the high-frequency design, harmonic ripple starts at two times the switching frequency. As a result, less than 10% THD occurs at substantially higher frequencies (essentially two times) for the third harmonic than in the mixed frequency design, since the third harmonic for the high-frequency design is six times the fundamental frequency.

High power-density LLC DC/DC converter

A GaN-based resonant LLC DC/DC converter design can provide several design advantages for soft switching applications. Figure 3 (a) shows a GaN-based zero voltage switching (ZVS) converter circuit. The consistently lower Coss in GaN devices (as much as 60 times less at drain voltages under 20 V and from 20 to 30% less at higher voltages) compared to Si MOSFETs provides a key part of the advantages.

This means lower stored energy compared to an SI-MOSFET, much as five times less energy at lower voltages (50 V or less) and at least two times less energy at higher voltages. Lower Coss also provides as much as seven times faster charging times at turn off enabling the LLC converters to be operated at higher switching frequency.

For the high-frequency design, harmonic ripple starts at two times the switching frequency. As a result, less than 10% THD occurs at substantially higher frequencies (essentially two times) for the third harmonic than in the mixed frequency design, since the third harmonic for the high-frequency design is six times the fundamental frequency

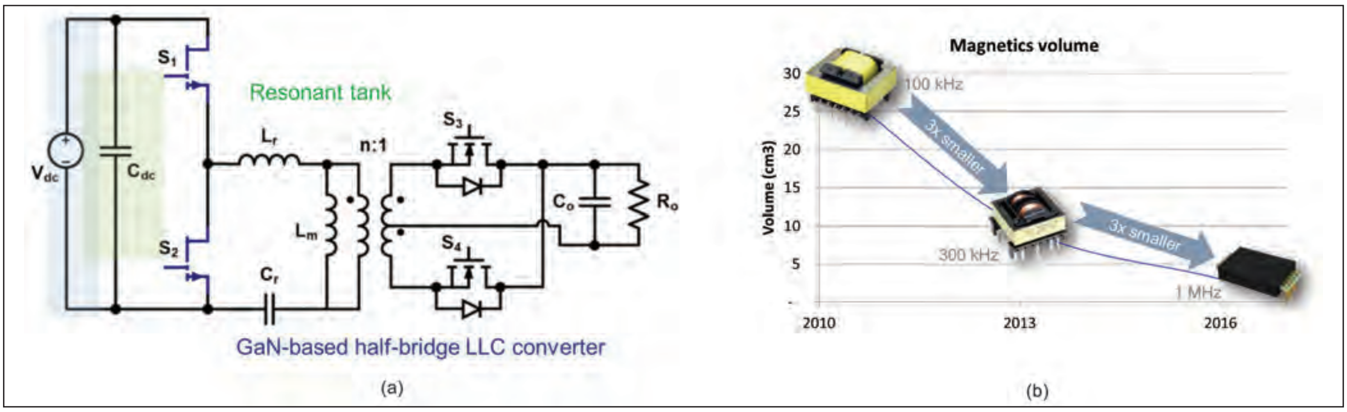


Figure 3: A soft switching ZVS LLC converter circuit using GaN half-bridge (a) and the resulting reduction of magnetics volume (b).

The smaller C_{oss} in the GaN-based half-bridge converter means a smaller air gap in the resonant tank for lower $P_{trans\_loss,}$ and lower I_{rms} for lower P_{sw_cond} losses. The combination provides high efficiency for the LLC converter. In addition, the ability to operate at higher frequencies provides high power density as well. As shown in Figure 3 (b) this has allowed the magnetics volume to decrease by a factor of three every three years since 2010 providing size reduction as an additional advantage.

GaN can also be used for high frequency, low power LLC, soft-switching converters. This design approach can focus on the lower Qg by using GaN and thus achieve faster switching speeds and lower gate driving losses.

Three-phase half-bridge inverter for motor

As shown in Figure 4 (a), GaN E-HEMTs can be used in an inverter for three-phase motors. The light-load and overall power loss improves considerably over an IGBT inverter (see Figure 4 (b)). The lower losses mean smaller, less expensive heatsinks while the high efficiency provides the ability to meet stringent regulations. In addition, GaN's high switching frequency capability means:

- No acoustic noise for quiet operation
- Smaller and less expensive filters
- Sinusoidal output filter for less expensive, unshielded cabling and longer cable lengths

Using GaN E-HEMTs to meet or beat design expectations

The practice of engineering is often described as an optimization process – applying technology to produce products that provide the best combination of performance and cost. The advances in GaN power conversion technology are making significant gains in efficiency, size, and cost. GaN was once cynically called the "technology of the future…and always will be." Those days are over as these four examples demonstrate the improvements that GaN technology can provide to common power electronics topologies.

