POWER ELECTRONICS EUROPE

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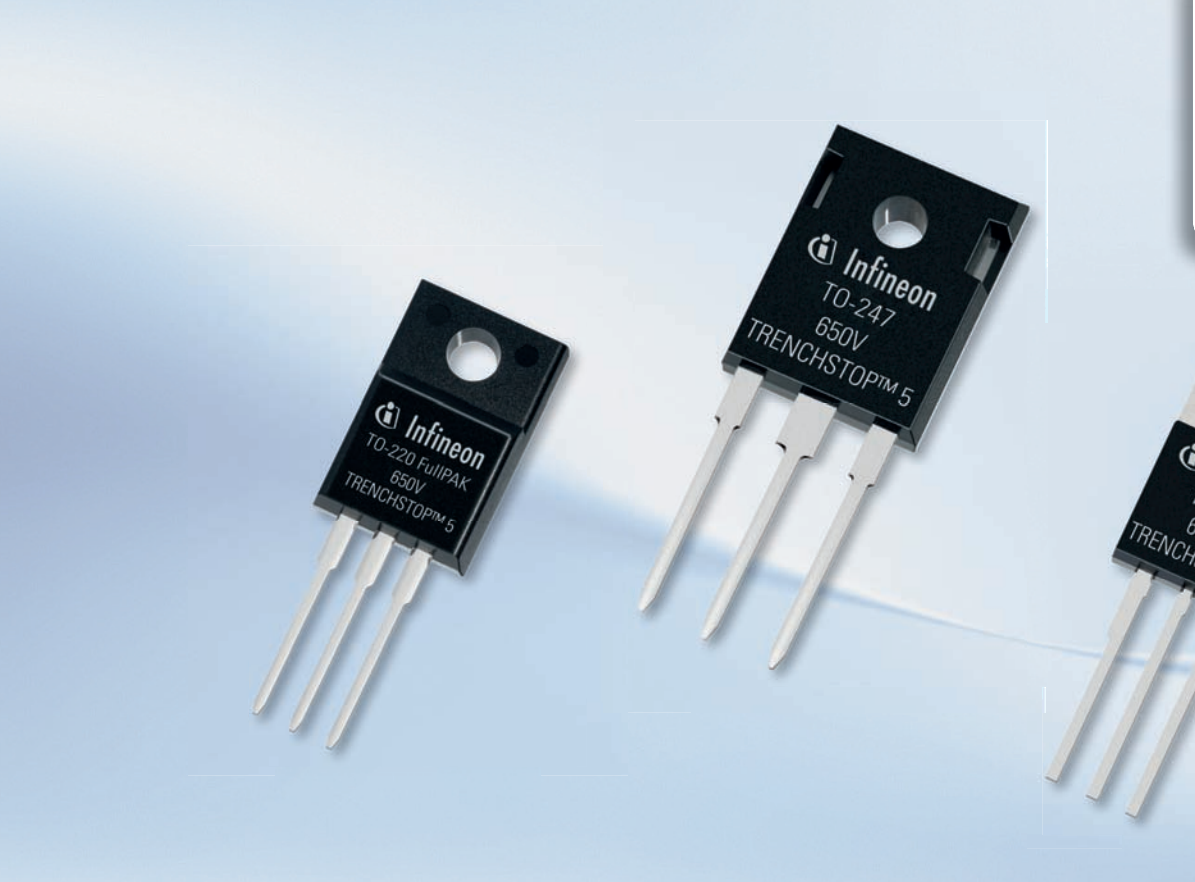
POWER MODULES

Silicon Carbide Boost Power Module Performance

THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Opinion | Market News | Power Electronics Research
PCIM 2013 | Industry News | Power Semiconductors
Power Modules | Products | Website Locator



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PAGE 6

Market News

PEE looks at the latest Market News and company developments

PAGE 10

Power Electronics Research

COVER STORY

Silicon Carbide Boost Power Module Performance

Silicon Carbide offers new approaches for the design of power semiconductors. In conventional power Silicon technology, IGBTs are used as switches for voltages higher than 600 V, and Silicon PIN freewheeling diodes are state of the art. The design and soft switching behavior of Silicon power devices cause considerable power losses. With the larger bandgap of Silicon Carbide, high-voltage MOSFETs can be designed with blocking voltages up to 15 kV, while providing extremely low dynamic losses. With Silicon Carbide, the conventional soft turn-off Silicon diodes can be replaced by diodes in Schottky design, also offering extremely low switching losses. As an additional benefit, Silicon Carbide has a 3 times higher thermal conductivity as compared to Silicon. Together with small power losses, Silicon Carbide is an ideal material to boost power density in power modules. Full story on page 34.

Cover supplied by SEMIKRON, Nuremberg, Germany

PAGE 13

PCIM 2013

PAGE 24

Industry News

New Single-Channel, 2.5-A/5-A Gate Drivers for IGBTs and SiC MOSFETs

PAGE 27

Power GaN Opens New Applications

Efficient Power Conversion Corporation (EPC) has been in production with enhancement mode GaN-on-Silicon power transistors (eGaN® FETs) for over three years. Much progress has been made improving device performance and reliability. There have also been several new power management applications that have emerged. Two of these applications, RF Envelope Tracking and high frequency Wireless Power Transmission are beyond the fundamental capability for the aging power MOSFET due to the requirements of high voltage, high power, and high frequency. As a result, these are early growth markets for GaN on Silicon devices. eGaN FETs have also made inroads in several other applications that we will discuss along with the latest in device technology and future direction for both discrete and GaN ICs. **Alex Lidow, Johan Strydom, David Reusch, Michael de Rooij, Efficient Power Conversion Corp., El Segundo, USA**

PAGE 30

Progress in Silicon-Based 600 V Power GaN

The readiness of 600 V GaN-on-Si based power devices fabricated using the GaNpowIR® technology platform for large scale production is presented in this article. The advantages of such devices over the Silicon incumbent alternatives in several common power conversion application circuits is also shown. **Michael A Briere, ACOO/International Rectifier, Scottsdale, USA**

PAGE 38

Pre-Applied Phase-Change Material Improves Thermal Behavior

There are several advantages to using phase-change material (PCM) rather than conventional thermal grease as the thermal interface material (TIM) between the power module and heatsink. Vincotech offers modules with a layer of pre-applied PCM. The thermal interface material is applied in a layer with uniform thickness by a screen-printing process. This article describes the benefits of this phase-change material and provides tips on handling modules. **Patrick Baginski, Field Application Engineer, Vincotech, Unterhaching, Germany**

PAGE 40

Products

PAGE 41

Website Product Locator

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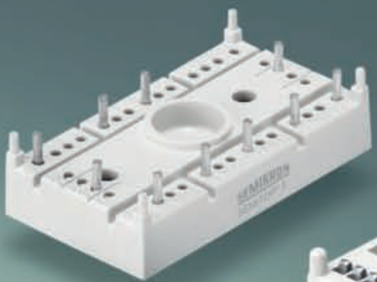
3-LEVEL POWER MODULES

Up to 1500 V DC link



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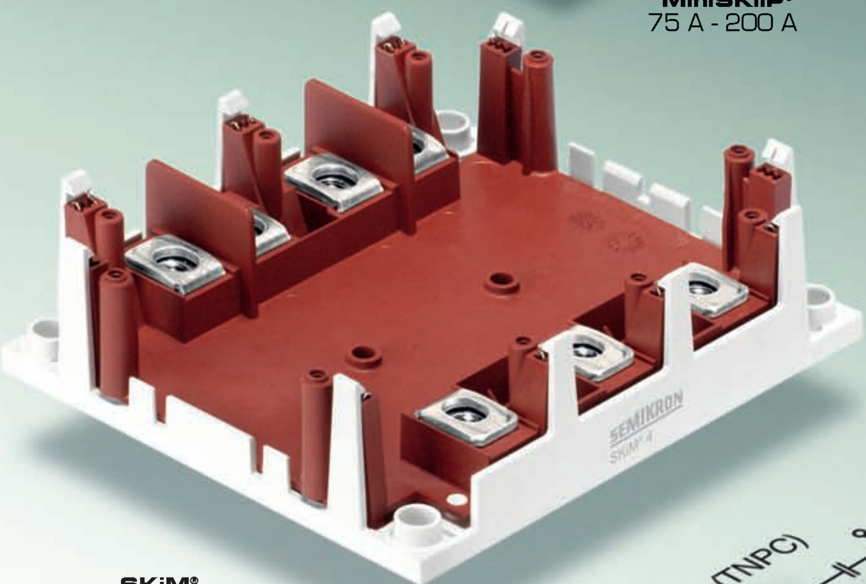

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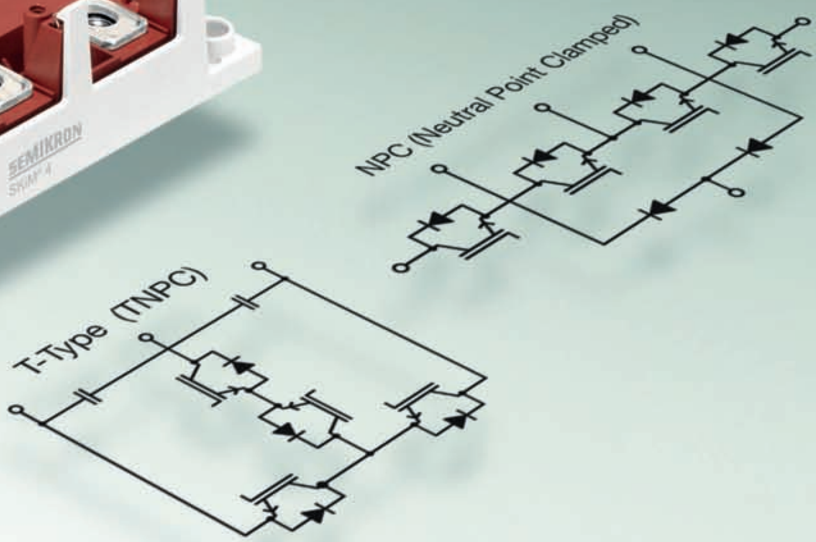

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Another Push for SiC and GaN

After APEC now PCIM Europe again pushed Silicon Carbide and in particular Gallium Nitride through conference awards, new market entries, and last but not least some projects which will gain also public interest. The project referred is railway traction at Alsthom in France. All new drive inverters in certain trains will be equipped with 1700 V SiC MOSFET power modules designed by Danfoss Silicon Power rated at 250 A output current. The message is clear – with SiC inverter efficiency can be increased by 1 % up to 99 %, at first sight not a high number. But with a 1 % increase in efficiency losses can be decreased by 50 % - and this is a huge number particularly in traction with its high-power drive inverters. Thus the cost of the SiC modules are of lesser importance due to the gains at system level, as Michel Mermet-Guyennet pointed out in his PCIM keynote. Since so far only two vendors are serving the SiC MOSFET market the choice is somewhat limited, but very recently Mitsubishi Electric and ST Microelectronics announced their plans to enter this market. Certainly more will follow and this trend will give some more pressure to the remaining SiC JFET manufacturers, also as at least one leading solar inverter vendor announced to make use of SiC MOSFETs in the near future. And with GaN first commercial implementations and feasibility studies have been presented at the PCIM conference and exhibition, showing a huge market potential for future applications even up to 1200 V. Additionally GaN foundries now will enter the market bringing their microwave experience into power applications.

Compared to SiC, GaN devices have a cost-saving potential but their development requires further research efforts especially for high voltage ratings. In general, the devices are characterized by high power density per unit volume or area. Therefore internal losses are dramatically cut down as compared to competitive other device families. Low on-state resistance values at a given high voltage capability of the devices are obtained. Furthermore, input and output capacitance values at a given on-state resistance capability are much lower as compared to other devices. The power density of GaN can be higher by a factor of 10 against Silicon if the heat of the small chips can be removed effectively. The lateral GaN technology has limitations at 1000 V and above, thus the structure has to go vertical with gate trenches on bulk GaN substrate. For large production foundries can process GaN on Si wafers on CMOS lines with 200 mm or larger wafers, for high-performance niches GaN on SiC is still of interest, and true vertical GaN devices will be used for very high voltage switching applications, so the conclusion at a recent SiC/GaN workshop. As a general result of research on various hard-switched converter topologies GaN and SiC devices behave more or less similarly, but GaN devices are better suited for high-frequency resonant applications. Additionally, the monolithic integration of a lateral half-bridge will be a step towards better GaN performance and cost reduction at system level. The cost of power semiconductors do not only depend on material wafer cost, but also on process steps, yield and volume. Thus GaN on Silicon devices have to settle on the 600 V market, before SiC gets too cheap.

So it is not a surprise that worldwide revenue from sales of SiC and GaN power semiconductors is projected by IMS/IHS to rise to $2.8 billion in 2022, up from just $143 million in 2012. SiC Schottky diodes have been around for more than 10 years, with SiC MOSFETs, JFETs and BJTs appearing in recent years. In contrast, GaN power semiconductors are only just appearing in the market. GaN is a wide bandgap material that offers similar performance benefits to SiC but has greater cost-reduction potential. This price/performance advantage is possible because GaN power devices can be grown on Silicon substrates that are larger and lower in cost compared to SiC. The key factor determining market growth will be how quickly GaN on Silicon devices can achieve price parity to Silicon MOSFETs, IGBTs or rectifiers. IMS expects this will be achieved in 2019, driving the GaN power market to pass the $1 billion mark in 2022.

SiC Schottky diode revenue exceeded $100 million in 2012, making it the best-selling SiC device currently. But even though SiC Schottky diode revenue is forecast to grow until 2015, it will decline when lower-priced 600-V GaN diodes become available. Still revenue will recover to approach $200 million by 2022, with sales concentrated at voltage ratings of 1200V and above. By then, SiC MOSFETs are forecast to generate revenue approaching $400 million, overtaking Schottky diodes to become the best-selling SiC discrete power device type. Meanwhile, SiC JFETs and SiC BJTs are each forecast to generate less than half of SiC MOSFET revenues at that time, despite their likelihood of achieving good reliability, price and performance. End users now strongly prefer SiC MOSFETs, so vendors of SiC JFETs and BJTs have a major task ahead in educating their potential customers on the benefits of these technologies. And industry confidence in GaN technology has increased, with more semiconductor companies announcing development projects or their market entry.

To illustrate what is possible today and in the near future PEE has organized a Special Conference Session at PCIM. Have a look in our PCIM report and our research notes and features.

Achim Scharf
PEE Editor

Research Project on Enhanced 300-Millimeter Power Pilot Line

Infineon Technologies has hosted end of April a two-day meeting at its Villach site to kick-off one of the largest European research projects focused on advancing industrial production capability. The research project, "Enhanced Power Pilot Line" (EPPL), is aimed at further strengthening Europe as a high-technology industrial production site.

A total of 32 European partners from industry and research are collaborating to advance production technology for power semiconductors, an industry segment where Europe already has the leading position. Europe is home to the first power semiconductor production sites manufacturing devices using 300-millimeter thin-wafer technology, i.e. on silicon wafers with a 300mm diameter which in addition are extremely thin (see "Power Semiconductors on 300-Millimeter Wafers", PEE April/May 2013, pages 44 - 47). With EPPL, Europe intends to further expand this production advantage.

The EPPL partners are Adixen Vacuum Products, Air Liquide electronics Systems, ams AG, CEST Kompetenzzentrum für elektrochemische Oberflächentechnologie GmbH, Commissariat a l'Energie Atomique et aux Energies Alternatives, CTR Carinthian Tech Research, E-MOSS, Entegris Cleaning Process, EV Group E. Thallner GmbH, Fachhochschule Stralsund, Fraunhofer E.V. IISB, Fronius International GmbH, Heliox BV, Infineon Technologies (with Austria, Germany and Italy), International Iberian Nanotechnology Laboratory, Ion Beam Services, KAI, Lear Corporation GmbH, Max-Planck-Institut für Eisenforschung GmbH, Montanuniversität Leoben, NANIUM S.A., Nmb-Minebea GmbH, Philips Healthcare (with Germany and the Netherlands), Plansee SE, SPTS Technologies SAS, and the Technical Universities of Dresden (Germany), Eindhoven (the Netherlands) and Graz (Austria).

The partner organizations cover the entire industry and research value chain of 300 millimeter power semiconductor production, comprising material research with a focus on Silicon, semiconductor development that includes 3D integration and packaging, and related developments in logistics and automation technologies. "A project volume of Euro 74 million and the commitment of 32 partner organizations strongly underline the importance of EPPL for the semiconductor industry in Europe," says Sabine Herlitschka, CTO of Infineon Technologies Austria.

The EPPL research aims to develop an advanced generation of power semiconductors manufactured in the 300-mm thin-wafer production technology, such as CoolMOS, IGBT, and SFET, as well as to further refine the production technology itself. The results of the project shall include the setup of a pilot-line as well as application demonstrators.

In its "Europe 2020" initiative, the European Commission has set ambitious targets to reduce greenhouse gas emissions, to improve energy efficiency and to establish electromobility in Europe. Power semiconductors that are designed and manufactured at competitive costs and in sufficient quantities in Europe are key enablers, and EPPL was set up to make a major contribution to achieve these targets.

The project will run until mid 2016, with Infineon as the project lead. Regarding the 2nd quarter results commented CEO Reinhard Ploss: "Revenues and margin have recovered nicely over the past quarter. The trough is behind us. Our order books are filling up, albeit still with a relatively high proportion of short term business. We therefore expect a further rise in revenue and margin in the current quarter".

Silica Will Boost Power System Designs at Device and System Levels

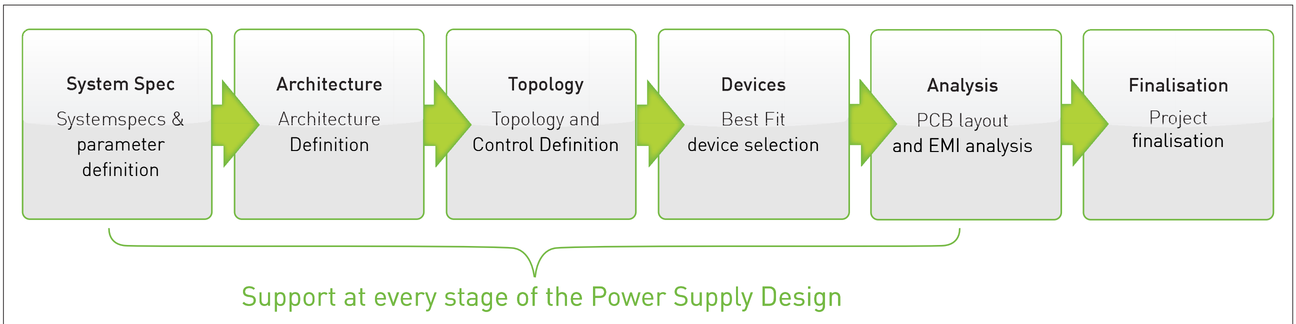
The lack of qualified power design engineers has led distributor Silica (an Avnet company) to assist their customers in the development of power supplies and even inverters through the recently announced initiative Power'n More.

Silica will develop the facilities to support designers from system specification, architecture definition and topology, through to assistance on device selection, PCB layout or EMC analysis. In doing so, the company is to put resources at design engineers' disposal providing its 14 dedicated power field application engineers with simulation technology, backed by five fully equipped power labs across Europe, which will be launched in 2013. "We have the major component suppliers in our portfolio. i. e. for Silicon Carbide Rohm and for Gallium Nitride International Rectifier, in total fourteen suppliers of power semiconductors and related devices", said Silica's regional VP Karlheinz Weigl.

Dedicated application engineers will combine power expertise with their knowledge of specific application areas, for example in industrial electronics, home automation, identification, lighting and other growth sectors. "In the past, the power supply was the least important stage in a design project, but this situation has been changed significantly. Now power management and power supply have to be optimized in an early design stage in order to realize the goals of energy savings", Weigl stated. This includes also simulation from device to system level via PowerSim. The company will extend this activity towards IGBT power modules and even drive inverters.

In-house resources are to be complemented by a network of independent power systems consultants, each able to provide customers with turnkey solutions for power projects. The strategy builds on Silica's expertise in programmable logic, MCU/MPU, analogue and lighting design support.

www.silica.com



Silica's design support activity in its Power'n More strategy

ABB Acquires Power-One

End of April announced ABB that the company will acquire Power-One for $1,028 million. The transaction would position ABB as a leading global supplier of solar inverters – the "intelligence" behind a solar PV system.