Depending on the design goals, high efficiency, high power density or a combination of both can be achieved with similar or reduced constraints of size, weight, power dissipation, and system cost. Engineers who embrace this new technology will place themselves and their companies on the leading edge of the most significant technology since the invention of the MOSFET.

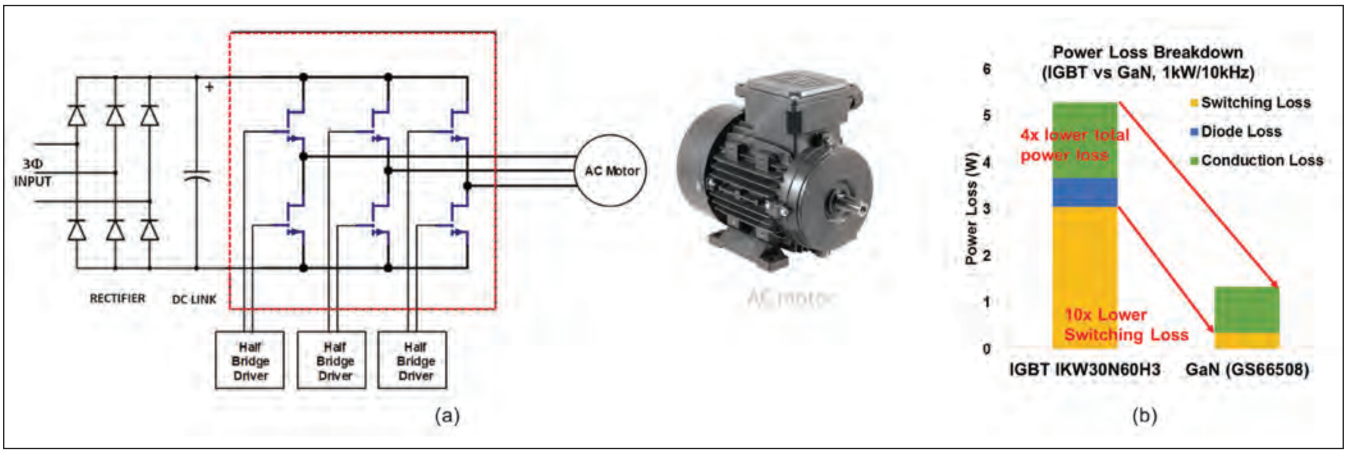
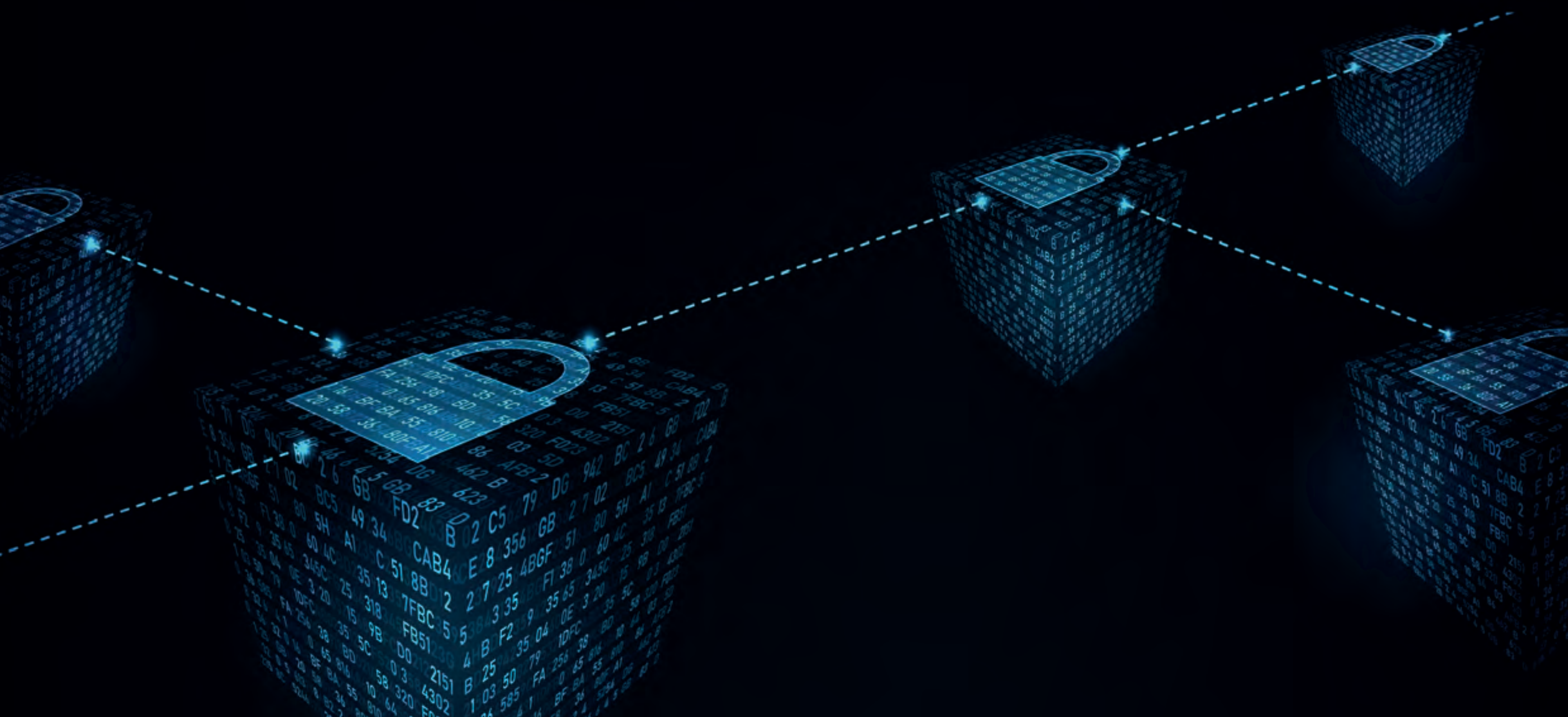


Figure 4 Circuitry for three-phase half-bridge inverter for an AC motor (a) and comparison of loss improvements from an IGBT inverter (b).



Sometimes it pays to go Solo!

Solo has created an energy trading economy that allows consumers to share renewable energy across the grid via a blockchain-based, peer-to-peer energy trading platform known as FlexiGrid

SOLO ENERGY is a renewable energy specialist that was established in Cork in 2015. It deploys and operates distributed energy storage systems, in the form of home batteries and 'Vehicle-to-Grid' (V2G) electric vehicle chargers, at any home or business in the UK that wishes to host one. Hosts store excess generation in exchange for low cost, 100% renewable electricity, which is supplied by one of Solo's local energy supply partners.

Solo has created an energy trading economy that allows consumers to share renewable energy across the grid via a blockchain-based, peer-to-peer energy trading platform known as FlexiGrid. It centrally controls the batteries and chargers, enabling hosts to share excess local generation quickly and easily across the grid.

This digitally connected series of batteries and electric vehicles is known as a Virtual Power Plant (VPP) - an intelligent, connected system of assets stored in homes and businesses across the grid that enables the flexible supply and demand of energy. This flexibility helps balance the intermittency of renewable energy generation and allows hosts to receive energy that is stored in the assets of other hosts when necessary, allowing Solo to shape demand to follow renewable supply.

By remotely controlling the hosted batteries and chargers, Solo can charge them from onsite solar and wind generation facilities, or from the grid when sufficient renewable generation is already present. When renewable generation decreases, the energy stored in hosts' batteries or electric vehicles is used to supply homes and businesses instead, which also enables the energy to be supplied cheaply.

The challenge

In order for the energy to be stored and shared securely, Solo needed to find a control platform capable of remotely communicating with and controlling the batteries and chargers, as well as enabling vast amounts of data to be recorded and securely stored. The platform needed to allow Solo to control and remotely communicate with all its distributed assets both individually and as a collective unit, enabling energy to be shared between them quickly and efficiently.