This market is forecasted by the International Energy Agency to grow by more than 10 percent per year until 2021. This rapid growth is being driven by rising energy demand, especially in emerging markets, rising electricity prices and declining costs. "Solar PV is becoming a major force reshaping the future energy mix because it is rapidly closing in on grid parity," said ABB's CEO, Joe Hogan. "Power-One is a well-managed company and is highly regarded as a technology innovator focusing on the most attractive and intelligent solar PV product. The combination of Power-One and ABB is fully in line with our 2015 strategy and would create a global player with the scale to compete successfully." Power-One employs almost 3,300 people, mainly in China, Italy, the US and Slovakia. Power-One has one of the market's most comprehensive offerings of solar inverters, ranging from residential to utility applications, and a broad global manufacturing footprint. It also has a power solutions portfolio that is adjacent to ABB's power conversion business.

On May 7 the company entered into an agreement with Microchip Technology Inc. for Digital Power Technology patents. Digital Power Technology drives increased system efficiency, improved design flexibility, faster time to market, decreased board space requirements and lower system costs. It also enables telemetry capability, providing access to critical information including current, temperature and voltage. Telemetry allows the system to accurately monitor its power consumption and thermal performance, enabling designers to easily engineer key features such as system power optimization, fault detection and predictive maintenance features into their end products.

Applications utilizing FPGAs, ASICS, DSPs continue to drive board densities higher, requiring complex power architectures to handle the increasing number of voltage rails and output voltages dropping below 1 V. Digital Power Technology is an extremely effective solution for these complex power requirements.

www.abb.com, www.power-one.com

New CEO at Transphorm

Fumihide Esaka will join Transphorm as its new CEO starting July 1, 2013. Esaka shall play a pivotal role in the company's expansion plans in GaN-based power conversion devices for power supplies and adapters, motor drives, solar panels, and electric vehicles. Esaka is currently CEO of Nihon Inter Electronics Corporation (NIEC), a Tokyo Stock Exchange-listed power solutions manufacturer with more than $300 million in revenues.

"When launching in 2007, we started with a breakthrough technology and ambitions to redefine energy efficiency," said Transphorm's Co-founder and CEO Umesh Mishra. "Since then, we've eliminated every daunting technical obstacle and just released at PCIM the first 1200 V GaN on Silicon product. I am proud to hand over the reins continue to work with him and Primit Parikh (Co-Founder and President) in my capacity as CTO to help make GaN the industry standard in electric power conversion." From material technology and device fabrication to circuit design and module assembly, Transphorm designs and delivers its EZ-GaN power conversion devices and modules (more in our PCIM review).

www.transphormusa.com

At PCIM Europe Transphorm's CEO Umesh Mishra announced 1200 V GaN technology and a new CEO

A GaN and SiC Power Decade Ahead

The emerging market for Silicon Carbide (SiC) and Gallium Nitride (GaN) power semiconductors is forecast to grow a remarkable factor of 18 during the next 10 years, energized by demand from power supplies, photovoltaic inverters and industrial motor drives. Market revenue is expected to rise by the double digits annually for the next decade.

Worldwide revenue from sales of SiC and GaN power semiconductors is projected to rise to $2.8 billion in 2022, up from just $143 million in 2012, according to a new report entitled "The World Market for SiC & GaN Power Semiconductors - 2013 Edition" from IMS Research (IHS). The result of over 50 semiconductor supply chain and potential end-user interviews, this SiC & GaN Power Semiconductor Report provides detailed analysis of this fast-moving market. The annual research report explains growth drivers and likely adoption rates in major application sectors. It provides 10-year price projections for various power devices, giving mid-case, optimistic and conservative scenarios. These price trends drive revenue forecasts for each device in key applications. It also analyses the supplier and competitive environment, and includes more than 50 company profiles.

SiC MOSFETs to become the best-sellers

SiC Schottky diodes have been around for more than 10 years, with SiC MOSFETs, JFETs and BJTs appearing in recent years. In contrast, GaN power semiconductors are only just appearing in the market. GaN is a wide bandgap material that offers similar performance benefits to SiC but has greater cost-reduction potential. This price/performance advantage is possible because GaN power devices can be grown on Silicon substrates that are larger and lower in cost compared to SiC. "The key factor determining market growth will be how quickly GaN-on-Silicon devices can achieve price parity and equivalent performance as Silicon MOSFETs, IGBTs or rectifiers," said Richard Eden, senior market analyst for power semiconductor discretes and modules. "IMS expects this will be achieved in 2019, driving the GaN power market to pass the $1 billion mark in 2022."

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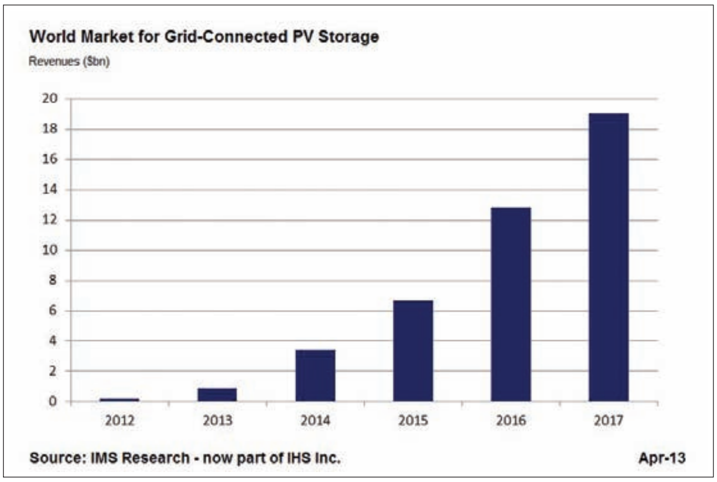
PV storage market set to explode

The worldwide market for PV storage is forecast to grow rapidly to reach $19 billion in 2017, from less than $200 million in 2012, according to a new IMS report entitled "The Role of Energy Storage in the PV Industry".

"Because domestic electricity rates now significantly exceed residential feed-in tariff rates, there is strong interest in increasing self-consumption in residential PV systems to maximize the financial return of the system," said Sam Wilkinson, PV analyst at IMS/IHS. "As a result, 8 megawatts of PV systems were already installed with storage in Germany in 2012, prior to the subsidy being released. The introduction of the widely anticipated subsidy will quickly accelerate uptake by making the lifetime cost of PV systems with storage cheaper compared to those without it." The proposed subsidy will reduce the average 20-year cost of a PV system with storage to 10 percent less than a system without it. Previously, the high cost of batteries had more than offset the savings created by increased self-consumption, and PV systems without storage offered a more attractive return.

As the first country to introduce a subsidy for PV storage, Germany will inspire other countries to follow suit, if the scheme proves successful, IHS expects. "We do expect that other countries will follow Germany's example and adopt similar subsidy schemes to promote the use of PV energy storage - particularly where there is a case for promoting self-consumption and grid stability," Wilkinson said. "Even without subsidies though, storage can be an attractive proposition in conjunction with residential PV systems in some markets, such as the UK, where the market is forecast to begin growing quickly in 2014, when the price of batteries is predicted to have fallen sufficiently to make PV storage financially viable." Storage is also predicted to be used in larger systems, in order to improve the integration of PV into the grid, increase the financial return of PV systems and meet the increasingly demanding connection requirements that some countries are imposing on intermittent electricity sources like PV. Utility-scale PV systems with storage are forecast to grow to more than 2GW annually by 2017 according to the report, with Asia and the Americas dominating this market.

www.ihs.com

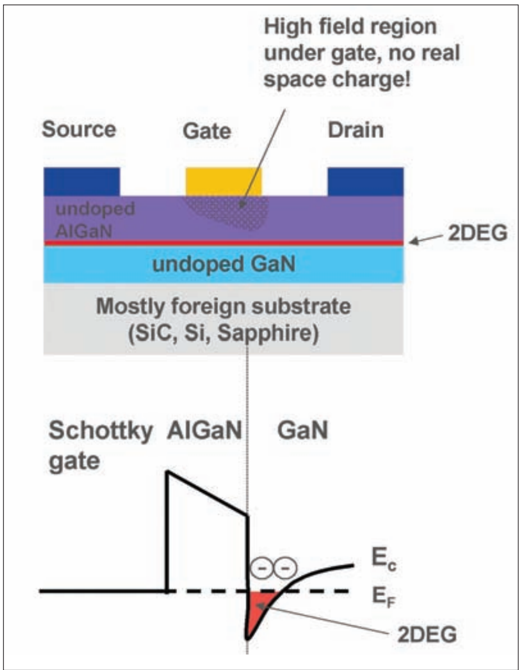


SiC Now and GaN Later

On May 2-3 the European Center for Power Electronics held its fifth User Forum in Munich, this year dedicated to the potential of Silicon Carbide and Gallium Nitride. The article points out the major facts of interest for the potential user.

Joachim Würfl from Ferdinand-Braun-Institute **(www.fbh-berlin.de)** gave an introduction to GaN devices for power applications. "Wide bandgap power semiconductors based on Gallium Nitride have the potential to operate at high switching frequencies while at the same time maintaining a low on-state resistance. These properties are especially advantageous in applications demanding a very high efficiency e.g. in photovoltaics, or in mobile applications where high switching frequencies can be used to reduce volume and weight of converters. In some of these applications, GaN is competing with Silicon Carbide power devices. Compared to SiC, GaN devices have a cost-saving potential but their development requires further research efforts especially for high voltage ratings. In general, the devices are characterized by high power density per unit volume or area. Therefore internal losses are dramatically cut down as compared to competitive other device families. Low on-state resistance values at a given high voltage capability of the devices are obtained. Furthermore, input and output capacitance values at a given on-state resistance capability are much lower as compared to other devices".

GaN HEMTs (High Electron Mobility Transistors) are lateral power transistors of normally-on or normally-off type. Responding to power electronics demands, normally-off transistors are developed at the Ferdinand-Braun-Institut (FBH) for different voltage classes up to 1000 V. According to Würfl GaN transistors need no doping, the current relies on the so-called 2-dimensional electron gas (2DEG). At the interface of the undoped AlGaN and the undoped GaN layer a sea of high-mobility electrons is formed providing the unipolar current flow. The 2DEG electron concentration depends on spontaneous polarization, piezoelectric polarization, and doping of the AlGaN barrier. The electron density in the 2DEG channel is controlled by charges induced in the gate electrode.



Basic functionality of GaN HEMTs Source: FBH

"The power density of GaN can be higher by a factor of 10 against Silicon if the heat of the small chips can be removed effectively. The lateral GaN technology has limitations at 1000 V and above, thus the structure has to go vertical with gate trenches on bulk GaN substrate. For large production foundries can process GaN on Si wafers on CMOS lines with 200 mm or larger wafers, for high-performance niches GaN on SiC is still of interest, and true vertical GaN devices will be used for very high voltage switching applications", Würfl commented.

	Si	GaAs	4H-SiC	6H SiC	GaN/ AlGaN
Band gap energy E_g (eV)	1.1 ind.	1.43 dir.	3.26 ind.	3.0 ind.	3.42 dir.
Electron mobility μ_e (cm²/Vs)	1500	8500	1000	500	1300 >2000 (2DEG)
Electric breakdown field E_{crit} (10^6 V/cm)	0.3	0.4	2.0	2.4	3.3
Saturation velocity v_{sat} (10^7 cm/s)	1.0	2.0	2.0	2.0	2.7
Thermal conductivity κ (W/Kcm)	1.5	0.46	4.9	4.9	2.4
Johnsons Figure of Merit (~$V_{Br}^2 \times v_{sat}^2$)	1	7	180	260	760
Maximum operation temperature T_{max} (°C)	200	300	500	500	500

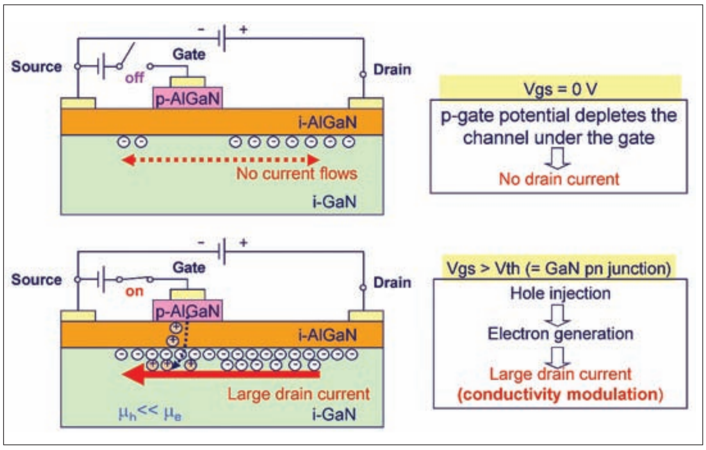
GaN shows highest power performance

GaN performance compared to other power semiconductor materials Source: FBH

GIT for normally-off operation

"Panasonic has already five years ago the Gate Injection Technique for normally-off GaN transistors", said Hideki Nakata from Panasonic's R&D Center Germany. "GIT feature a p-doped AlGaN layer underneath the gate leading to conductivity modulation". Panasonic's **(http://panasonic.net)** 600 V/15 A normally-off Gate Injection Transistors are processed on 6-inch Si substrates via proprietary technologies for the epitaxial growth of GaN by metal organic chemical vapor deposition (MOCVD). The p-type gate of the GIT greatly helps to reduce the on-state resistance taking advantages of the conductivity modulation by the hole injection from it. The GIT exhibits low $R_{on} \times Q_g$ of 715 mΩnC which is one thirteenth lower than that by the state-of-the-art Si MOS transistors. Panasonic also demonstrated 1 MHz operation of resonant LLC DC/DC converters at high efficiency of 96.4 %.

The University of Padova/Italy **(www.unipd.it)** cooperates with Panasonic on the GIT for many years. Researcher Enrico Zanoni thus explained the basic structure and conduction modulation in more detail. "The use of p-doped AlGaN gate determines a significant decrease in the electron concentration of the 2DEG under the gate leading to normally-off operation. Furthermore, at suffiently high gate voltages, holes can be injected into the channel resulting in a significant channel conductivity modulation. For gate voltages above 5 V



Operation of GIT in transistor mode Source: Panasonic

hole injection induces a transconduction increase. At high temperatures a change in the conduction mechanism is responsible for breakdown from gate-drain leakage to drain-source conduction. Trap effects in GaN HEMTs may be relevant due to the wide energy gap and the surface role in generating channel charge, which can be controlled by improved material quality, passivation, and field plate engineering. Experience gained on microwave technologies enables reliability improvements through correct device design".

ST introduces SiC FETs

Simone Buonomo, Market & Application Development Manager at ST Microelectronics **(www.st.com)** introduced the company's strategy on wide badgap switches, SiC diodes (600/1200 V) are already on the market. "We will introduce in July our first Silicon Carbide MOSFET SCT30N120 rated 1200 V and 45 A featuring 80 milliohm on-resistance in the HiP247 package allowing for junction temperature of 200°C", he said. The gate charge is around 100 nC. "One of the advantages of our SiC MOSFET is the use of the internal body diode for freewheeling application. Though it has a higher forward voltage than an external SiC diode it has no reverse recovery charge and thus is capable of high switching frequencies, eliminating the external freewheeling diode", Buonomo stated. But he suggested to use this body diode in inverters for short time intervals, i. e. for dead time control in synchronuous rectification applications.

As driver the standard ST TD350 can be used, perhaps an external isolation between control and power stage is required. This drawback shall be overcome with the so-called GAPDRIVE providing galvanic isolation as well as negative gate driving and active Miller clamp, 2-level turn-off, and SPI interface for parameter setting and diagnostics.

Comparing SiC MOSFETs with IGBTs in a boost converter application the 1200 V SiC MOSFET is able to guarantee similar efficiency levels than 1200 V IGBTs, but at 4 times higher switching frequency, in other words a SiC FET has similar efficiency at 100 kHz than an IGBT at 25 kHz. As consequence: "The IGBT is out of the game", Buonomo concluded. The company is also working on GaN.

Evaluation of devices

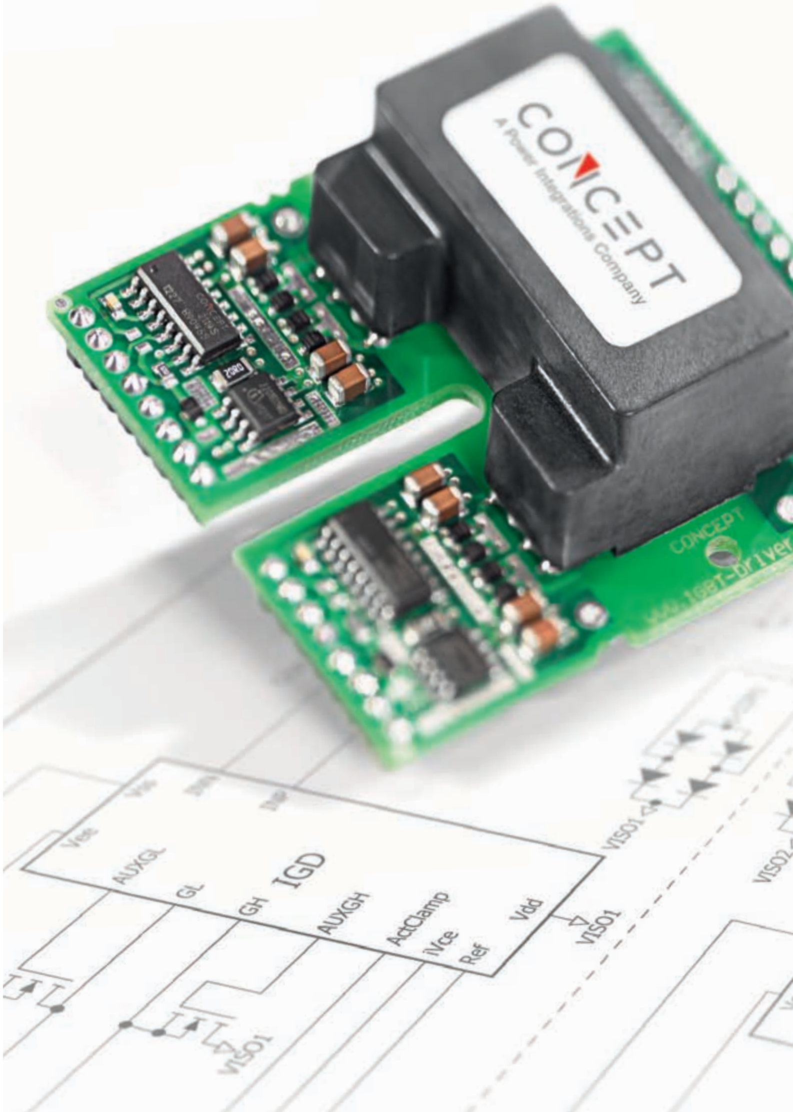
The German Fraunhofer Institute for Solar Energy Systems ISE **(www.ise.fraunhofer.de)** demostrated some results of its evaluation of wide bandgap semiconductors in the presentation "Application of Gallium Nitride Transistors in Hard Switched and Resonant Power Electronics".

"Using GaN or SiC devices is a proper way to increase efficiency and power density, and reduce weight and also cost of passive components", ISE researcher Dirk Kranzer stated. As an example he showed three inductors for hard switched 5-kW PV inverters switching at 16 kHz having a weight of 8 kg and volume of 2-0 l, a 48 kHz version (2.3 kg/0.61 l) and a 144 kHz vrsion (0.8 kg/0.29 l). "Reduction of passive components size thus are inductors is the main motivation for the use of these devices. "One should look at the system and not on the component cost", he said.

In comparing SiC and GaN so far most commercial SiC devices are focused on breakdown voltages of 1200 V and above, whereas most available GaN prototypes are focused on 600 V and below. With SiC a p-doping and thus a bipolar or a parasitic bipolar (BJT, JFET, MOSFET) behavior is possible, whereas GaN devices are just unipolar (HEMT. GIT), which leads to a different avalanche behavior of both technologies. Additionally, GaN devices are mostly lateral whereas SiC have a vertical structure, leading to different heat management and mounting. Thus SiC and GaN are not pure rivals since technologies and applications are not identical.

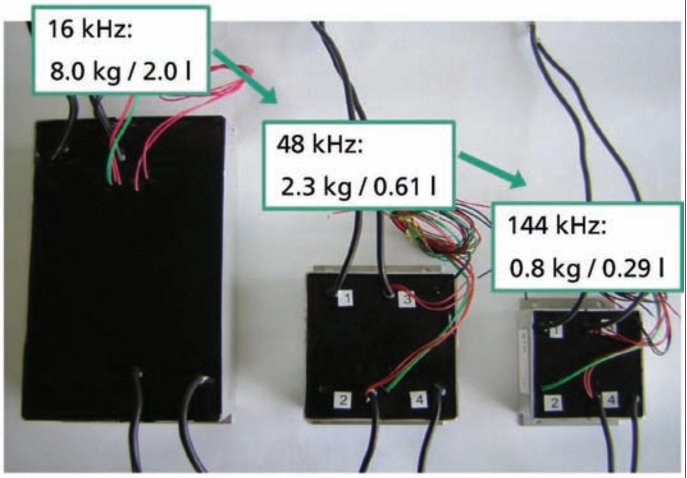
To the question of normally-on or normally-off Kranzer said: "A cascode configuration leads to a normally-off behavior of a normally-on device, a challenging problem here is the sensitivity of oscillations which can be avoided by an external RC snubber circuitry. The availability of normally-off eGAN devices (EPC) ranging from 20-200 V at low price ($ 3-5) is very interesting, but the flip-chip packaging results in improper handling and soldering.