It also needed to provide visualisation tools capable of enabling Solo to visualise and analyse all its energy data so that it could identify trends and improve performance of the VPP, and present this information back to its customers as a simple, user-friendly interface. In order to allow Solo's software to grow along with the business, the virtualisation software also needed to be fully scalable.

With data security of paramount importance, Solo also needed to find the most secure environment in which to host the control platform - one which required zero IT infrastructure in order to deliver a cost-effective option, and which could be quickly setup, deliver 24-hour monitoring and comprehensive customer support, and guarantee uptime.

The solution

Daniel Dransfield, VP of Engineering at Solo Energy, said: "We needed a control platform that we could deploy quickly, that would remove the need for secondary Open Platform Communications (OPC) software, offer object-based deployment to make scaling more efficient, allow for quick development of visualisation clients for the VPP, and deliver excellent data storage and reporting capabilities. It was also important for us that our platform provider be able to deliver comprehensive customer support, particularly while the project was in its infancy."

As a result, in 2017, Solo contacted industrial IT solutions provider SolutionsPT for a recommendation. SolutionsPT's Wonderware Product Manager, Andrew Graham, identified Wonderware System Platform 2017 as the software most suitable for Solo's needs.
He said: "System Platform 2017 is essentially an operating system for industrial applications – a responsive control solution for SCADA, manufacturing execution systems (MES) and the Industrial Internet of Things (IIoT). It provides configuration, deployment, communication, security, data connectivity and people collaboration, bringing essential context to organisations' data, greatly assisting with diagnostics and troubleshooting, and providing valuable system documentation throughout the system lifecycle – everything Solo was looking for.

"It also includes the first ever fully responsive Operations Management Interface (OMI). This provides improved situational awareness and an intuitive experience through its modern user interface (UI) that enables users to bring together information from all relevant systems and give it real context, enabling them to understand current performance and accurately predict future behaviour.

As an organisation unrestricted by the safety or latency concerns that would make an on-premise solution necessary, Solo made the decision to host System Platform in a cloud environment. By doing so, it eliminated the need for additional IT infrastructure and delivered a fully scalable and easily deployable system that could be installed with minimal resource

"Additionally, System Platform allows screen resolution-independent asset templates to be digitally modelled and shared on any device. This allows Solo to receive insights from its operations anywhere in the world and keep development and maintenance costs minimal. Crucially, it also enables application scaling from a single node to hundreds of nodes without the need to redesign the entire application. Using drag and drop technology, assets can be easily deployed onto other machines, allowing users to scale up from a single box solution to multi-tier deployment and in keeping with the needs of the business, as well as the technology supporting it, offering a future-proof investment."

As an organisation unrestricted by the safety or latency concerns that would make an on-premise solution necessary, Solo made the decision to host System Platform in a cloud environment. By doing so, it eliminated the need for additional IT infrastructure and delivered a fully scalable and easily deployable system that could be installed with minimal resource.

To assist in the adoption of the technology, SolutionsPT also provided Wonderware System Platform training and certification to Solo. Throughout the trial and set-up of the solution, full technical support was provided, meaning any queries could be dealt with promptly.

After trialling System Platform 2017, Solo acknowledged it as the right solution for its operation. As well as being quick and easy to setup, System Platform has allowed Solo to:

- Minimise costs as there was no need to setup and/or maintain any IT infrastructure
- Keep security a priority – the cloud service also delivers a fully managed firewall service, IP limited VPN connection and 24-hour monitoring, and
- Guarantee uptime and improve resilience.

The outcome

By embracing a cutting-edge control platform and hosting it in a cloud environment, Solo has:

- Become a constantly evolving company with runtime operations and a full system platform development setup
- Completed a number of pilot projects which, in turn, have enabled it to prove its business model in the UK and Ireland
- Moved from a testbed agreement to a commercial agreement with the Cork Internet Exchange by proving the viability of its business model
- Begun preparations for its commercial rollout

Daniel Dransfield said: “We’re delighted with the new control platform, and glad that we took the decision to host it in a secure cloud environment.

The wide range of solutions the platform offers has been invaluable as it’s essentially an ‘everything under one roof’ product. Had we opted for a different platform, we’d have needed to employ additional services from other third-party companies, which would have increased operating costs significantly.

“System Platform has also helped with the pilots we’ve been working on. For example, one in the Orkney Islands in Scotland – a new housing development of circa 30 houses - was required by building regulations to have renewable energy, however the network operator was unable to connect all the homes to the grid.