As a general result of his reearch on various hard-switched converter topologies GaN and SiC devices behave more or less similarly, but GaN



devices are better suited for high-frequency resonant applications. Additionally, the monolithic integration of a lateral half-bridge will be a step towards better GaN performance and cost reduction at system level. "The cost of power semiconductors do not only depend on material wafer cost, but also on process steps, yield and volume. Thus GaN on Silicon devices have to settle on the 600 V market, before SiC gets too cheap", Kranzer concluded.

Michael Schlechtweg from Fraunhofer IAF **(www.iaf.fraunhofer.de)** sketched the progress of the German Power GaN Plus program featuring the industrial partners Bosch, Ixys, Kaco and UMS. The running project comprises two demonstrator units for automotive (Bosch) and photovoltaic (Kaco) applications, IXYS is in charge for the module development of these demonstrators.



Inductors for hard-switched 5-kW PV inverters at different switching frequencies. Very obvious are the reductions in weight and volume at higher switching frequencies

Source: ISE

The epitaxy relies on 3- and 4-inch GaN on SiC and 4-inch GaN on Si with AlGaN/GaN barrier and in total of four passivation and two metallization layers. So far vertical 600 V/2 A Schottky diodes and 600 V/90 A GaN on SiC switches (65 mΩ on-resistance) featuring only 40 mJ switching energy have been realized.

The Bosch buck DC/DC demonstrator unit converts 100 V to 41 V at switching frequency up to 100 kHz with 94 % efficiency at 4 A and 98 % at 1 A output current. The second Kaco demonstrator is a boost converter with 3-phase output bridge up to 5 kW output power achieving efficiency levels above 98 %.

Also PV inverter manufacturer SMA Solar Technology **(www.sma.de)** is evaluating SiC MOSFETs and GaN for central inverters, since the company has some experience with SiC JFETs in 20 kW inverters so far. "Because of the lower blocking voltages of GaN we are looking for Micro- or 3-phase String Inverters around three years ahead from now", development manager Regine Mallwitz stated.

For the automotive industry Continental's **(www.conti-online.com)** Hans-Peter Feustel expects a price target of 3 € / kW in the year 2020, that is the pressure from the automotive OEMs on the Tier 1 suppliers. "Thus for us it is very important that the wide bandgap semiconductors will drop in pricing significantly, and from the system's view size, weight and cooling effort of the inverters needs to be reduced. Also packaging of the power devices have to be improved in order to make advantage of the high switching frequencies and also high temperature capabilities coming with these devices, and that all at this given price point".

AS

Literature: "European Power Electronics on the Forefront", Power Electronics Europe April/May 2013, pages 10-13

Best PCIM Europe Ever

PCIM Europe 2013 ended on May 16 with a 15 percent increase in visitors up to 7,883 (2012: 6,874), 395 exhibitors (2012: 365) and 87 represented companies (2012: 88). For three days the latest developments and trends in power electronics, intelligent drive technology, renewable energy and energy management have been here on display. The conference was visited by a total of 726 (2012: 744) delegates. PCIM Europe 2014 will take place from 20 – 22 May 2014 at the Exhibition Center Nuremberg.

The Best Paper and three Young Engineer Awards were presented during the opening ceremony of the PCIM Europe Conference 2013. The Best Paper winner was Eckart Hoene of Fraunhofer IZM **(www.izm.fraunhofer.de)** for his paper "Ultra-Low-Inductance Power Module for Fast Switching Semiconductors". He received prize money and an invitation to the PCIM Asia 2014 Conference in Shanghai, sponsored by Power Electronics Europe and Semikron.

The three PCIM Young Engineer (under 35 years old) Awards have been handed over to Radoslava Mitova of Schneider Electric/France for the paper "Half Bridge Inverter with 600 V GaN Power Switches"; Samuel Araujo, University of Kassel/Germany for the work "High Switching Speeds and Loss Reduction: Prospects with Si, SiC and GaN and Limitations at Device, Packing and Application Level", and Daniel Wigger, University of Rostock/Germany for "Impact of Inhomogeneous Current Distribution on the Turn-off Behavior of BIGTs". The three Young Engineer Award winners received prize money of € 1,000 each sponsored by ECPE, Infineon Technologies and Mitsubishi Electric.

The award winning papers were selected from more than 280 papers by the conference directors. The determining criteria were originality, topicality and quality. The awards were presented by the Scientific Advisory Board Chairman, Prof. Leo Lorenz of ECPE, Germany.

Packaging for SiC and GaN

The developments in switching semiconductors have come to a point, were the packaging of the semiconductors becomes a severe influence on switching performance. Especially wide bandgap materials like SiC or GaN switch so fast, that parasitic influences of wire bonds or pins influence the components performance. Furthermore expert knowledge to design a switching cell properly in needed and inhibits the broad use of the superior semiconductor properties.

In the BPA paper "Ultra Low Inductance power module for Fast switching Semiconductors" new strategies and technologies presented to face this challenge. First of all a packaging technology was developed that combines a Direct Copper Bond (DCB) Substrate with Printed Circuit Board (PCB) technologies. Thereby the superior thermal properties of the ceramic is combined with the design freedom of the PCB. These possibilities were then used to create packages with extraordinary electromagnetic properties with the additional feature to be able to directly solder components like capacitors or drivers onto the module. The manufactured module comprises a half bridge with SiC JFETs and a blocking voltage of 1200 V. The DC link inductance was measured to be below 1 nH, which sets the new standard in packaging. The concept of the module is to integrate the critical switching cell into the module including a DC link capacitor. This module concept shows the way to make high-speed switching available to users with less experience in design for high power and speed.

GaN for inverters

The YEA "Half Bridge Inverter with 600V GaN Power Switches" presented by Radoslava Mitova from Schneider Electric also covered the emerging Gallium nitride (GaN) power devices which promise to outperform the legacy Silicon devices

From May 14-16 it was again time for more than 700 PCIM conference delegates and around 8000 exhibition visitors

LEFT: The Best Paper Award was handed over by PCIM Conference Director Prof. Dr. Leo Lorenz (right) to Eckart Hoene of Fraunhofer IZM and PEE Editor Achim Scharf and Uwe Scheuermann from Semikron

and challenge the Silicon Carbide devices in 600 voltage range; thanks to their faster switching speed and low switching and conduction losses. In last few years several device manufacturers have communicated their development on GaN based power devices in the range of 200-600V. This article presents the evaluation of a new 600V GaN High Electron Mobility Transistor [HEMT] in a half-bridge inverter prototype. The static and dynamic characterizations of these devices are presented. Several experiments have been conducted to test the GaN HEMT performances. The results shows that the GaN based devices improves the efficiency of the inverter prototype compared to the Silicon and SiC based devices. The advantage of using higher switching frequency on the size of the inverter output filter inductor was also commented.

Fast switching and loss reduction

The second YEA "Prospects with Si, SiC and GaN and Limitations at Device, Packing and Application Level" presented by Samuel Araujo from University of Kassel covered the prospect of increasing the switching frequency without sacrificing efficiency. This will be mainly achieved through new device technologies, not only relying on WBG materials but also on Silicon, capable of operating at much faster switching speeds and thus with lower losses.

In the path towards such development it is thus interesting to identify the true limitations for each device technology based on inherent properties and also on properties of the freewheeling path. Several enhancements in the field of packing are also still necessary in order to fully exploit the referred power devices' capabilities. In addition to this, other issues at application level concerning EMI, driving and also the influence of transient speed at inductor losses still need to be addressed. This paper presented an overview of these issues based on experimental results and literature research in order to assert future development trends. In addition a benchmarking of different SiC switch technologies based on a new figure of merit has been performed.

These awarded papers demonstrated very obviously the impact of wide bandgap devices and in particular GaN for future power electronic designs, which was also the aim of PEE's Special Session "Power GaN for Highly Efficient Converters".

Turn-off behavior of BIGTs

The impact of Inhomogeneous Current Distribution in the BIGT has been presented by the third YEA Daniel Wigger, University of Rostock. ABB's **(www.abb.com/semiconductors)** BIGTs are a new type of power semiconductors. In opposite to a conventional IGBT/diode module, this device includes the functionality of the diode and the IGBT. An advantage of the device is the softness of the turn-off behavior in the IGBT-mode compared to a conventional IGBT. The reason for this is the inhomogeneous current distribution in the BIGT.

The BIGT has a different chip design, compared to an IGBT. The BIGT chip contains the pilot-IGBT with a conventional design and the RC-IGBT with the shorts on the collector. The pilot-IGBT is needed to prevent the snapback effect. Due to the lack of the shorts the p-emitter efficiency is higher in the pilot area. As a reason of that, the plasma concentration during the on-state is higher in the pilot-IGBT, as in the RC-IGBT. The inhomogeneous charge carrier distribution will have an influence on the turn-off behavior in the IGBT mode. This behavior has been investigated at different current levels and compared to a state-of-the-art IGBT. At low current the BIGT has a significant higher dvCE/dt and a lower over-voltage. The large hole density in the pilot area causes a high dE/dx and a short space charge region at the same blocking voltage. So there remains a lot of charge in the BIGT, which leads to a large tail current. At high current the high dE/dx in the pilot-IGBT will cause the dynamic avalanche. Due to the dynamic avalanche the dvCE/dt and the di/dt will be limited. Compared to the IGBT the inception voltage of this effect in the BIGT is significantly smaller, that's why the device is softer than the conventional IGBT.

More awards from Semikron

Also the SEMIKRON Foundation **(www.semikron-stiftung.de)** and the ECPE **(www.ecpe.org)** jointly honored the team of Michael Eberlin, Florian Reiners, Olivier Stalter, Sebastian Franz (all of Fraunhofer ISE, Freiburg) and Frank Seybold (KACO new energy) with the Innovation Award 2013 for their "Innovative Power

LEFT: Winners of the Young Engineer Award and sponsors (in the back) Radoslava Mitova (Jörg Malzon-Jessen/Infineon, left), Daniel Wigger (Gourab Majumdar/Mitsubishi), and Samuel Araujo (Thomas Harder/ECPE)

LEFT: The SEMIKRON Young Engineer Award has been handed over to Jordi Everts by ECPE President Leo Lorenz

Electronics for the next generation village energy supply" concept. "The researchers have developed power electronics components for a complete off-grid solar energy supply system", said Bettina Heidenreich-Martin, member of the Semikron Foundation Board, during the award ceremony. "The innovation is considered a holistic approach to off-grid PV supply for larger consumers, such as villages and businesses, particularly in emerging countries."

The SEMIKRON Young Engineer Award has been handed over to Jordi Everts, PhD student and research assistant at the Catholic University of Leuven (KU Leuven) in Belgium, Department of Electrical Engineering (ESAT), for his concept of a "Bidirectional Isolated ZVS DAB DC-DC Converter with Ultra Wide Input and/or Output Voltage Range, being Applied in a Single-Stage PFC AC-DC Electric Vehicle Battery Charger". With these awards, the SEMIKRON Foundation and the European ECPE Research Network honor outstanding innovations in projects, products, prototypes, services and innovative concepts in the field of power electronics. In total, there were 19 applications and submissions for the two SEMIKRON awards, 5 of which have been nominated for the Young Engineer Award as well. Prof. Dr. Leo Lorenz, President of ECPE, presented the awards on behalf of the SEMIKRON foundation.

"One of the key objectives for the ECPE European Centre for Power Electronics is to foster and support research and education in the field of power electronics", said Lorenz. "The ECPE network, with its 70 members, currently includes 70 European universities and research institutes as so-called Competence Centres. I welcome the support for young researchers in the field of power electronics, and want to express my thanks to SEMIKRON Foundation for issuing the awards".

HVDC keynote

Jörg Dorn from Siemens/Germany gave the first interesting keynote on the challenges of power distribution particularly in Germany due to the so-called "Energiewende" or stepping out of nuclear power.

The growing share of power generation from renewable energy sources leads to continuative challenges in the field of electric power transmission. The load centers are often far away from the location of generation and very long transmission distances have to be considered. Requirements, such as low environmental impacts, low transmission losses and high availability have to be fulfilled. In many cases, HVDC (High Voltage Direct Current) transmission it is the only technical and economical solution to cope with these challenges.

Line-commuted converter technology was the unique solution for many decades and is today focusing on bulk power transmission up to 8 GW. Since the introduction of IGBT based modular multilevel converters (MMC) into HVDC transmission, this VSC technology is becoming significantly important. It combines low losses, excellent controllability and failure handling with the capability to build large multi-terminal systems or even HVDC grids in the future.

HVDC will play a dominant role in tomorrow's power transmission systems. In UK, it is planned to connect more than 30,000 MW offshore by HVDC until 2030, in Germany about 20,000 MW until 2020. In Germany, that power has to be transmitted to the load centers.

Since complete new AC transmission overhead lines are critical due to the visual impact, parts of the transmission lines will be realized as cable. As a result, HVDC will have to be used. According to the current status of the network development plan in Germany, three HVDC corridors from the North to the South are planned by the Federal Network Agency, with a total capacity of 8,000 MW. The integration of hydropower – including hydro storage - in Scandinavia and Eastern Europe and solar power from North Africa will also lead to new HVDC systems, which might result in a huge HVDC overlay grid in the future. As a vision, even continents can be interconnected with the possibility to balance power generation and load peaks over the day and night phases.

The second keynote by Alsthom covered the

RIGHT: Jörg Dorn from Siemens/Germany gave an interesting keynote on the challenges of power distribution particularly in Germany due to the so-called "Energiewende"

LEFT: Full house during the PCIM conference sessions

move from IGBTs towards SiC MOSFETs in transportation, the third keynote focused on voltage regulator modules for powering microprocessors.

Special session on gallium nitride

PEE's Special Session "Power GaN for Highly Efficient Converters" on May 16 afternoon attracted some hundred conference delegates. The The third PCIM keynote by Qiang Li, Virginia Polytechnic Institute on this morning, was a perfect introduction to this subject, because it impressively showed how Power GaN technology can optimize the multi-phase voltage regulator (VR) technology that powers almost every Intel processor today. The VR technology is a specialized distributed power system that provides precisely regulated output with fast dynamic response so that energy can be transferred as fast as possible to the microprocessor. Four papers have been presented in this session.

Efficient Power Conversion Corporation (EPC) has been in production with enhancement mode GaN-on-Silicon power transistors (eGaN FETs) for over three years. Much progress has been made improving device performance and reliability. There have also been several new power management applications that have emerged. Two of these applications, RF Envelope Tracking and high frequency Wireless Power Transmission are beyond the fundamental capability for the aging power MOSFET due to the requirements of high voltage, high power, and high frequency. As a result, these are early growth markets for GaN on Silicon devices, as CEO Alex Lidow demonstrated.

Devices based on GaN have emerged and now matured enough to demonstrate higher efficiency in inverter circuits for both solar and motor drive systems. The presentation given by Transphorm's VP Product Development investigated how GaN is making such rapid performance progress and uses test results to illustrate what is now possible using GaN compared to recent SiC transistor performance.

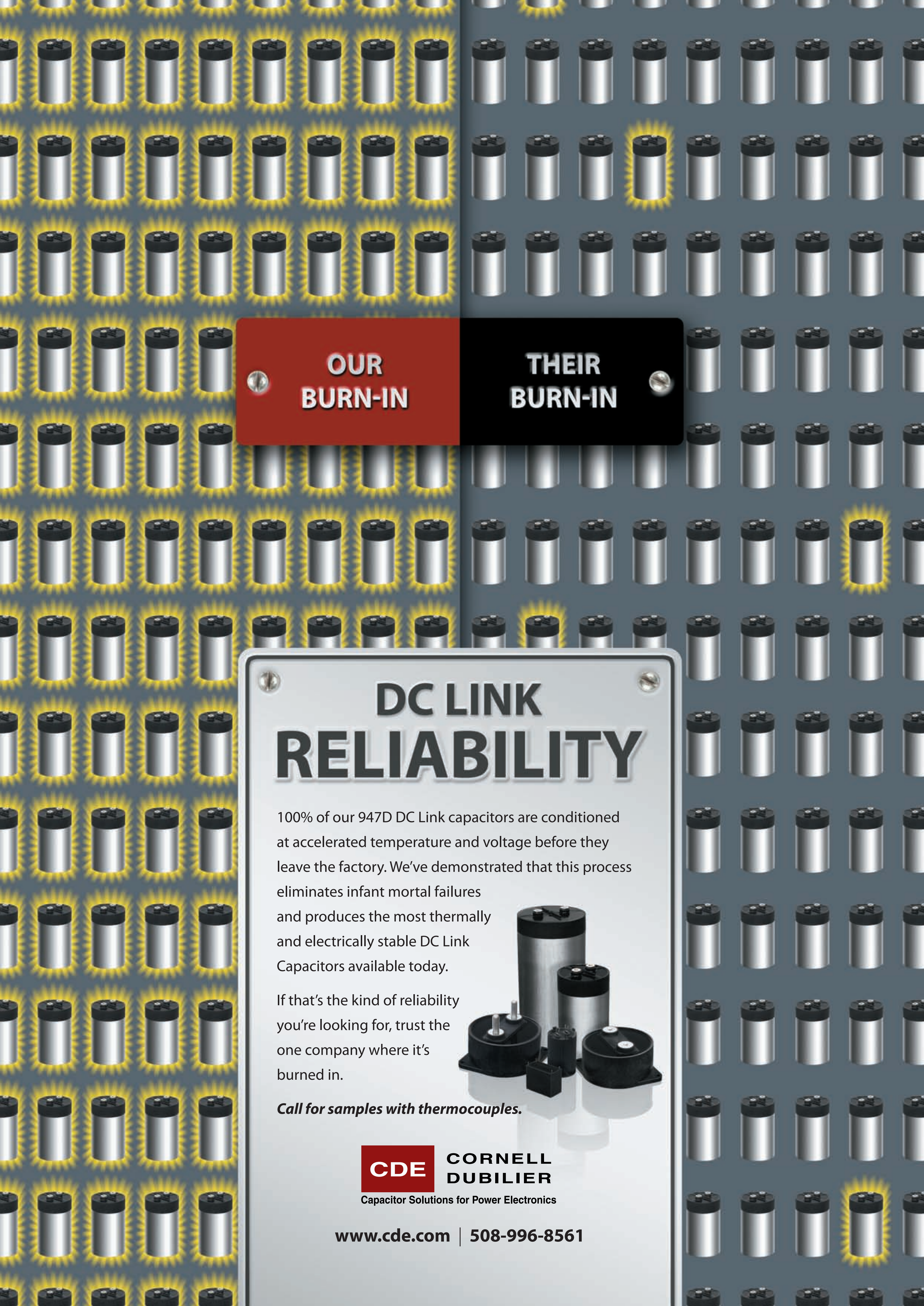
GaN Systems is investing heavily to accelerate the adoption of the new technology by designing CMOS integrated driver solutions onto which the GaN die is mounted directly in a stacked chip assembly combining the switch, its driver, sensors and customized interface circuitry. In solar and wind inverter applications the high voltage operation, embedded galvanic isolation and high speed operation of these devices offer the prospect of higher switching speeds with improved conversion efficiency, lower component count, smaller size and reduced conversion loss, as CEO Girvan Patterson explained.

Experimental results for the use of GaN based power devices in highly efficient high frequency power circuits such as AC/DC power supplies, DC/DC boost and DC/AC motor drive inverters were presented by Michael Briere, also the current status of the development and current performance of the required 600 V rated GaN on Si based devices at International Rectifier, including the development of crack free AlxGayN alloy based epitaxy on standard thickness 150 and 200 mm Si substrates. Results of long term reliability studies of more than 5000 hrs were presented, as well as results for device robustness under standard application conditions. We will publish these papers in this and upcoming issues. **AS**

Literature

"More Power for a Greener World", Power Electronics Europe, April/May 2013, pages 25-27

PEE Special GaN Session speakers Alex Lidow, Girvan Patterson, Michael Briere, and Yifeng Wu at the final podium discussion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More Power at PCIM Europe Exhibition

Due to the event's continuing expansion the exhibition has been moved to halls 7 and 9 which have led to a significantly increase in space. On an area of 18,500 square meters (up 12 %), 395 exhibitors and 87 represented companies (up 8 %) from 27 countries presented their companies and products to more than 7800 international trade visitors. 55 % of the exhibitors come from abroad, mostly from the US, followed by Britain, Italy, France and China.

ABB's **(www.abb.com/semiconductors)** new 1200V and 1700V SPT++ chip-sets featuring higher current densities which enable module producers to boost their performance especially in medium to fast switching applications. The HiPak product range will be improved by means of reliability and performance whilst keeping identical switching behavior. The improved package features an epoxy-less encapsulation complying with the latest Fire&Smoke standards, an improved emitter bonding boosting the power cycling performance and an aluminum bonded substrate gate-print connection as a substitution of soldered connections. New 4500 V StakPak press-pack IGBT modules feature exceptional high current ratings and are suited for heavy duty applications where series connection may be required. Also the rectifier diode family has been enlarged with the 5SDD 50L5500 which has a performance that earlier only has been seen on diodes in a next larger housing.

AVX's **(www.avx.com)** new TCH series hermetically sealed SMD tantalum chip capacitors with polymer electrode have been specifically developed in a project with ESA for mission critical systems with the need for large capacitance and low ESR. Tantalum polymer capacitor technology offers the benefits of much lower ESR values, lower derating and higher ripple current capabilities. However, its sensitivity to the combination of high temperature and humidity conditions has so far restricted its use in the aerospace industry. By now placing the polymer capacitor into a hermetically sealed SMD case filled by an inert gas, a much improved stability has been achieved. The hermetical sealing suppresses humidity and oxidative degradations. The improved construction of the new capacitors allows the devices to be used for European aerospace applications and offers a significant payload reduction for power supplies. Capacitance values of up to 680µF and high voltage of up to 100V are available.

Avago **(www.avagotech.com)** demonstrated a new line of 2.5A hermetic gate drive optocouplers featuring the ACPL-5160 and ACPL-5161. The ACPL-5160 is a rugged commercial-grade version. The ACPL-5161 is a MIL-STD compliant version manufactured and tested to Class H quality conformance level under MIL-PRF-38534 specifications. Optimized for high power motor control and power conversion applications, these devices are robust and withstand harsh environments across the military temperature range of -55 to +125°C. Complimenting the HCPL-515x and HCPL-512x gate drivers, the ACPL-5160 and ACPL-5161 have higher output current drive capability supporting high-power MOSFET and IGBT with power ratings up to 150 A and 1200 V. In addition, these new hermetic devices incorporate new functions including V_{CE} desaturation (DESAT) detection, under voltage lockout (UVLO), "soft" IGBT turn-off, and isolated open collector fault feedback.

CT-Concept **(www.IGBT-Driver.com)** launched the 1SC0450V, a single-channel gate-driver for 6.5 kV IGBT modules. The driver is able to support the operation of up to four IGBT modules in parallel, and the use of SCALE-2 ASICs results in a significantly lower component count compared to a discrete solution and a service life guarantee of over 15 years. Featuring an on-board power supply, the drivers have a gate current of ±50 A and operate from a +15 V/-10 V supply. Power capability is 4 W at 85°C. Devices can be configured for parallel operation of IGBT modules using one central driver. Isolation is in accordance with IEC 61800-5-1 and IEC 60664-1, and the UL-compliant devices also feature Advanced Active Clamping, short-circuit protection and under-voltage lockout. Applications include traction, HVDC, STATCOM, wind-power converters and other medium-voltage converters/drives.

Fairchild **(www.fairchildsemi.com)** introduced the FOD8160, a high noise

The PCIM Europe 2013 exhibition now in halls 7 and 9 at Nuremberg Exhibition Center were widely accepted by the 7800 visitors. Among SiC and GaN devices and applications automotive played a major role

immunity logic gate optocoupler with Optoplanar® technology in a wide body 5-pin small outline package (SOP). The FOD8160 allows designers the flexibility of incorporating the isolation on the high voltage side of the circuit, or replacing two smaller creepage/clearance distance digital isolators or optocouplers. In addition, the device has a max. repetitive peak isolation voltage of 1414 V and a creepage/clearance distance of 10 mm, which is much greater than the standard high speed optocouplers. This is a must for designs that require a repetitive peak isolation voltage value of equal to or greater than 1000V. Also on stage were 1200 V SiC BJTs demonstrated on various application scenarios. Additionally the FTCO3V455A1 3-phase (40 V/up to 130 A) Variable Speed Drive Automotive Power Module has been shown. This device, intended for 3-phase motor control applications under 2 kW such as electric power steering (column-mount and rack-mount), electro-hydraulic power steering, electric water pumps, electric oil pumps and engine cooling fans.

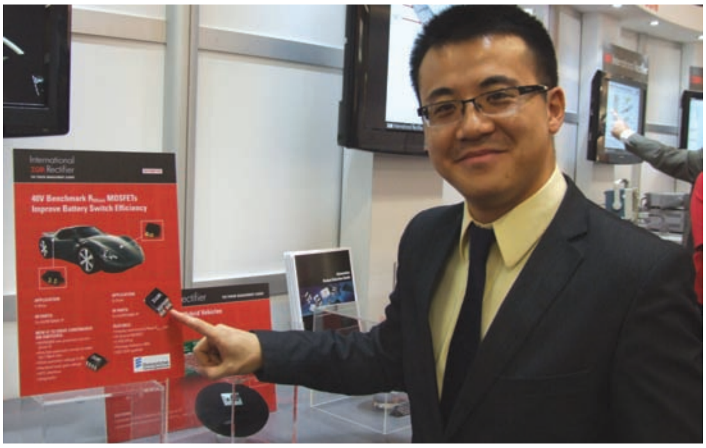
Hoffmann Elektrokohle's **(www.hoffmann.at)** Aluminium Graphite Composites are materials for thermal management. They are suited for applications requiring a high degree of reliability as they combine optimal thermal expansion behavior with a high thermal conductivity. Customer-specific products can be manufactured via a range of machining processes to give, for example, base plates or heat sinks. Additionally, platings can be applied to facilitate bonding to DCBs.

Infineon's next generation of high-voltage IGBT gate drivers **(www.infineon.com/automotive-eicedriver)** are designed for the main inverter of hybrid and electric vehicles (HEV). The new EiceDRIVER™ SIL and the EiceDRIVER™ Boost drivers enable automotive system suppliers to more easily and more cost-effectively design HEV drivetrain subsystems that are compliant with ASIL C/D functional safety requirements (ISO 26262). Target applications are HEV inverters of up to 120 kW using 400 V, 600 V and 1200 V IGBTs. EiceDRIVER SIL is based on the Coreless Transformer technology, providing galvanic isolation between low-voltage and high-voltage domains. It features a standard SPI interface for control and diagnosis, with transmission speed up to 2 Mbaud. A large spectrum of safety-related functions is implemented to support functional safety requirements at system level. These include over-current monitoring, runtime monitoring of all power supplies, oscillators, gate signals and output stage. A verification mode allows system-level diagnosis including error injection and weak turn-on. On the high-voltage side the EiceDRIVER SIL is dimensioned to drive an external booster stage. It comes in a PG-DSO-36 package. The EiceDRIVER Boost is a single-channel IGBT booster fully compatible with the EiceDRIVER SIL. EiceDRIVER Boost is based on high-performance bipolar technology and replaces buffer stages based on discrete devices. Because of its thermally optimized exposed pad package, the EiceDRIVER Boost is able to drive and sink peak currents up to 15A. Early samples of the EiceDRIVER SIL and EiceDRIVER Boost are available now with broad sampling planned as of December 2013.

International Rectifier **(www.irf.com)** demonstrated the first commercial implementation of its GaN devices in a home theater entertainment system. Also a new family of automotive-qualified COOLiRFET™ MOSFETs are intended for heavy load applications including electric power steering (EPS), braking systems and other heavy loads on internal combustion engine (ICE) and micro hybrid vehicle platforms have been introduced. The 22 AEC-Q101 qualified 40 V N-channel MOSFETs feature proven Gen12.7 trench technology that delivers on-resistance as low as 0.75 mΩ at 10 Vgs with a current rating up to 240 A. The new devices offer low conduction losses and robust avalanche performance to deliver higher efficiency, power density and reliability. With this performance, many applications using these new devices

"GaN is accepted and already implemented in a home theater system", IR's Manager Emerging Technologies Tim McDonald underlined

"EiceDRIVER SIL and the EiceDRIVER Boost drivers enable automotive system suppliers to more easily design HEV drivetrain subsystems that are compliant with ASIL C/D functional safety requirements", stated Mark Nils Münzer, Head Electric Drive Train Infineon Technologies



"Our new family of COOLiRFET 40V automotive-qualified MOSFETs deliver a highly efficient solution for high current automotive applications. We already have won Tier1 supplier Eberspächer for Daimler in Germany," said Jifeng Qin, Product Manager, Automotive MOSFETs, IR's Automotive Products Business Unit

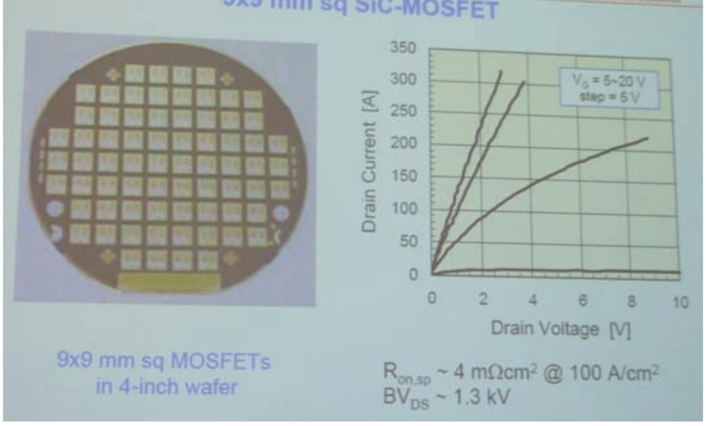
run significantly cooler than with state-of-the-art MOSFETs. Pricing ranges begins from $0.39 each for the AUIRFU8401 to $1.70 each for the AUIRFS8409-7P in 100,000-unit quantities. Automotive Tier1 suppliers in Germany are already evaluating these new MOSFETs.

Magnetics' **(www.mag-inc.com)** new AmoFlux amorphous powder cores starts with low core loss amorphous ribbon that is pulverized into powder and then pressed into a toroid. By converting the amorphous ribbon into a powder form, the resulting AmoFlux cores have the same excellent properties, including soft saturation, as Magnetics other powder core materials: Kool Mu, MPP, High Flux, and XFlux. What makes this amorphous powder core material unique is the combination of low core loss and high DC bias. AmoFlux is a new distributed gap material for PFC and various types of output chokes in computer, server, and industrial power supplies that require maximum efficiency at high DC currents.

Mitsubishi Electric **(www.mitsubishichips.eu)** announced the development of higher current rated intelligent power modules (IPMs) mainly for (hybrid) electric vehicle applications. Two new models of the J-Series in 3-phase inverter configuration (6 in 1) have been introduced, based on low-loss

Mitsubishi's Gourab Majumdar explained the company's power module and SiC strategy

CSTBT chip technology. The PM800CJG060G is rated at 600 V/800 A with a low saturation voltage of typically 1.8 V. For PM500CJG120G these values are 1200 V/500 A with a typical saturation voltage of 2.0 V. Both are supporting at the same footprint area larger currents than existing types of the J-series, starting from 300 A at 600 V rating respectively from 150 A at 1200 V. Additionally, both are equipped with built-in power supplies for IGBT drive and logic circuits. First samples will be available from August 2013 onwards. Mass



Mitsubishi's SiC MOSFET properties

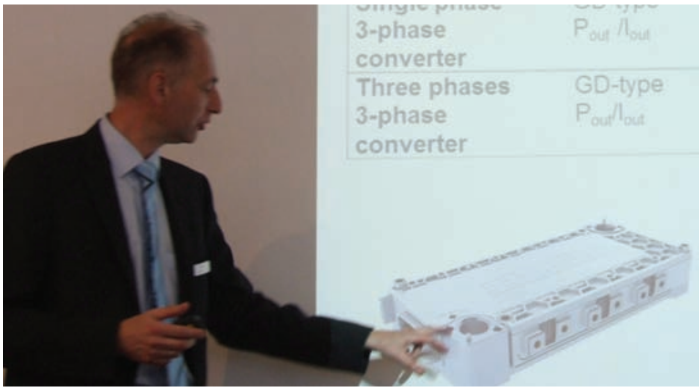
production of the RoHS compliant modules is expected to begin in 2014. Common features of the IPM J-Series are IGBT driver & protection functions and an isolation by using automotive high-grade photo-couplers. Additionally this J-Series provides analog output functions on a high-accuracy level to monitor the temperature at the chip center and the inverter DC-link voltage (optional). All J-Series IPM can be controlled by a ready-signal input for fail-safe operation. Regarding SiC hybrid modules are used already for traction applications in Japan, full SiC will be the next step. Mitsubishi is also working on 3.3 kV/100 A SiC MOSFETs and full SiC IPMs.

Power Integrations **(www.powerint.com)** introduced the Qspeed™LQA200 series of 200 V diodes. These Silicon diodes are based on merged-PIN technology that offers 'soft' switching and low reverse recovery charge. This balance of features enables high-frequency operation and permits the use of small, inexpensive magnetic components. Available from 10 A to 40 A in common-cathode configuration, these diodes reduce peak reverse voltage, increasing voltage margin and enhancing operational reliability and ruggedness. The need for snubber capacitors is also reduced or even eliminated, which further improves efficiency and lowers cost. When compared with equivalent Schottky products, the Qspeed diodes reduce reverse recovery by up to 80 %, and have a 45 % lower junction capacitance. LQA200 diodes are available in DPAK, D2PAK and TO-220 packages, ranging from $0.40 to $1.20 each in 10K quantities.

RFMD **(www.rfmd.com)**, so far a SiC/GaN California-based foundry announced with the RFJS3006F E an own 30 A/650 V normally-off sourced switched FET (SSFET) GaN HEMT providing the same insulated gate ease of use as a power MOSFET or an IGBT, but enabling much higher PWM frequencies. The SSFET uses the bidirectional capability of the GaN HEMT to provide an ultra-fast freewheeling diode function eliminating the need of for a separate antiparallel diode. The RFJS3006F is housed in a standard 3 lead TO247 with a UL-recognized isolated mounting tab; separate insulating hardware is not needed. The 650 V, 30 A "fast version" is optimized as a drop-in replacement or for system redesigns for higher efficiency in medium to high power converter applications operating at PWM frequencies from 100 to 500 kHz.

ROHM **(www.rohm.com/eu)** presented its new line-up of N-channel SiC Power MOSFETs. The SCT2xx series without Schottky diode features different on-resistance types and max. currents in a TO247 package. They handle a junction temperature of 175°C and with low on-resistance, high breakdown voltage, high speed switching and low reverse recovery these new SiC MOSFETs are easy to parallel and to drive. With hybrid MOSFETs the company introduced a newly developed transistor combining the advantages of a MOSFET and IGBT to a "hybrid MOS" by adopting a new device structure to the PFC circuit for the power supply. The new hybrid MOSFET is featuring the "best of both worlds" such as high-speed switching characteristics, low-current performance of the MOSFET and high breakdown voltage of the IGBT. As a result, the high temperature and high current performance improved significantly while energy saving is possible over the full range – from small to large currents. The product is expected to begin sampling in summer 2013.

Semikron **(www.semikron.com)** launched the MiniSKiiP Dual Module for industrial motor drives, solar inverters and power supplies up to 90 kW. For the first time MiniSKiiP Spring Technology is available for power ratings higher than 40 kW. The benefits are lower material costs as compared to traditional inverter designs because the expensive bus-baring of the load connectors can be replaced by a cost-efficient PCB connection. In combination with a solder-free assembly, this allows for reducing the system costs by up to 15 %. The spring contacts make the layout of the PCB simpler and more flexible because the PCB does not need holes for soldering pins. Also, the springs allow for a more flexible connection between the PCB and the module than a soldered joint, which adds extra benefits particularly under thermal and mechanical stress. For high-power applications the new SKiiPX allows condensation during operation. The SKiN base technology enables the integration of a 3 MW drive in a single cabinet due to a reduced number of components and interfaces. SKiN enables doubling of the power density within the module. Consequently, the total volume of the inverter can be decreased by up to 50 %, inverter costs may be reduced by up to 15 %. SKiiPX allows for the first time the



Semikron's Head of Product Management Thomas Grashoff introduced its new SKiiPX hermetically sealed system for 3 MW wind turbine applications

integration of a 3 MW wind inverter into a single cabinet. Due to the high integration level, the probability of an inverter failure - expressed by the FIT rate – is reduced by 30 %. The newly designed integrated liquid cooling system allows for a constant operating temperature of the coolant of up to 70°C. This hermetically sealed system requires less numbers of gaskets as compared to conventional systems ensuring higher reliability. The SKiiPX is supplied as a fully tested subsystem (IPM) with integrated gate driver electronics, cooling and protection functions.

Toshiba Electronics Europe **(www.toshiba-components.com)** announced a hybrid N-channel IEGT (Injection-Enhanced Gate Transistor) module that features an embedded SiC fast recovery diode (FRD). Rated at 1700 V and 1200 A, the half-bridge MG1200V2YS71 is intended for industrial, rail traction, renewable energy and electricity transmission and distribution systems. The module incorporates two switches (IEGTs), each with its own embedded SiC diode. Use of an SiC diode leads to a significant decrease in reverse recovery current and a corresponding decrease in turn-on loss. As a result the new PMI offers a reverse recovery loss up to 97 % lower than a module with a conventional Silicon diode. Thus the cooling is much smaller than its Silicon-based predecessor. In addition, thanks to the size reduction of some motor control parts, overall equipment size could be reduced by as much as 40 %. The new module has an isolation rating of 6000 VAC (rms for one minute) and will operate with junction temperatures from -40°C to 150°C.

Transphorm **(www.transphormusa.com)** demonstrated a high-efficiency off-line 1 kW 48 V power supply that has peak efficiency of 97.5 %. The power supply design utilizes GaN on Silicon 600 V HEMTs to implement a 99 % efficient totem pole power factor correction (PFC) front end, combined with a 98.6% efficiency LLC converter. Based on Transphorm's EZ-GaN technology, the TPH3006PS HEMT combines low switching and conduction losses to reduce energy loss by 50 %. The TO-220-packaged GaN transistor features low on-state resistance of 150 m?, low reverse-recovery charge of 54 nC and high-frequency switching capability.

TT electronics **(www.ttelectronics.com)** offers wide bandgap high temperature packaging. The advantages of using GaN and SiC are well known: low switching losses, little or no turn off losses, fast switching. TT electronics has combined this with the latest Silicon Nitride packaging technology to enable the devices to be used for long periods of time at elevated temperature. Reliability data on SiC devices at 225°C for 8000 hours can be supplied. Silicon Nitride packaging allows via connections to the outside world thus eliminating fragile glass / ceramic to pin feed through. Typical weight savings of 30 % can be achieved over conventional metal hermetic packages. This type of packaging has already achieved Space flight heritage in prestigious

European space agency programs and is now gaining interest in down hole geothermal exploration. Indeed, reliability data show that no delamination occurs beyond 3000 temperature cycles (-40 to +125°C).

Vicor Corp. **(www.vicorpower.com)** announced the expansion of its Picor Cool-Power® PI31xx series of isolated, ZVS-based DC/DC converters optimized for 24 V industrial, 28 V aerospace/defense and/or demanding wide temperature applications. The new Cool-Power PI31xx converters retain the product series' signature 0.87" x 0.65" x 0.265" surface-mount package profile to provide up to 334 W/in³ power density and 2,250 V input to output isolation. At less than 50 % the size of a conventional isolated 1/16th brick, Cool-Power PI31xx converters provide exceptional performance in an IC package for use in high density system designs. Cool-Power PI31xx series converters utilize ZVS architecture and planar magnetics to enable IC-like density and greater PCB layout flexibility in space-constrained environments. The high-switching frequency (900 kHz) of PI31xx series converters reduces input filter and output capacitance requirements, further reducing space constraints.