“We used FlexiGrid to get all the households connected by storing renewable generation from their solar panels in our FlexiGrid-controlled batteries and prevented any excess generation from being exported to the wider grid.

“We’re now in a position to begin rolling out our service commercially across the UK and Ireland and that’s not something that would have been possible without the new control platform.”

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Jackie Cannon

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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

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New battery technologies may fuel flexible electronics growth

PEW Technical Editor Mark Andrews considers the importance of new battery technology

AS RENEWABLE ENERGY RESOURCES have made non-traditional electricity generation possible at commercial scale, new battery technologies are key to delivering more fully on the sought-after allure of alternative energy as a primary resource that could one day displace coal and other fossil-fueled energy infrastructure. Battery banks accomplish this by providing power 'as-needed' during off-peak and non-generating hours.

New battery technology is constantly evolving as demonstrated by recent research from the Chalmers University of Technology, Sweden, and the National Institute of Chemistry, Slovenia. Researchers announced they have found a way to far exceed the power density of legacy aluminum storage cell concepts, a feat that they believe can ultimately challenge the reliability and power density supremacy of Lithium Ion cells and do so without volatility dangers or reliance on rare earth ingredients. The cost per watt with aluminum is cheaper, too, and they represent that their aluminum cells will in almost every way be safer, more environmentally responsible and a better alternative than lithium ion cells because an aluminum-based battery technology can draw raw materials from today's extensive global aluminum recycling system. Readily available and cheap raw materials could enable moving an aluminum-based battery technology to manufacturing at scale relatively cheaply should the research indeed prove its merits.

Mobile electronics including flexible circuits for medical, health monitoring and wellness applications are sought after by many across the microelectronic manufacturing supply chain because the technology represents a means to improve and personalize medicine via greater portability and customization. New sensor technology, AI enhancements, flexible circuits and materials innovations are continuing to expand opportunities within this area. Flexible electronics are also a natural, albeit far reaching advancement for consumer products that visionaries are already seeing as paste-on/peel-off headphones or computer displays to facilitate everything from medical diagnoses to gaming to saving lost hikers in avalanches– Depending on how rapidly key ingredients can scale and how quickly market potential might ramp, the possibilities of flexible electronics could lead to remarkable product adaptations.

Power remains a key challenge impeding faster, more widespread development of flexible electronics; perhaps second only to silicon's inherent rigidity the need for power has forced all manner of innovative approaches to creating flexible electronics that are as capable as or better than their 'fixed' counterparts.

Even though researchers and product developers have solved one flexibility issue after another, flexible electronics nevertheless need a power source this is not only thin and light enough to facilitate portability and all-day wearability, flexibility without today's most common solutions is a key requirement for leaping ahead. Can advanced battery technology be key to enabling new generations of medical diagnostic and treatment devices as well as a revolution in smartphones and mobile computing?

In an article that appeared first in the SEMI Blog 'Technology and Trend' on 27th October 2019, EJ Shin of Jenax, a leader in developing flexible, thin batteries, shows how the next 'big thing' in electronics may be batteries that are so unnoticeable they blend into a device's structure.

Can batteries really fuel innovation?

BY EJ SHIN, DIRECTOR, JENAX

TECHNOLOGY ADVANCEMENTS seem to be coming at us fast and furiously. Every time you turn around, another company is introducing a breakthrough product with claims of far-reaching implications on how we live and work. But how often do consumers really experience disruptive innovation, like the kind that smartphones and cloud computing have had on our lives?

Instead of astounding people, many new products that hit the market today are merely upgraded versions of their predecessor – perhaps offering smaller footprints with faster processors, more attractive packaging, or add-on features. These upgrades tend to underwhelm customers, offering no compelling reason to justify their accompanying price hikes.

What consumers want is disruptive technology that truly enhances their lives, whether at work, at home or at play. And that's exactly what product manufacturers want to deliver. So what's holding them back?

The limits of traditional batteries

The challenge doesn't lie in envisioning exciting new offerings. Vendors are great at that. Rather, when it comes to consumer-focused, electronics-based products, the culprit is often conventional, rigid and thick batteries that limit what can be designed around them.

But it doesn't have to be this way.