Vincotech **(www.vincotech.com)** released a new low-inductive power module designed for applications ranging up to 400 kW such as three-phase solar inverters. This high-voltage 2xflowNPC 4w module features a higher power rating in the new wide-body housing. Its Neutral Point Clamped (NPC) topology provides maximum efficiency for higher switching frequencies. Equipped with extremely fast 1200 V components to achieve a 2400 V/800 A rating, the 2xflowNPC 4w module is destined for solar and UPS applications with up to 400 kW and a DC link of 1500 V. Its low-inductive (5nH) technology and onboard DC capacitors extend maximum PWM frequencies up to 20 kHz. The 3xflowNPC 4w comes in the new wide-body housing and is well suited for applications such as three-phase solar inverters ranging up to

Vincotech's Director of Product Marketing Werner Obermaier presented the company's new high-power NPC power modules. "Though SiC MOSFETs can reduce the complexity of 3-level inverters down to 2 levels, werely on Trenchstop 5 IGBTs and Stealth diodes for NPC"

200 kW. Rated for 1200 V/600 A, the module's inductance is asymmetrical. It achieves low turn-off inductance with integrated DC snubber capacitors and uses parasitic inductance to reduce turn-on losses, so there is no need for low-inductive busbars. This design and its onboard DC capacitors extend PWM frequencies beyond 20 kHz. A new housing size for 90° PCB mounting is called flow90 0. The first product with this new housing is flow90PACK 0 featuring 1200 V/6-35 A six-pack topology. The flow90 0 housing follows up the flow90 1 housing that Vincotech rolled out a few years ago. The idea behind this design is to mount the power module at a 90° angle to the PCB, making it much easier to connect the module to the heatsink. Regarding SiC the company will switch over to MOSFETs, possibly reducing the complexity of 3-level inverters down to 2 levels, but the Silicon solution meets the price points of the customer base today. **AS**

New Single-Channel, 2.5-A/5-A Gate Drivers for IGBTs and SiC MOSFETs

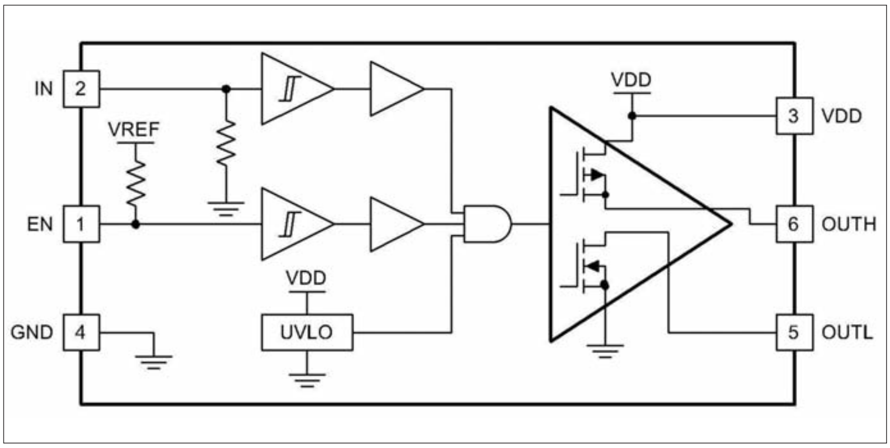
Texas Instruments recently introduced the 35-V, single-channel, output stage power management gate drivers UCC27531/32 for IGBTs and SiC FETs. Its split output provide efficient output drive capability, short propagation delay and increased system protection for isolated power designs, such as solar DC/AC inverters, uninterruptible power supplies and electric vehicle charging.

Today's renewable energy applications require power components that safely deliver more power with greater efficiency. Designers prefer to use IGBTs or the latest SiC FETs that achieve lower power loss at higher voltages. Those devices also have breakdown voltages up to 1200 V, and offer lower on-resistance than equivalent MOSFETs. They are often managed by a microcontroller or dedicated digital power controller. Next-generation IGBT- and SiC FET-based designs also require both power and signal isolation from the noisy switching environment of the power stage. The UCC27531 and UCC27532 prevent the digital controllers from operating too close to the power circuitry, extending the lifetime of isolated power designs.

More features than buffers

High-current gate driver devices such as the UCC27531 and UCC27532 are required in switching power applications for a variety of reasons. In order to enable fast switching of power devices and reduce associated switching power losses, a powerful gate driver can be employed between the PWM output of controllers or signal isolation devices and the gates of the power semiconductor devices. Further, gate drivers are indispensable when sometimes it is just not feasible to have the PWM controller directly drive the gates of the switching devices. The situation will be often encountered since the PWM signal from a digital controller or signal isolation device is often a 3.3-V or 5-V logic signal which is not capable of effectively turning on a power switch. A level shifting circuitry is needed to boost the logic-level signal to the gate-drive voltage in order to fully turn on the power device and minimize conduction losses. Traditional buffer drive circuits based on NPN/PNP bipolar, (or p- n-channel MOSFET), transistors in totem-pole arrangement, being emitter follower configurations, prove inadequate for this since they lack level-shifting capability and low-drive voltage protection. Gate drivers effectively combine both the level-shifting, buffer drive and UVLO functions. Gate drivers also find other needs such as minimizing the effect of switching noise by locating the high-current driver physically close to the power switch, driving gate-drive transformers and controlling floating

New UCC27531/32 drives IGBTs and SiC MOSFETs in demanding applications



Block diagram of UCC27531/32 gate drivers (EN Pull-Up Resistance to VREF = 500 kΩ, VREF = 5.8 V, in pull-down resistance to GND = 230 kΩ)

power device gates, reducing power dissipation and thermal stress in controllers by moving gate charge power losses into itself.

The UCC27531/32 are very flexible in this role with a strong current drive capability and wide supply voltage range up to 35 V. This allows the driver to be used in 12-V Si MOSFET, 20-V and -5-V (relative to source) SiC FET, 15-V and -15-V(relative to emitter) IGBT applications and many others. As a single-channel driver, the UCC27531/32 can be used as a low-side or high-side driver. To use as a low-side driver, the switch ground is usually the system ground so it can be connected directly to the gate driver. To use as a high-side driver with a floating return node however, signal isolation is needed from the controller as well as an isolated bias to the UCC27531. Alternatively, in a high-side drive configuration the UCC27531 can be tied directly to the controller signal and biased with a non-isolated supply. However, in this configuration the outputs of the

UCC27531 need to drive a pulse transformer which then drives the power-switch to work properly with the floating source and emitter of the power switch. Further, having the ability to control turn-on and turn-off speeds independently with both the OUTH and OUTL pins ensures optimum efficiency while maintaining system reliability. These requirements coupled with the need for low propagation delays and availability in compact, low-inductance packages with good thermal capability makes these gate drivers important components in switching power applications.

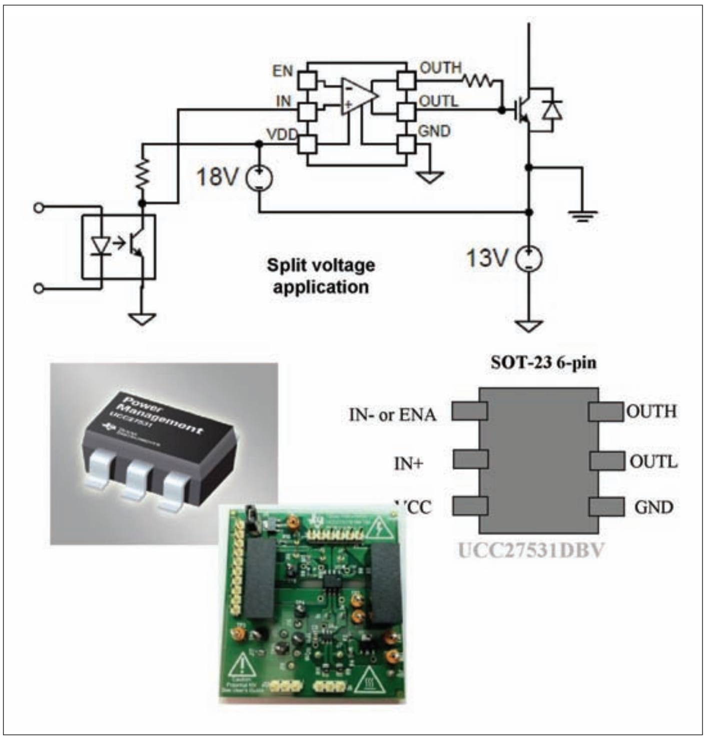
Gate driver applications

A special feature is split-output configuration where the gate-drive current is sourced through OUTH pin and sunk through OUTL pin. This pin arrangement allows the user to apply independent turn-on and turn-off resistors to the OUTH and OUTL pins respectively and easily control the switching slew rates.

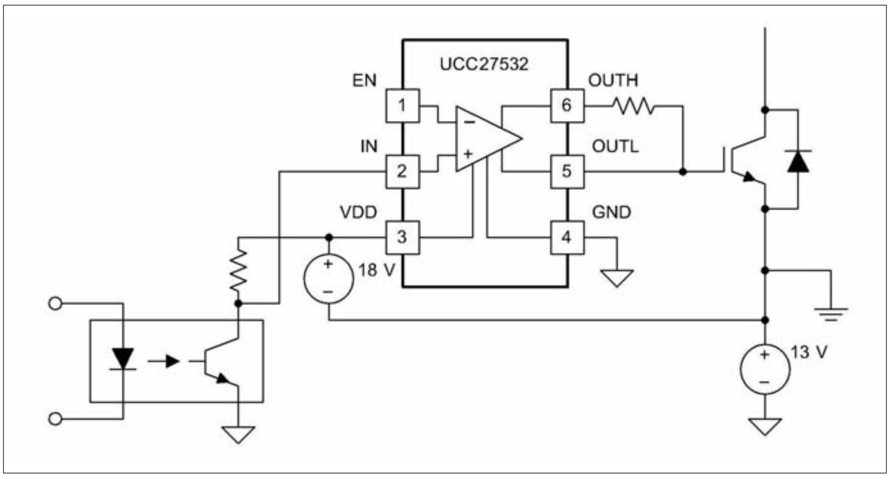
The driver has rail-to-rail drive capability and small propagation delay of typically 17 ns. The input threshold is based on TTL and CMOS compatible low-voltage logic, which is fixed and independent of the supply voltage. The 1-V typical hysteresis offers excellent noise immunity. The driver has EN pin with fixed TTL compatible threshold. EN is internally pulled up; pulling EN low disables driver, while leaving it open provides normal operation. The EN pin can be used as an additional input with the same performance as the IN pin. Leaving the input pin of driver open holds the output low. Internal circuitry on VDD pin provides an under voltage lockout function that holds output low until V_{DD} supply voltage is within operating range.

The internal under voltage lockout (UVLO) protection feature on the VDD pin supply prevents the operation of the gate driver at low supply voltages. Whenever the driver is in UVLO condition (when V_{DD} voltage less than V_{ON} during power-up and when V_{DD} voltage is less than V_{OFF} during power down), this circuit holds all outputs LOW, regardless of the status of the inputs. The UVLO is typically 8.9 V with 700-mV typical hysteresis. This hysteresis helps prevent chatter when low V_{DD} supply voltages have noise from the power supply and also when there are droops in the V_{DD} bias voltage when the system commences switching and there is a sudden increase in I_{DD}. The capability to operate at voltage levels such as 10 V to 32 V provides flexibility to drive Si MOSFETs, IGBTs, and emerging SiC FETs.

The input pin is based on a standard CMOS compatible input threshold logic that is dependent on the V_{DD} supply voltage. The input threshold is approximately 55 % of VDD for rise and 45 % of V_{DD} for fall. With 18-V V_{DD}, typical high threshold = 9.4 V and typical low threshold = 7.3 V. The 2.1-V hysteresis offers excellent noise immunity compared to traditional TTL logic implementations, where the hysteresis is typically less than 0.5 V.



Split voltage application showing also driver device and daughter card



Driving IGBT with 13-V negative turn-off bias

For proper operation using CMOS input, the input signal level should be at a voltage equal to VDD. Using an input signal slightly larger than the threshold but less than V_{DD} for CMOS input can result in slower propagation delay from input to output for example.

The drivers also features tight control of the input pin threshold voltage levels which eases system design considerations and guarantees stable operation across temperature. The very low input capacitance, typically 20 pF, on these pins reduces loading and increases switching speed.

The devices features an important safety function wherein, whenever the input pin is in a floating condition, the output is held in the low state. This is achieved using GND pull-down resistors on the non-inverting input pin (IN pin), as shown in the device block diagram.

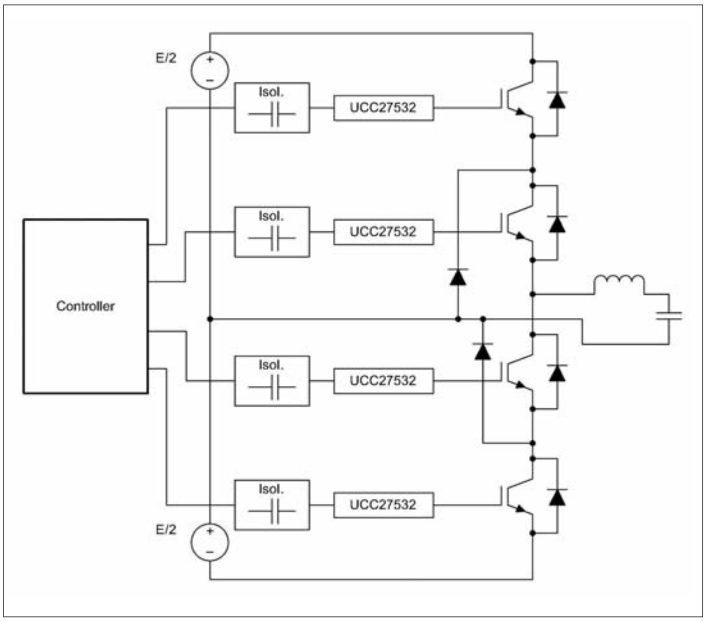
The input stage of the driver should preferably be driven by a signal with a short rise or fall time. Caution must be exercised whenever the driver is used with slowly varying input signals, especially in situations where the device is located in a separate daughter board or PCB layout has long input connection traces.

If limiting the rise or fall times to the power device to reduce EMI is necessary, then an external resistance is highly recommended between the output of the driver and the power device instead of adding delays on the input signal. This external resistor has the additional benefit of reducing part of the gate charge related power dissipation in the gate driver device package and transferring it into the external resistor itself.

The Enable (EN) pin has an internal pull-up resistor to an internal reference voltage so leaving Enable floating turns on the driver and allows it to send output signals properly. If desired, the Enable can also be driven by low-voltage logic to enable and disable the driver.

The output stage features a unique architecture which delivers the highest peak source current when it is most needed during the Miller plateau region of the power switch turn-on transition (when the power switch drain/collector voltage experiences dV/dt). The device output stage features a hybrid pull-up structure using a parallel arrangement of N-Channel and P-Channel MOSFET devices. By turning on the N-Channel MOSFET during a narrow instant when the output changes state from low to high, the gate driver device is able to deliver a brief boost in the peak sourcing current enabling fast turn on.

The UCC27531 and UCC27532 gate drivers are available in a 6-pin, SOT-23 package and are priced at $0.75 in quantities of 1,000. The UCC27531EVM-184 IGBT driver daughter card evaluation module is priced at $49. A PSpice model and application note 35-V single-channel gate drivers for IGBTs can help speed design time.



Using UCC27531 drivers in an inverter

www.ti.com/ucc27531-pr

Power GaN Opens New Applications

Efficient Power Conversion Corporation (EPC) has been in production with enhancement mode GaN-on-Silicon power transistors (eGaN® FETs) for over three years. Much progress has been made improving device performance and reliability. There have also been several new power management applications that have emerged. Two of these applications, RF Envelope Tracking and high frequency Wireless Power Transmission are beyond the fundamental capability for the aging power MOSFET due to the requirements of high voltage, high power, and high frequency. As a result, these are early growth markets for GaN on Silicon devices. eGaN FETs have also made inroads in several other applications that we will discuss along with the latest in device technology and future direction for both discrete and GaN ICs. **Alex Lidow, Johan Strydom, David Reusch, Michael de Rooij, Efficient Power Conversion Corp., El Segundo, USA**

For Silicon power devices, the gains in performance have slowed as the technology has matured and approached its theoretical limits. Gallium nitride (GaN) devices have emerged as a possible replacement for Silicon devices in various power conversion applications and as an enabler of new applications not previously possible. GaN devices are a high electron mobility transistor (HEMT) with a higher band gap, electron mobility, and electron velocity than Silicon and Silicon Carbide devices [1]. These material characteristics make the GaN device more suitable for higher frequencies and higher voltage operation.

The first commercially available enhancement mode Gallium Nitride on Silicon transistors (eGaN FETs) have a lateral structure with voltages ranging from 40-200 V. These devices operate similarly to the traditional Si MOSFETs and offer superior power conversion performance. As GaN technology matures, significant performance gains and higher blocking voltages are projected.

Wireless power application

Wireless power applications are gaining popularity in many applications such as mobile phone chargers, medical equipment, and defense electronics. Most of the wireless power solutions have focused on tight coupling with induction coil solutions at operating frequencies around 200 kHz, and Class E, F and S converter topologies. Recently, however, there has been a push for operation in the restricted and unlicensed lower ISM band at 6.78 MHz where traditional MOSFET technology is approaching its capability limit. Enhancement mode GaN devices offer an alternative to MOSFETs as they can switch fast enough to be suited for such wireless power applications. To illustrate the opportunity to improve efficiency, an experimental evaluation was performed for an induction coil wireless energy system using eGaN FETs in a half-bridge topology operating at 6.78 MHz designed to be suitable for multiple 5 W USB-based charging loads (Figure 1). The experimental system was compared to a similar unit based on equivalent MOSFETs in the power converter stage.

Switching-based converters are required for wireless power applications because classic amplifiers do not have sufficient conversion efficiency to make them practical choices. This reduces the number of suitable converter choices for high efficiency wireless energy applications to Class D, Class E & F and Class S configurations. The amplifier selected was a Class D converter operating at a fixed frequency. The converter is operated above the resonant frequency to take advantage of zero-voltage switching (ZVS) and therefore obtain maximum power amplifier efficiency. The smallest 40 V eGaN FET, EPC2014, was chosen because it has a low on-state resistance and low C) which are factors that will ensure minimum losses.

A demonstration unit was designed and built to evaluate the performance of both the eGaN FET and the MOSFET. Using eGaN FETs in the power amplifier yields a 4 % amplifier efficiency improvement over the MOSFET version (a 24% reduction of power losses).

Envelope tracking application

The concept of envelope tracking (ET) for radio frequency (RF) amplifiers is not new. But with the ever increasing need for improved cell phone battery life, better base station energy efficiency, and more output power from very costly RF transmitters, the need for improving the RF Power Amplifier (PA) system efficiency through ET has become an intense topic of research and development.

The key to improve efficiency lies in the

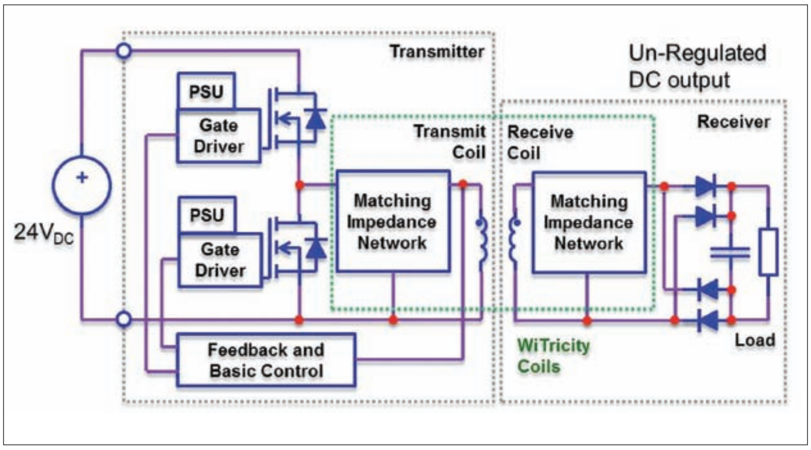


Figure 1: Schematic block diagram of the evaluated wireless energy system

PA's peak to average power (PAPR) requirements. As shown in Figure 2 it is possible to achieve peak PA efficiencies as high as 65 % with a fixed supply, but given PAPRs as high as 10 dB, the average efficiency is likely to be lower than 25 %. Through modulation of the PA supply voltage, this can be improved to over 50 % - essentially doubling the efficiency and reducing PA losses by two thirds. This not only reduces power consumption, but also lowers the cost of operation, cooling requirements, and size.

The high PAPR requirements that make ET possible also mean that average output voltage is typically between 30 – 50 % of the buck converter supply voltage, with short duration excursions below and above this average. Thus, for demonstration purposes a steady state buck converter running at a similar duty cycle can be used to demonstrate the efficiency and thermal requirements of a multi-phase ET buck converter. This can be further simplified by evaluating a single phase of a multi-phase system, as all phases are identical. Standard EPC9002 or EPC9006 development boards were used to generate all the results in this work.

Efficiency results for both converters are shown in Figure 3 and show that building a buck converter for high power envelope tracking applications is viable using eGaN FETs. The actual power level and number of phases required will depend on the power level and bandwidth requirements of the specific application. Over 97 % efficiency was achieved at 1 MHz and over 94 % efficiency was achieved at 4 MHz.

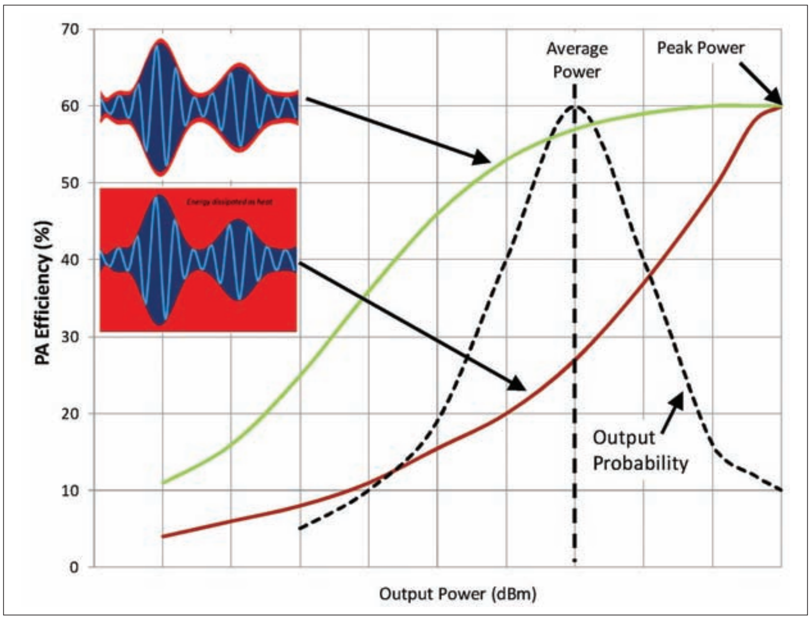


Figure 2: Conceptual PA efficiency vs. output power for fixed supply and ET operation

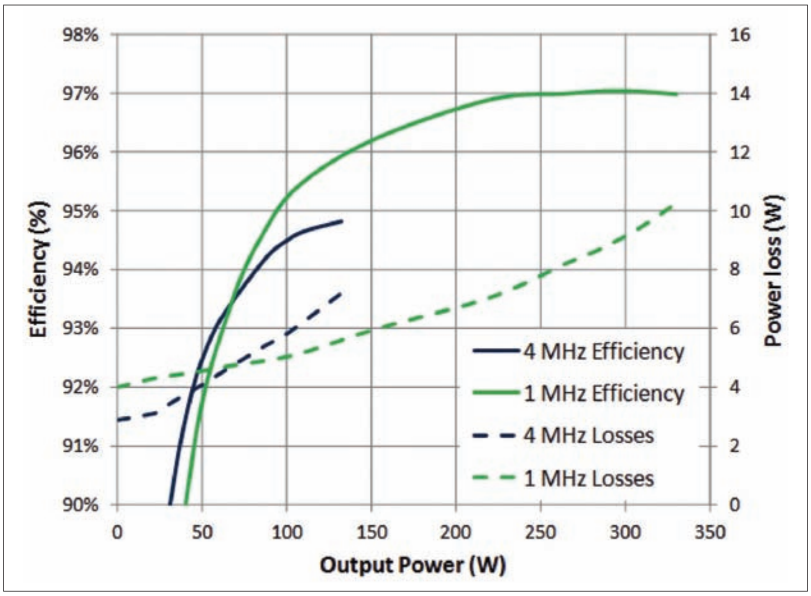


Figure 3: Efficiency results for EPC9006 and EPC9002 demonstration boards in ET application operating at 45 V input and 22 V output voltage

Resonant converter application

To achieve improved efficiency at higher switching frequencies, resonant topologies may be considered. Resonant topologies are particularly beneficial in DC/DC transformer applications due to the removal of the regulation requirements, allowing the converter to always operate at the resonant frequency. To demonstrate the opportunities enabled by converting from Silicon-based power MOSFETs to enhancement mode GaN devices, we chose the topology as shown in Figure 4 that employed a resonant technique utilizing the transformer's magnetizing inductance (L_M) and resonance of the leakage inductance (L_K), together with a small output capacitance (C_O), to achieve zero voltage switching (ZVS), limit turn-off current, and eliminate body diode conduction.

To obtain a direct comparison in performance between GaN devices and Si MOSFETs in a high-frequency resonant bus converter application, devices with similar on-resistance were selected, the same circuit topology was used, and a similar layout was maintained for both designs. The Figures of Merit (FOM) of importance in this work are Q_G x $R_{DS(ON)}$ and Q_{OSS} x $R_{DS(ON)}$ due to the soft switching topology that reduces the switching related losses, thereby rendering the FET gate drive and conduction being the major loss contributors. The device's output charge has a direct impact on the energy required to achieve ZVS. A reduction in energy required to achieve ZVS can result in reduced dead time, providing a larger power delivery period and lower RMS currents in a high frequency resonant converter.

These FETs show significant improvements when compared to Si MOSFETs, with the gate drive FOM (QG x RDS(ON)) improved by a factor of approximately 4 and 3 for the 100 V and 40 V devices respectively, while the output charge FOM (Q_{OSS} x $R_{DS(ON)}$) is improved around a factor of 1.6 and 2 for the primary and secondary devices respectively. They also provide performance improvements in the form of reduced Miller charge that reduces the turn-off switching losses in the primary devices. As a further advantage, the land grid array (LGA) packaging has low parasitic package inductance as compared to the traditional Si MOSFET package (TSDSON-8, 5x6 mm). When putting all these benefits together, multi-MHz switching frequencies can be obtained through the use of advanced topologies combined with low-loss eGaN FETs.

Due to almost a factor of 2 decrease in output charge (Q_{OSS}) provided by the primary and secondary eGaN FETs, the ZVS transition is achieved in a proportionally shorter period, increasing the effective duty cycle and improving the overall converter performance. With the faster switching eGaN FETs, the dead time was reduced to 42 ns resulting in a 42 % duty cycle for each device while allowing for an extended power delivery period.

Radiation tolerance

Enhancement-mode FETs have also demonstrated their ability to operate reliably under harsh environmental conditions and high radiation conditions. Normal operation can be maintained after more than 1 MRad(Si) gamma radiation exposure and have also shown the ability to perform to data sheet specifications after substantial single event effects (SEE). As a result, both hard-switched and resonant topologies with very high efficiency, such as those discussed herein, can be used in satellites as well as other applications requiring these extreme conditions.

Conclusion

It has been previously shown that Gallium Nitride devices have a distinct advantage over Silicon MOSFETS in conventional applications, but little has been demonstrated about the impact of GaN devices in emerging applications such as envelope tracking and soft switching converters which are commonly used in wireless power and high frequency intermediate DC/DC bus converters. In this work, it is shown that eGaN FETs can also provide significant efficiency improvements over power MOSFETs in these emerging applications. Putting eGaN FETs to work in high frequency applications can help push the frequency without sacrificing converter performance, even in very demanding environments [2].

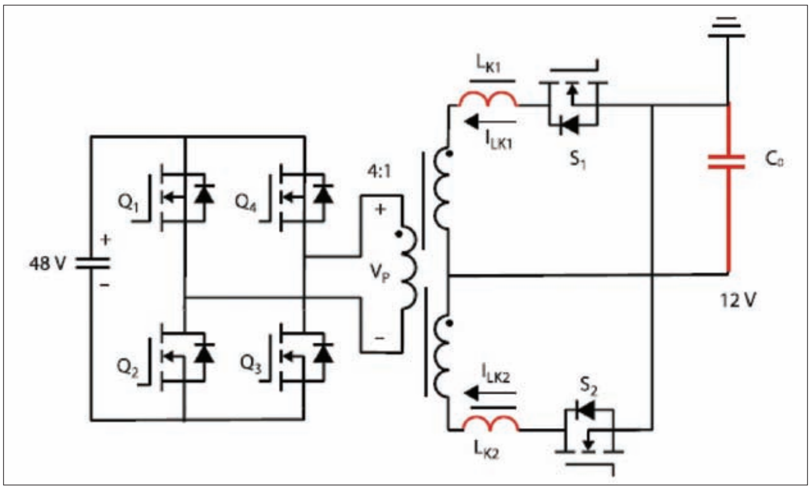


Figure 4: **High frequency bus converter schematic**

Literature

[1] "GaN Transistors for Efficient Power Conversion", Power Electronics April/May 2013, pages 38-40

[2] "GaN on Silicon Technology, Devices and Applications", PEE Special Session Power GaN for Highly Efficient Converters, PCIM Europe 2013, Nuremberg

Progress in Silicon-Based 600 V Power GaN

The readiness of 600 V GaN-on-Si based power devices fabricated using the GaNpowIR® technology platform for large scale production is presented in this article. The advantages of such devices over the Silicon incumbent alternatives in several common power conversion application circuits is also shown.

Michael A Briere, ACOO/International Rectifier, Scottsdale, USA

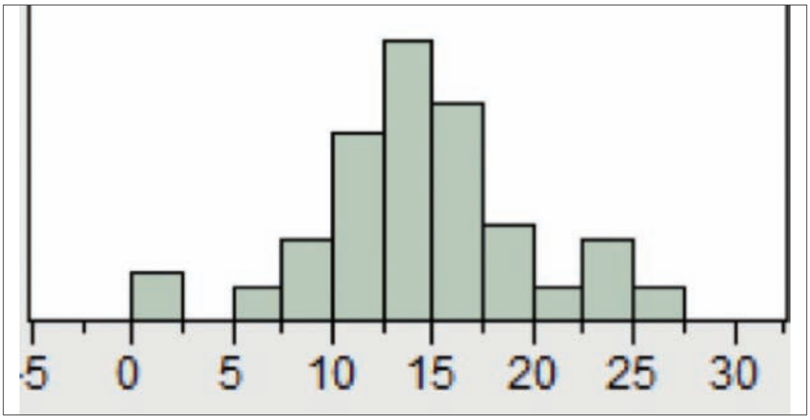


Figure 1: Measured distribution of final wafer bow for over 20 multi-wafer process runs producing more than 60 crack free 2.25 µm thick AlGaN alloys based hetero-epitaxy on 200 mm standard thickness (725 µm) Silicon substrate

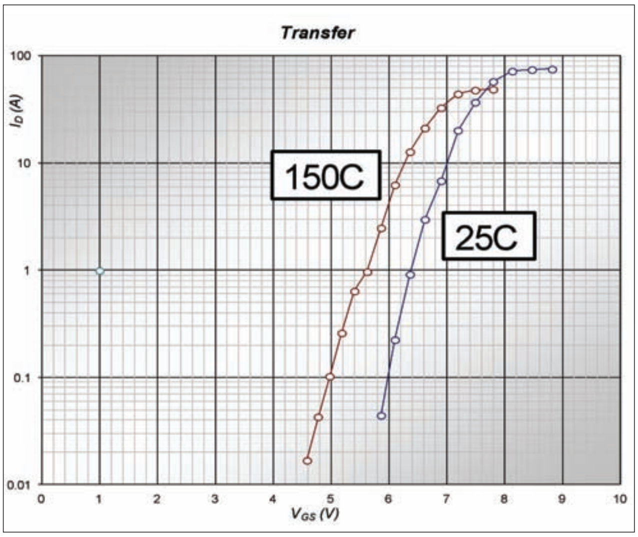


Figure 2: Measured transfer characteristics of a 600 V rated GaN-on-Si based HEMT with an active area of 8 mm? and a gate width of 330 mm, cascoded with a low voltage Silicon FET, in a dual sided cooled package, at room temperature and 150°C

It has been well documented that the advent of high voltage GaN based power devices provides unprecedented opportunities to reduce both conduction (R_{dson}) and switching losses (Q_{sw}) in a wide variety of power conversion circuits. The combination of hetero-epitaxy using Silicon substrates and device fabrication along side Silicon CMOS products in high volume factories provides the necessary cost structure to compete commercially with Silicon based alternatives.

The capability to grow thick crack free AlxGayN alloys on standard thickness Silicon substrates in manufacturing volumes has often been underestimated either as an essential element to commercialization of GaN based power devices or as a significant technological hurdle when moving from non-commercially viable substrates such as SiC. In the ranking of required capabilities to successfully compete in the commercialization of GaN based power devices, such capability, together with supporting intellectual property should be considered the most important. As such, IR has previously demonstrated the manufacturability of up to 5 µm thick AlxGayN epitaxy on standard thickness 150 mm Si substrates. In addition, Figure 1 shows the manufacturability of low distortion crack-free GaN on Si epitaxy for 2.25 µm thick films on standard thickness (725 µm) 200 mm diameter Silicon substrates.

The use of such substrates is essential to achieve commercial viability of the technology platform. These results are made possible through the use of IR's proprietary compositionally graded transition layer III-N on Si epitaxial technology. Another essential requirement for commercialization is the ability to produce devices alongside the incumbent high volume silicon based power devices. In addition to the use of standard photolithographic and plasma and wet chemical process technologies, this requires the elimination of Gold based ohmic contacts. In this regard, IR was the first to reproducibly demonstrate sufficiently low ohmic contact resistances (< 0.35 ohm-mm) in volume production.

Enhancement mode not required

Further, it is often stated that development of an enhancement mode GaN based high electron mobility transistor (HEMT) is an essential element of commercialization. This is not a valid assertion. Besides the opportunity to use depletion mode, normally-on devices in a majority of power electronic circuits (using DC enable switch based topologies), several topologies such as AC/AC converters used for motor drive actually are superior when implemented with the inherently bi-directional capable depletion mode GaN based HEMT devices, In addition, the inherent instability of the two dimensional electron gas (2DEG) to positive applied fields which collapse the built in barrier potential of the AlGaN barrier layer (in AlGaN-GaN HEMTs) presents a severe crippling restriction of gate drive to

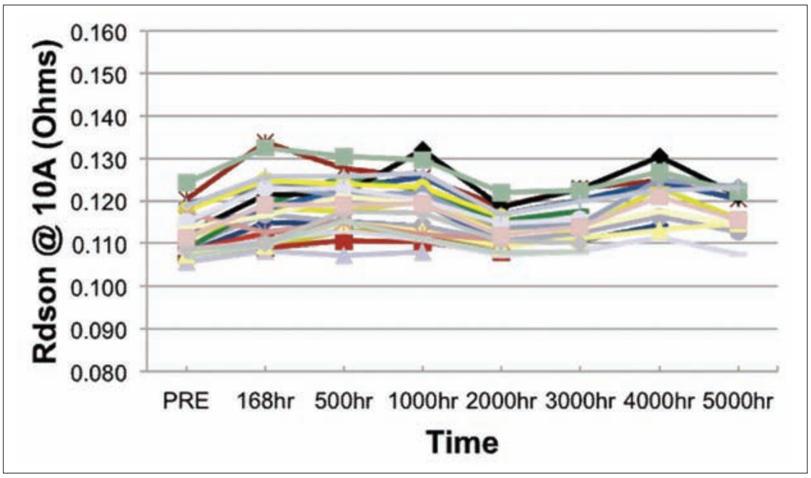


Figure 3: **Source-drain resistance of 600 V rated cascode switch for a population of representative cascoded GaN-on-Si based HEMT devices with W_g = 120 mm, under a drain bias of 480 V and 0 V gate bias for 5000 hrs at 150°C**

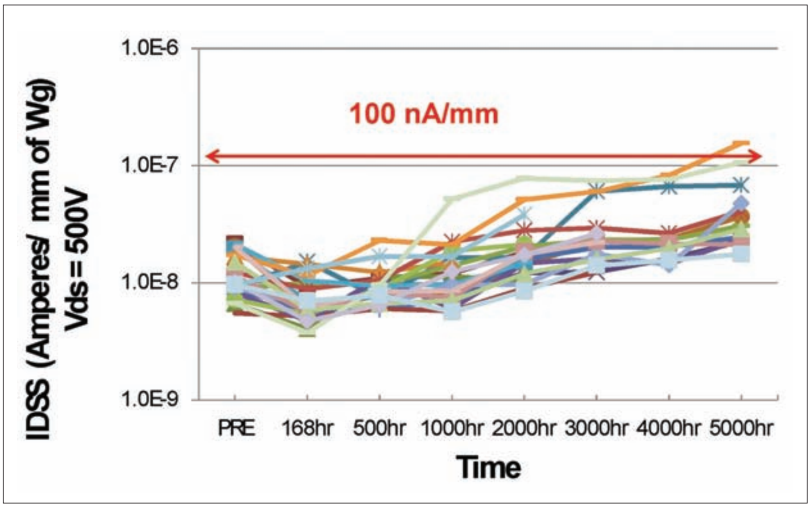


Figure 4: **Source to drain leakage current measured with 500 V drain bias and 0 V gate bias of 600 V rated cascode switch for a population of representative cascaded GaN-on-Si based HEMT devices with W_g = 120 mm, under a drain bias of 480 V and 0 V gate bias for 5000 hrs at 150°C**

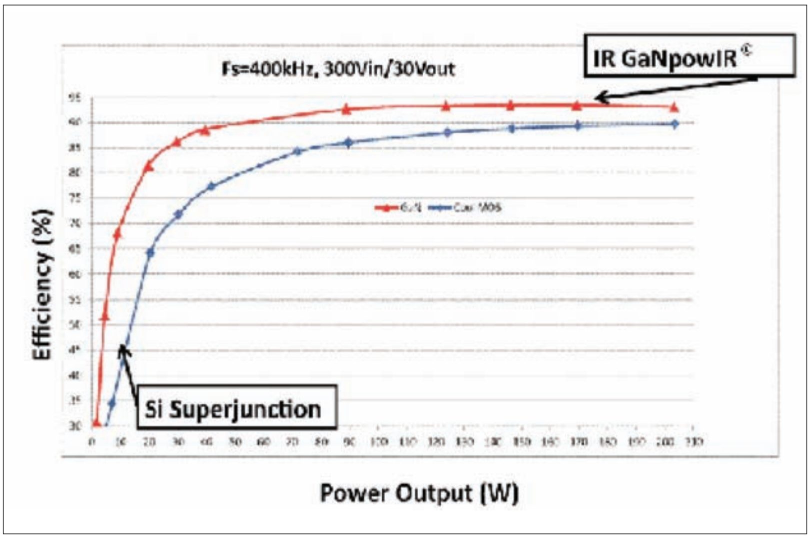


Figure 5: **Measured conversion efficiency for a resonant LLC converter with 300 V input and 30 V output voltage operating at 400 kHz, using either IR's GaNpowIR® based devices on both the primary (600 V rated) and secondary side (100 V rated) of the transformer (with synchronous secondary side rectification) or state-of-the-art Silicon alternatives**

any enhancement mode barrier based 2DEG device, through the limitation of applied overdrive gate voltage above threshold.

Of course, the addition of voltage clamps, e.g. in intimately coupled gate drive circuitry, can be used at the expense of increased effective gate capacitance, leakage currents and cost. Therefore, in the cases where normally-off behavior is preferred, the cascoded configuration, using a low voltage MOSFET, is recommended. In addition to providing a well established and reliable gate drive interface for external circuits, this approach has many advantages not found in an enhancement mode GaN based power device. When properly configured, one such advantage is the effective HEMT gate drive current capability afforded by the milli-ohm level low voltage cascode device on-resistance, compared to 0.2 to 1 Ω resistance found in commercial driver ICs.

In addition, the effective overdrive capability of the cascoded HEMT is the voltage between V_{pinch} and ground, often about 6-12 V. This is compared to the 2-4 V of overdrive available to a standard clamped enhancement mode GaN based HEMT. This internal gate drive configuration maintains the HEMT gate in the optimal voltage range of $-V_a$ to ground, where V_a is limited by the avalanche clamped breakdown voltage of the low voltage MOSFET. In addition to improved power device performance, the cascode based gate drive configuration reduces hot carrier induced degradation through beneficial barrier potential between the 2DEG and the gate structure, as opposed to the decreased barrier inherent to positive voltage HEMT gate overdrive.

Circuit performance and reliability

In addition to inherent and revolutionary integratability, the lateral GaN based (HEMTs) exhibit advantages of significantly lower terminal capacitances, several times lower specific source-drain resistance and essentially zero reverse recovery charge compared to either Silicon based Superjunction FETs or IGBT alternatives. It is shown that the often feared current handling capability limitation associated with the lateral nature of the HEMTs can be effectively addressed through the use of front side solderable devices and dual sided surface mount packaging techniques. Current handling densities of more than 500 A / cm^2 at 150°C are demonstrated with 600 V rated devices capable of processing more than 80 A at room temperature. Figure 2 shows the measured normally-off transfer characteristics for such a device, in a cascaded configuration with a low voltage Silicon FET.