Advances in flexible and thin batteries can spark a whole new level of product differentiation. Even though such batteries have been available now for a few years, they are still a foreign concept to many product designers accustomed to conventional off-the-shelf energy storage that is fixed in rigidity and shape. It's hard for some people to believe that batteries can fold and flex while maintaining their performance and safety. As a result, they design products around rigid battery parameters.

Image: Jenax EJShin, Jenax Director, EJ Shin

The Jenax 'JFlex Wave' illustrates how bendable batteries can be when designed for flexible electronics"

The promise of flexibility

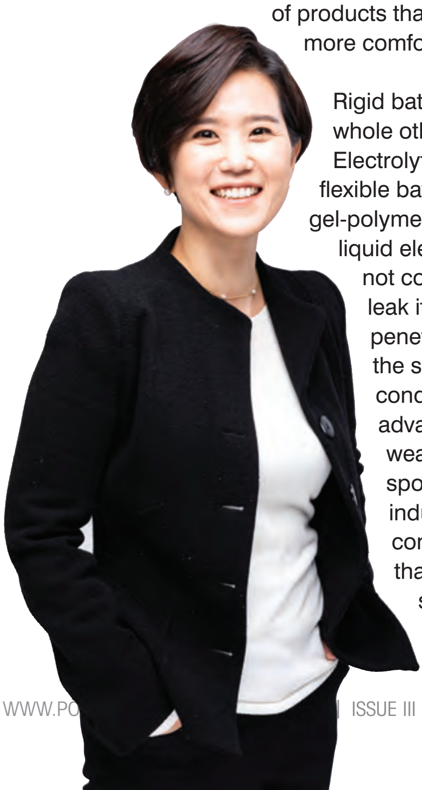
Fortunately, flexible battery technology is available today, even for high-volume production.
While the allure of flexible battery technology is strong, we find ourselves having to reassure manufacturers that flexible batteries are every bit as dependable as their rigid progenitors. Our testing shows that performance-integrity in flexible batteries is strong. They can be flexed, bent and even rolled in any direction without deteriorating performance. For

Flexible electronics need battery power that is very bendable while maintaining high performance

Image: Jenax EJShin, Jenax Director, EJ Shin

instance, we tested a flexible battery by bending it 10,000 times to prove that it has essentially the same capacity as a non-bent battery. This flexibility gives designers and engineers a new level of freedom in hardware design: Manufacturers can now place batteries in spaces not possible or practical before. Take smartwatches, for instance. Instead of locating batteries in only the head case, engineers can embed a flexible, thin battery in the strap band to increase accessible energy or lengthen battery life.

As market demand grows for wearables and hearables, smart apparel and other personal battery-powered products, consumers want more natural-feeling experiences. Unlike fixed off-the-shelf energy solutions offered in a limited range of form factors and capacities, flexible batteries can support customization by size, thickness and capacity, enabling development of products that are smaller, lighter and more comfortable.



Rigid batteries are problematic on a whole other level, and that's safety. Electrolyte advancements ensure flexible batteries are safer. The latest gel-polymer electrolyte is safer than liquid electrolyte because it does not contain liquid that would leak if the battery is pierced or penetrated – yet it still delivers the same high level of ionic conductivity. This is a great advantage for manufacturers of wearables in medical devices, sports equipment and fabrics, industrial applications, and consumer electronics. Knowing that their devices contain safer components not only brings peace of mind to manufacturers and consumers but also increases both adoption and usage rates.

Staying competitive in any technology-driven market requires a steady stream of innovation. To rise above the pack, companies must fearlessly embrace advancements that will differentiate them in the marketplace. Your choice of battery is critical to your hardware design – especially if consumers will be in direct contact with the battery. The performance and enhanced safety inherent in next-generation flexible batteries can free you to create disruptive products that deliver a compelling user experience.

About the Author:
EJ Shin is Global Director at Jenax Inc., a company that pioneered the next-generation flexible, thin battery that can be bent and rolled in any direction. She has been with Jenax since the company initiated its battery development. EJ helps device and wearable companies leverage Jenax's customized battery solution for their innovative products. Earlier, she held communications consulting positions at Fleishman Hillard and the G20 Summit in Korea. EJ holds an MBA from Yonsei University, South Korea, and a B.A. in International Relations from Tufts University, U.S.