The establishment of simultaneous long-

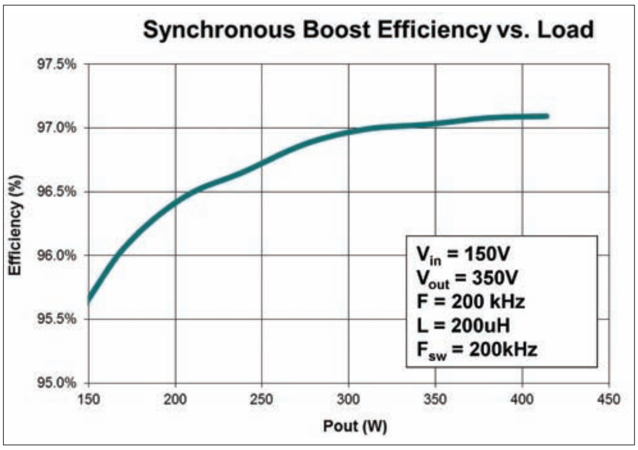


Figure 6: Measured conversion efficiency for synchronous boost power factor correction front end of an AC/DC converter using GaNpowIR® based devices for both switches

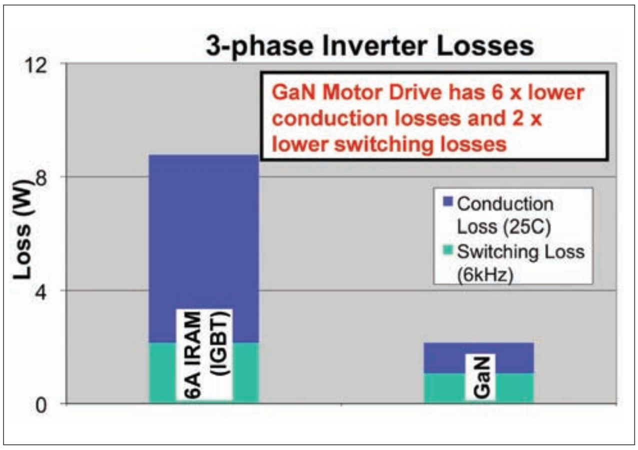


Figure 7: Measured conversion efficiency for nominally 500 W motor drive inverter using either GaNpowIR based devices or IGBTs (I_c = 1.5 A, V_{bus} = 300 V, V_{out} = 160 V, P_{out} = 415 W, T_c = 150°C)

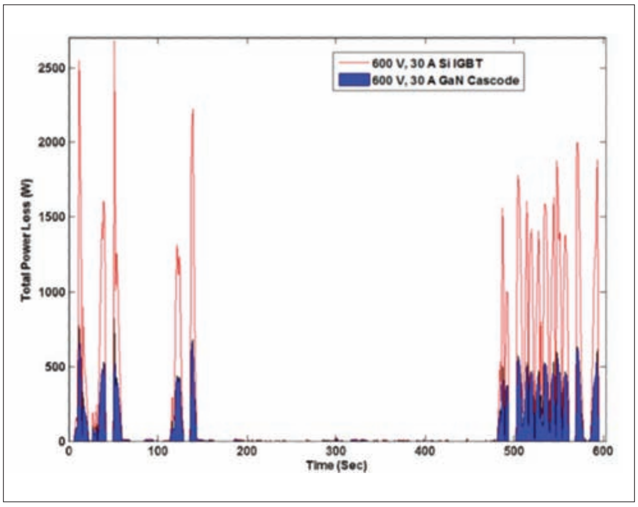


Figure 8: Modeled inverter power loss over the system power processing model for electric propulsion US-06, for a nominally 60 kW motor drive inverter, comparing the expected performance based on device and circuit models for Si IGBTs and diodes and 600 V rated GaNpowIR cascoded switches

term reliability and device robustness RBSOA (including dynamic R_{dson} effects) and FBSOA in application conditions is essential for the adoption of any power device technology. Figures 3 and 4 show some early results demonstrating exemplary stability for such devices under 480 V drain to source reverse bias stress for 5000 hours.

Application performance

These 600 V rated GaN-on-Si based devices have been tested in several widely used power conversion topologies. Figure 5 shows the improved conversion efficiency for a 300 V to 30 V LLC resonant converter operating at 400 kHz, exhibiting remarkably improved efficiency (> 17 %) at light loads and > 3 % improvement at full load conditions. Figure 6 shows the performance of a GaN based synchronous boost converter for application in a power factor correction front end of an AC/DC converter. Though the replacement of the boost diode with a GaN based power device in a synchronous boost converter circuit was first presented in the issued US patent number 7276883, filed in August 2004 assigned to IR, only now are the requisite 600 V devices available to make this circuit commercially available. Note that such a circuit would be impractically expensive if implemented with SiC MOSFETs or JFETs.

One of the most wide-spread applications for 600 V rated devices is in the inverter drive circuitry for motors. It is therefore important to assess the value provided by GaN based power devices in motor drive applications. Two of the largest potential volume applications are appliances and electric or hybrid electric vehicles. Figure 7 shows the drastic improvement in power loss in a nominally 400 W motor drive inverter circuit, using IGBTs and first generation 600 V GaN cascoded switches. As can be seen the conduction losses are reduced by a factor of 6, while at the same time the switching losses are reduced by a factor of 2. This remarkable result is based on the 4-10 x improvement in the V_{ceon} x E_{sw} (or R_{dson} x Q_{sw}) improvement in the performance figure of merit (FOM) of the GaN based devices over the Silicon based IGBTs previously reported. Such improvements in power handling capability allow for the related increase in the inverter power density of a factor of more than 10. In this instance, taking into account that the GaN based inverter does not require the heat sink of the IGBT-based inverter, the power processing volume density is actually increased by more than 100. Such improvements in power processing efficiency and density are examples of the potential of GaN based power devices to transform power electronics.

Another example is shown in Figure 8 for a nominally 60 kW inverter drive for an electric vehicle propulsion system. This work was the result of cooperation between International Rectifier, Delphi Automotive Systems and Oak Ridge National Laboratory, funded through a grant by US Department of Energy through ARPA-e. As can be seen the modeled performance of a state-of-the-art Silicon based inverter is compared to that of a GaNpowIR based inverter using a simulated drive cycle/power schedule known as US-06. The results are based on the extracted device models of measured high current devices, such as those shown in Figure 2 and leveraging the performance of dual sided cooled packaging developed at Delphi known as VIPER. The GaN based inverter exhibits an approximately 50 % reduction in power loss with a coolant temperature of 105°C.

Literature

"The Status of 600 V GaN on Si based Power Device Development at International Rectifier", PEE Special Session Power GaN for Highly Efficient Converters, PCIM Europe 2013, Nuremberg

Silicon Carbide Boost Power Module Performance

Silicon Carbide offers new approaches for the design of power semiconductors. In conventional power Silicon technology, IGBTs are used as switches for voltages higher than 600 V, and Silicon PIN freewheeling diodes are state of the art. The design and soft switching behavior of Silicon power devices cause considerable power losses. With the larger bandgap of Silicon Carbide, high-voltage MOSFETs can be designed with blocking voltages up to 15 kV, while providing extremely low dynamic losses. With Silicon Carbide, the conventional soft turn-off Silicon diodes can be replaced by diodes in Schottky design, also offering extremely low switching losses. As an additional benefit, Silicon Carbide has a 3 times higher thermal conductivity as compared to Silicon. Together with small power losses, Silicon Carbide is an ideal material to boost power density in power modules. **Volker Demuth, Head of Product Management Components, SEMIKRON, Nuremberg, Germany**

It is been a long way for Silicon Carbide (SiC). I remember purchasing 2-inch SiC wafers for crystal defect analysis at the university in the mid 90's at unbelievable prices. In fact, those were "science grade" wafers, as "industrial grade" wafers were even more expensive. The defects were a nightmare for crystal growers and device manufacturers: high defect density and hollow tubes in crystal growth direction, that would show as holes in the SiC wafers after cutting. More than 15 years later, the SiC industry moves to 6-inch wafer production as a standard, and by intelligent growing techniques, the crystal defects are reduced to a minimum, increasingly making SiC an alternative to standard Silicon devices in power electronics. And the future looks promising. In some markets, such as solar, SiC devices are already in operation despite the fact that the prices for those modules are still higher by factors as compared to conventional Silicon devices. Current designs are available in SiC hybrid modules (IGBT + SiC Schottky diodes) and full-SiC modules.

SiC hybrid modules

In SiC hybrid modules, a conventional IGBT is switched together with a SiC Schottky diode. Although the main benefits of SiC devices are clearly related to low dynamic losses, the static losses of SiC Schottky diodes are discussed first.

Oftentimes, the static losses of SiC devices seem to be higher compared to conventional Silicon devices. Figure 1 shows the forward voltage drop Vf of a conventional soft switching 600 V SEMIKRON CAL HD freewheeling diode, a Fast Silicon diode optimized for low switching losses and a SiC Schottky diode, all rated at 10 A.

At rated current of 10A, the Silicon freewheeling diode reveals the lowest forward voltage drop, the V_f of the SiC Schottky diode is higher, whereas the Fast Si diode shows the highest forward voltage drop. The temperature dependence of the forward voltage is quite different: the Fast Silicon diode has a negative temperature coefficient, as V_f is lower at 150°C than it is at 25°C. The temperature coefficient of the CAL is positive for currents above 12 A and the SiC-Schottky diode, as characterized by positive temperature coefficient even for currents as low as 4 A.

Since diodes are often paralleled to achieve high power devices, a positive temperature coefficient is required to avoid unbalanced current sharing and inhomogeneous operation temperature of the paralleled diodes. Here the SiC Schottky diode shows the best behavior. But compared to the conventional Silicon diode, the static losses are higher for the SiC Schottky. As the diodes were compared based on the nominal current of 10A, it is important to take into account that the definition of nominal currents is sometimes unequal between devices by different suppliers. To gain better insight to device performance, it is useful to the plot the current density (forward current divided by chip area) as a function of the forward voltage drop, which takes into account the chip area. Figure 2 shows that for equivalent current densities, the conventional Silicon and SiC Schottky

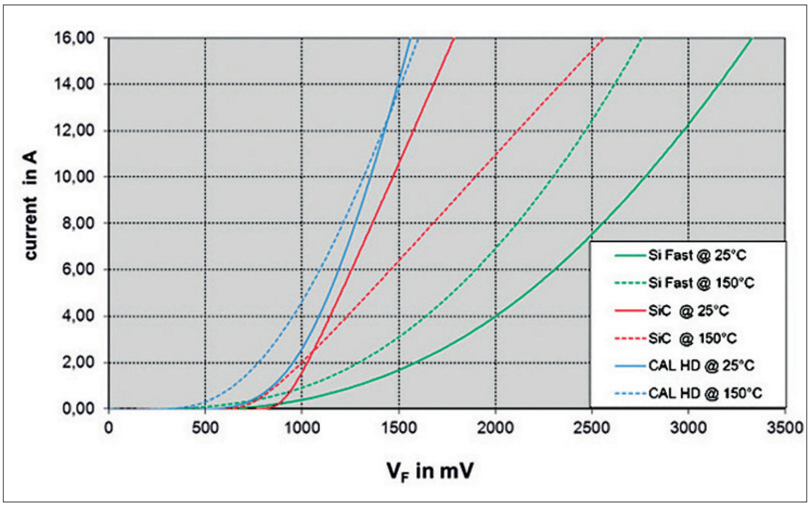


Figure 1: Forward current and forward voltage drop of different 10 A freewheeling diodes at 25°C and 150°C (SiC Schottky diode, soft switching Silicon diode (CAL HD), and fast Silicon diode (Si-Fast))

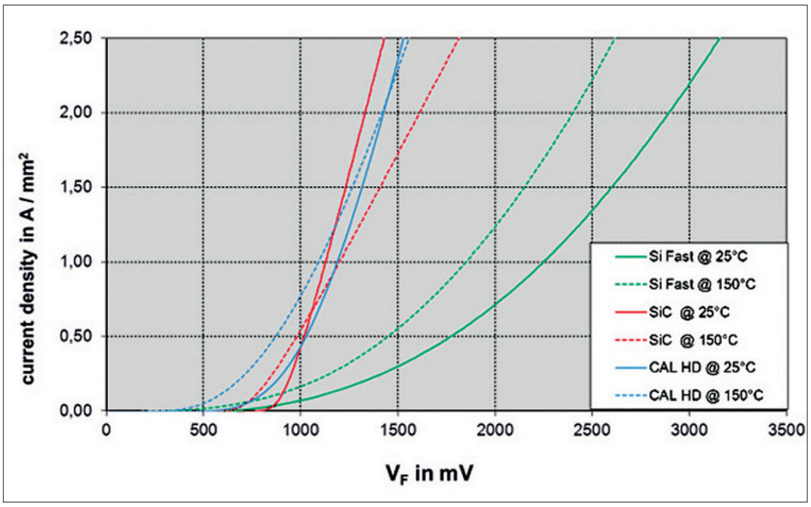


Figure 2: Forward voltage drop and current density (forward current divided by chip area) of the diodes in Figure 1

diode have quite similar forward voltage drops, whereas the V_f of the Fast Si diode is still highest. In other words: Silicon and SiC diodes have comparable static losses, as identical chip areas are used. Usually SiC chips exploit smaller chip sizes, as the nominal current rating is done considering static and dynamic losses, causing low total losses, and therefore allow a chip size shrink. Looking at the dynamic losses, the main benefit of SiC devices becomes clear (see Table 1).

Compared to the conventional Silicon diode, the reverse recovery current IRRM is more than 50 % lower for the SiC Schottky diode, the reverse recovery charge Q_{RR} drops by a factor of 14 and the turn-off energy E_{off} is lower by a factor of 16. The Si Fast diode shows better characteristics than the conventional Silicon diode, yet it does not reach the superior dynamic characteristics of the SiC Schottky diode. Due to the low dynamic losses of SiC Schottky diodes, the inverter losses can be reduced significantly, saving expenses for cooling and increasing the power density of the inverter. In addition, the low dynamic losses make the SiC Schottky diodes ideal for high switching frequencies.

On the other hand, fast-switching freewheeling diodes may come with a drawback, as the very steep decrease of the reverse current may lead to a current cut-off and oscillations. In the case of Silicon diodes, the current cut-off is controlled by soft turn-off characteristics. Figure 3 compares the turn-off characteristics of the CAL HD and the SiC Schottky freewheeling diodes.

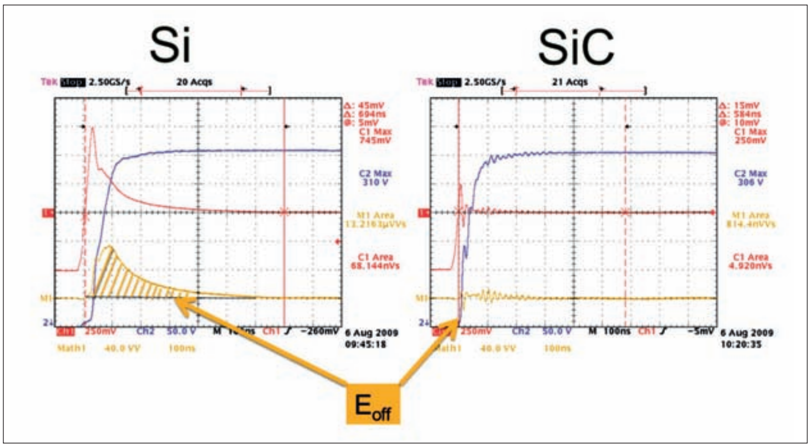
With the Silicon-based CAL HD diode, the well-known soft turn-off behavior is observed. As the reverse current is reduced smoothly, no over-voltage peaks nor oscillations are visible. On the other hand, the soft turn-off behavior causes a significant turn-off energy, because a considerable reverse current is flowing as the voltage at the diode rises. The SiC Schottky diode basically does not show any reverse recovery charge, and consequently an extreme low turn-off energy. Due to the rapid decrease of the reverse current, small oscillations are induced, visible as ripples in the reverse current and in the voltage drop. In our case, the fast turn-off behavior of the SiC Schottky diode was addressed by an optimized chip layout on the DCB and a low stray inductance of the module. Consequently, the voltage oscillations are small and do not lead to significant over-voltage peaks. It is therefore possible to manage the disadvantages of fast-switching diodes and fully exploit the benefits of SiC Schottky diodes by optimized module designs. In Figure 4 the advantage of the SiC diodes is shown by comparison of a conventional Silicon module and a SiC hybrid module equipped with fast Silicon IGBTs and SiC Schottky diodes.

As expected, the superior dynamic behavior of the SiC Schottky diodes increases the output power of the module significantly. With the given chip setup, which was chosen for optimum performance at higher switching frequencies, the usable output current can be increased by more than 70 % at 30 kHz. As the switching frequency rises further, the benefit of the hybrid SiC module is even larger.

The lower losses and the resulting higher power output on module level can be exploited on several ways. Weight and volume of inverters can be reduced significantly, important for example for automotive and aerospace applications. Exploiting high switching frequencies smaller LC-filters are possible, reducing

Table 1: Dynamic parameters of a conventional Silicon freewheeling diode (CAL HD), a SiC Schottky diode and a Fast Silicon diode (1200 V, 10 A rating)

	CAL HD	SiC	Si-FAST
	V_R = 300 V, I_F = 10 A, T_J = 150°C		
di/dt in A/µs	750	700	750
I_{RRM} in A	14,9	5,0	8,2
Q_{RR} in µC	1,36	0,098	0,226
E_{off_D} in mJ	0,264 ← x 16	0,016	0,024



LEFT Figure 3: Turn-off characteristics of Silicon and SiC freewheeling diodes. The turn-off energy of the SiC diode is barely visible. As the turn-off energy of the SiC diode is small, the reverse current drops rapidly, leading to small oscillations in reverse current and voltage

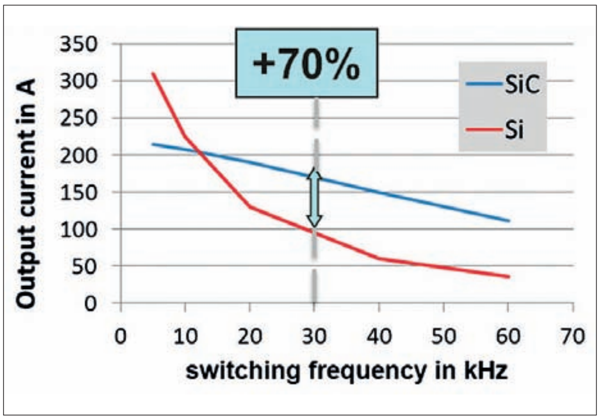


Figure 4: Output current of a conventional Silicon 6-pack module (1200 V, 450 A trench IGBT + CAL freewheeling diode) and a SiC hybrid 6-pack module (1200 V, 300 A Fast IGBT + SiC Schottky). Thermal loss calculation of SKiM93 modules on water cooler

		25A IGBT 6-pack Mini-SKiiP 13AC12T4	20A Full-SiC 6-pack Mini-SKiiP 13ACM12V15
V_{CE}	20A, 150°C	1,8V	2,1 V
E_{ON}	150°C, 20A, 600V	2,7mJ	0,9mJ
E_{OFF}		1,9mJ	0,3mJ

Table 2: Static and dynamic losses of a 1200 V, 25 A IGBT module (trench IGBT + CAL diode) in comparison to a 20 A full SiC module (SiC MOSFET + SiC Schottky)

size and inverter cost. Last but not least, the lower losses cause also an significant advantage in energy efficiency, important for solar, UPS, and automotive applications.

Full SiC modules

Using SiC switches like SiC MOSFETS the overall losses of power modules can be decreased even further. In Table 2, static and dynamic losses of a 1200 V, 25 A 6-pack IGBT module are compared to a 20 A Full-SiC module.

The static losses of the full SiC module are higher by 17 %, while the dynamic losses are significantly lower: turn-on losses are lower by a factor of 3, the turn-off losses by a factor of more than 6. Consequently, the usable output power of a full SiC module much higher compared to conventional Silicon technology, especially at higher switching frequencies (see Figure 5).

At switching frequencies higher than 20 kHz, the output power of the full SiC module is more than 100 % higher as compared to the IGBT module. In addition, there is little dependency of the output power on the switching frequency. In turn, the full SiC power module can be used up to very high switching frequencies, as the output power is only 28 % lower at 40 kHz compared to the output power at 10 kHz. At switching frequencies lower than 5 kHz, the IGBT modules shows higher output power. This is a result of the SiC chipset used in the full SiC module, which was optimized for very high switching frequencies.

An optimization for lower switching frequencies is also possible. Again, it is useful to address the power density of both modules by considering the chip areas used for the Silicon and SiC chips. In Figure 6 the output power is divided by the chip area, showing the power density. The power density of the full SiC module is much higher as compared to the IGBT module, even at switching frequencies lower than 5 kHz. An optimization of full SiC modules for low switching frequencies is therefore possible by using larger chip sizes. SiC devices can provide higher output currents and output power over a broad range of switching frequencies, as the SiC chip sizes are adapted.

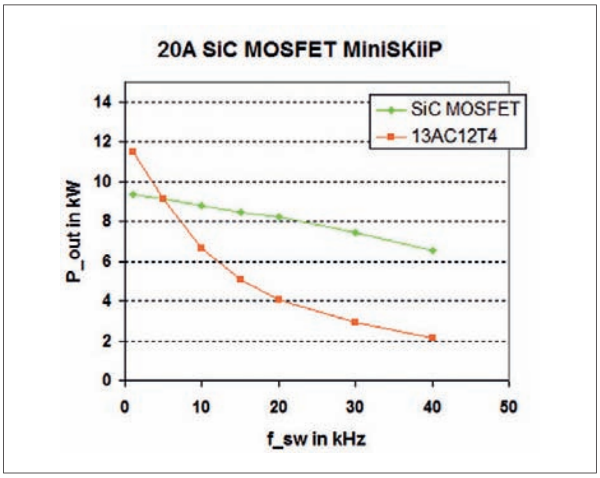


Figure 5: Output power P_{out} of a 1200 V, 20 A 6-pack Full-SiC module and a conventional 1200 V, 25 A 6-pack IGBT module

Conclusions

At module level, SiC has two main benefits: smaller chip sizes and lower dynamic losses. At system level, these advantages can be exploited in several ways. Lower dynamic losses lead to a significant increase of the output power, offering the chance to save weight and volume. Worth mentioning is the fact that this power increase can be achieved without additional cooling power. Since SiC leads to an actual loss reduction compared to Silicon devices, higher output power is possible with the same cooling efforts. Small power losses improve the energy efficiency, enabling the design of high efficient inverters, e.g. for solar and UPS applications. In addition, low dynamic losses make SiC devices ideal for higher switching frequencies above 20 kHz.

Exploiting high switching frequencies allows for reducing the cost and size of LC filtering. Depending on the chip area used, SiC shows advantages also at switching frequencies as low as 4 kHz. Other advantages of SiC are related to the enhanced thermal heat dissipation and the positive temperature coefficient, important for paralleling SiC chips. All of that makes SiC a very attractive material for a wide range of possible applications. However, the price of SiC power devices is still higher by factors, causing the prices of hybrid and full SiC modules to be much higher compared to conventional Silicon solutions. These higher costs constrain the market entry, and SiC solutions have found their way into niche applications mainly. Cost evaluations show that in many applications, the price of SiC

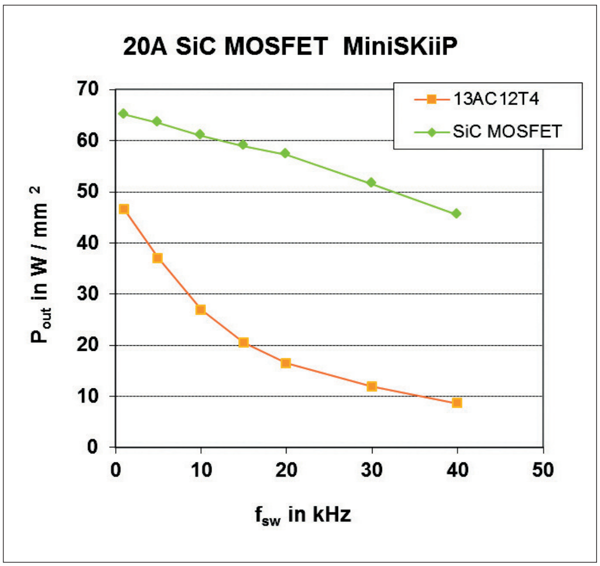


Figure 6: Output power divided by chip area showing the power density of the used power semiconductors. Thermal loss calculations on air-cooled heat sink, 40°C ambient temperature

modules needs to be 2-3 times higher in order to achieve positive business cases. In some applications, higher prices may be affordable, as benefits like small size, low weight, high efficiency, etc. can outweigh the higher cost. Much more than with conventional Silicon solutions, the total cost of ownership needs to be carefully considered with SiC.

Some benefits are not related directly to higher power output or higher efficiency. For example, reduced size and weight of wind inverters not only saves space inside the wind installation, but also reduces transportation and installation efforts. SiC offers lots of benefits and forces designers of power systems to think differently, to review conventional designs and to find new ways to take full advantage of the SiC technology. At module level, low inductive designs, optimized DCB layouts for extensive chip paralleling and of course new assembly technologies like sinter technology for high reliability and high operating temperatures are needed. SEMIKRON supports the SiC solutions by intensive research, SiC devices can be assembled in all standard packages; optimized solutions and topologies are evaluated in close relationship with the customers, which is indeed necessary. Tailored solutions are the way to be cost competitive.

However, the price issue persists and needs to be resolved for a broad breakthrough of SiC devices in the power electronics market. And the outlook is positive: according to market studies, the prices of SiC Schottky diodes are expected to drop by ~30 %, the prices for SiC MOSFETs are expected to drop by about 40 % within the next years, significantly increasing the competitiveness of SiC. It can be expected that the prices of hybrid and full SiC modules will be suitable not only for niche applications, but also for standard solutions within the next 3 years. Indeed, it's been a long way for SiC into power electronics, and the quest for a broad market entry is not yet finished. But the signs are positive for SiC to become a mature technology for power electronic applications within the next years.

Pre-Applied Phase-Change Material Improves Thermal Behavior

There are several advantages to using phase-change material (PCM) rather than conventional thermal grease as the thermal interface material (TIM) between the power module and heatsink. Vincotech offers modules with a layer of pre-applied PCM. The thermal interface material is applied in a layer with uniform thickness by a screen-printing process. This article describes the benefits of this phase-change material and provides tips on handling modules. **Patrick Baginski, Field Application Engineer, Vincotech, Unterhaching, Germany**

Heat has to be transferred from the module to the heatsink and thermal interface material is a necessary evil that gets the job done. However, thermal resistance increases if the layer is too thin or thick. This issue can be addressed by supporting modules with a pre-applied layer of phase-change material. The module's size and technology determines the layer's thickness.

The phase-change material is solid at room temperature, so it requires no special care during transportation, handling and application. Because of its thixotropic consistency, the material softens but does not flow when heated during soldering. The surface needs protection only if the power module's phase-change material comes into contact with other objects during or directly after soldering, for example, the soldering oven's carpet. The screen-printing process is precise, thereby maximizing heat-transfer capability. Figure 1 shows the backside of a flow0 module with pre-applied phase-change material.

The user is spared the task of applying thermal interface material, thereby saving time and reducing the failure risk. No additional process step is needed at the customer's side.

Properties of the phase-change material

Vincotech uses Loctite PSX-Pm phase-change material. It has the advantage that it can be applied by screen or stencil printing. It is fluid during the application and dries out over time and temperature. Another strong advantage can be seen in Table 1. The thermal conductivity is much higher compared to a lot of standard thermal greases. This result in a lower junction temperature compared to modules where usual grease is used. And for sure this material is silicone free. Once the phase-change material solidifies, the module may be handled like any conventional module.

Faster, easier module mounting, optimized thickness of the thermal interface material, improved thermal resistance (R_{th}) and reduced risk of DBC crack, no need for screen-printing facilities, automated screen printing for utmost

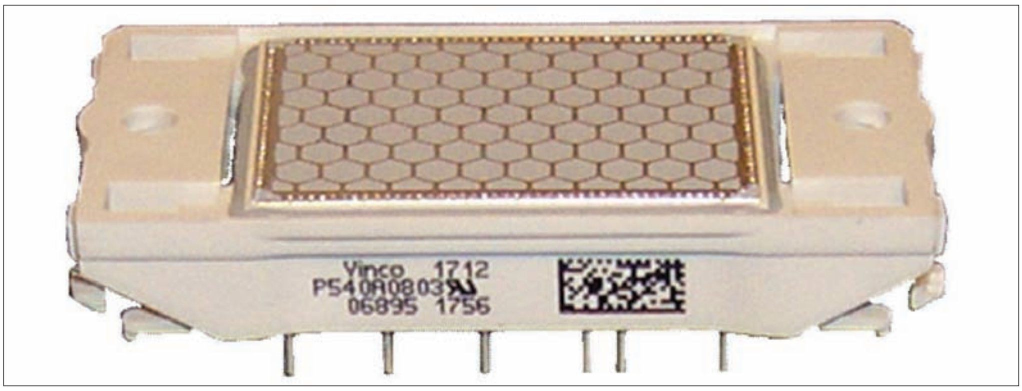


Figure 1: **Modules with applied phase-change material**

Parameter	Value	Unit
Specific Gravity	2	g/cm²
Thermal Conductivity	3.4	W/m*K
Phase Change Temperature	45	°C
Viscosity above phase change temperature	Thixotropic	
Color	Grey	

Table 1: **Physical and thermal properties of the phase-change material**

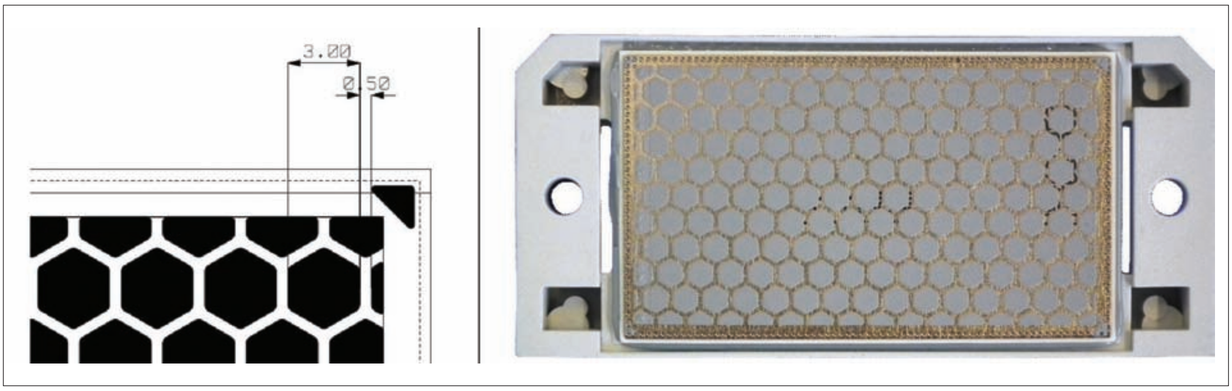


Figure 2: **Dimension and pattern after screen-printing**

reliability, no risk of smearing of the thermal paste (material is solid at room temperature), standard solder profile applicable (e.g. J-STD-001, J-STD-003), and compatible with press-fit pins are some features of modules that are applied with this material.

The physical and thermal properties of the used phase-change material can be seen in Table 1. For more information please refer to the manufacturer's datasheet (http://tds.loctite.com/tds5/docs/PSX-PM-EN.PDF).

Modules with pre-applied PCM

Vincotech offers its modules with a pre-applied layer of phase-change material. All modules are UL-listed; therefore modules with phase-change material are also UL-approved. They come in a standard blister box with a protective lid.

Modules should be stored in these blister boxes. No aging effect is known; means no expiration date.

This compound was subjected to a battery of tests like a TST and high temperature storage to verify its reliability. Figure 2 shows the pattern of the applied phase-change material onto the modules backside in thickness and dimension after the screen printing. The small triangle at the top right of the printed phase-change pattern is one of four corner markers used to align the press-in tool for modules with Press-fit pins.

Handling and operation

The module can be mounted to the heatsink after it has been soldered or pressed in. A special press-in block has to be used in case of modules with Press-fit pins. The press-in block has to have needles because the phase-change material would stick on this block if a flat block would be used.

The procedure is the same as the standard mounting process described in the housing specifications or handling instructions, apart from one major difference: screws to the heatsink can be fastened and tightened in a single step. The phase-change material is solid at room temperature, so screws can be tightened immediately without having to give the material any relaxation time.

Upon initial start-up, the R_{th} between the junction and the heatsink of a system without soft material will be 10 to 15 % higher than that of an operating system; that is, a system where the module is operating a temperature higher than 45°C and the phase-change material has attained its ultimate thickness (Figure 3). The higher R_{th} is not a problem because the heatsink temperature is below 45 to 50°C, a state at which chips cannot overheat. Time-to-melt is a function of temperature and the speed of temperature change. The material will not flow unless heat and force are applied.

Once the module has been mounted, the system should be heated up (e.g. during the system's burn-in test) while leaving enough time for the phase-change material to melt. If the temperature of the PCM exceeds 45°C, the material will melt, fill gaps and after a short time provide an optimal thermal connection between the module and heatsink. Screws do not have to be tightened again.

The phase-change material returns to its solid state when the temperature drops below 45°C. This means the material's phase changes every time it reaches 45 °C.

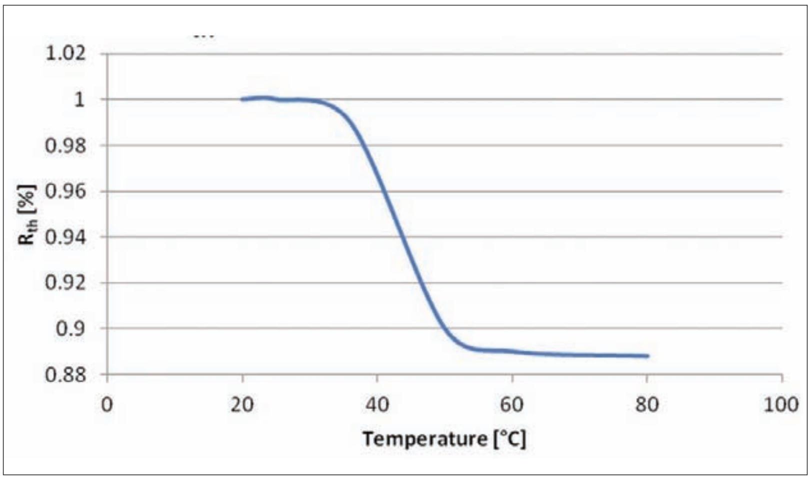
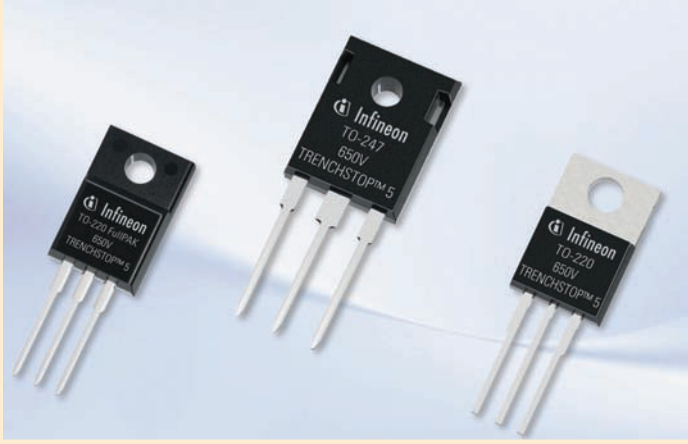


Figure 3: **Thermal resistance versus heatsink temperature**

Conclusion

Vincotech offers modules with pre-applied phase-change material. This PCM is applied in a screen printing process that leaves an optimum and always consistent layer thickness. This phase-change material is thixotropic and therefore will not flow without the application of pressure. Standard soldering profiles may be used. A lid or a foil can prevent the phase-change material's surface from coming into contact with the soldering oven's carpet. Power modules with Press-fit pins and phase-change material are compatible. Please refer to the module's handling instructions to learn more about this.

650 V TRENCHSTOP 5 IGBTs



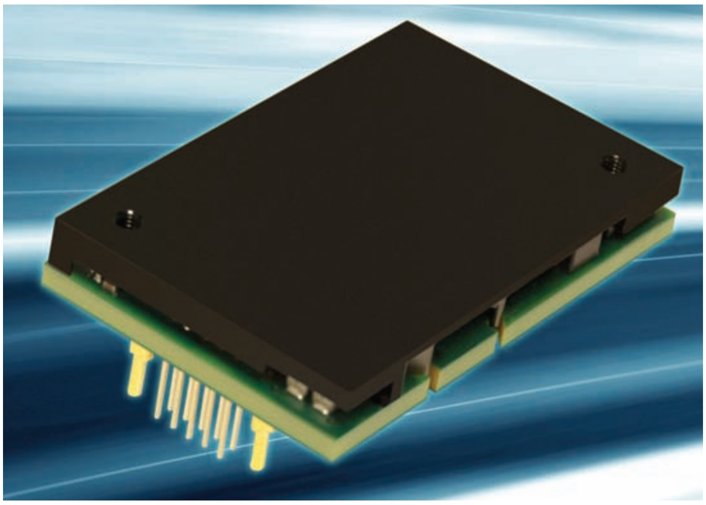
Infineon's TRENCHSTOP™ 5 IGBT efficiency results in 60 % lower turn-off switching losses compared to HighSpeed (H3) family plus mild positive temperature coefficient of the saturation voltage, which is associated with the conduction losses. The gate charge is 2.5 times lower compared to H3, which translates into an IGBT that is easier to drive, offering a cost reduction since the driver can be smaller. Furthermore, TRENCHSTOP 5 features a temperature stable forward voltage drop of the fast recovery free-wheeling diode and reverse recovery time of less than 50 ns. Low output capacitance provides outstanding light-load efficiency, which is perfect for designs that predominately operate below 40 % of maximum rating. Applications include the boost stage in photovoltaic inverters switching between 16 and 30 kHz, or UPS PFC stages and battery chargers switching between 20 and 70 kHz. The increased efficiency allows for either lower junction temperatures during operation, which ensures higher lifetime reliability, or higher power density designs. The latter enables customers to rethink designs and adopt smaller packages, for example implementing a TO-220 package instead of TO-247. Samples are available from 8A to 50A in TO-220, TO-220FP and TO-247 packages.

www.infineon.com/trenchstop5

420 W PMBus Compliant 1/4 Brick Converter

The 420 W regulated UDQ2204/001 is the first in a series of DC/DC converters from Murata Power Solutions to include a PMBus compatible digital interface. The UDQ series is packaged in the industry standard quarter-brick format incorporating the ABC (Advanced Bus Converter) pinout for PMBus communications to an isolated DC/DC converter. Input voltage ranges from 36 V–75 V with a typical efficiency of 95.5 % at 12 V output. To achieve this level of performance the UDQ utilizes a 32-bit ARM7 processor and proprietary firmware to control all critical functions. The module provides a digital interface (ABC pinout) supporting the PMBus standard for digital power management in systems. By attaching the UDQ to the system's I2C bus, an engineer can monitor V_{in}, I_{in}, V_{out}, Iout, and operating temperature. The PMBus can be used to set warning flags for these parameters and allows the user to customize these and others. A GUI and evaluation boards are available to assist the power engineer in designing a state-of-the-art power system. Typical applications for the UDQ series include Distributed Power Architectures (DPA) and Intermediate Bus Architectures (IBA) in MicroTCA, data center, server, storage, networking, wireless base stations, fan trays, industrial and test equipment applications.

www.murata.eu



Low Input Current Optocouplers

Vishay Intertechnology extends its optoelectronics portfolio with the release of two series of 4-pin optocouplers. They offer a high CTR (Current Transfer Ratio) from 40% to 600% at low input currents of down to 1mA and a phototransistor output. The new series in the ultra-compact SSOP-4 mini-flat package are available at distributor Rutronik. The new series VOS618A and VOS617A feature a GaAs infrared emitting diode and a Silicon planar phototransistor detector. DC input currents is 1 mA (VOS618A) and 5 mA (VOS617A). They are designed for isolated feedback loops, I/O isolation, and isolation in switch-mode power supplies, AC adapters, motor drives, solar invertors, networking switches, telecom line cards and home appliances. The optocouplers, also known as opto-isolators, in the compact half-pitch mini-flat package save more than 60 % board space compared to a DIP-4 package. Their package provides a 3750 VRMS isolation voltage rating, a half lead pitch of 1.27 mm, package height of 2 mm and creepage and clearance distance of ≥5 mm.

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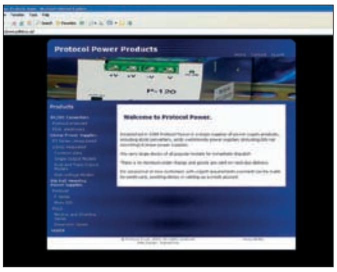

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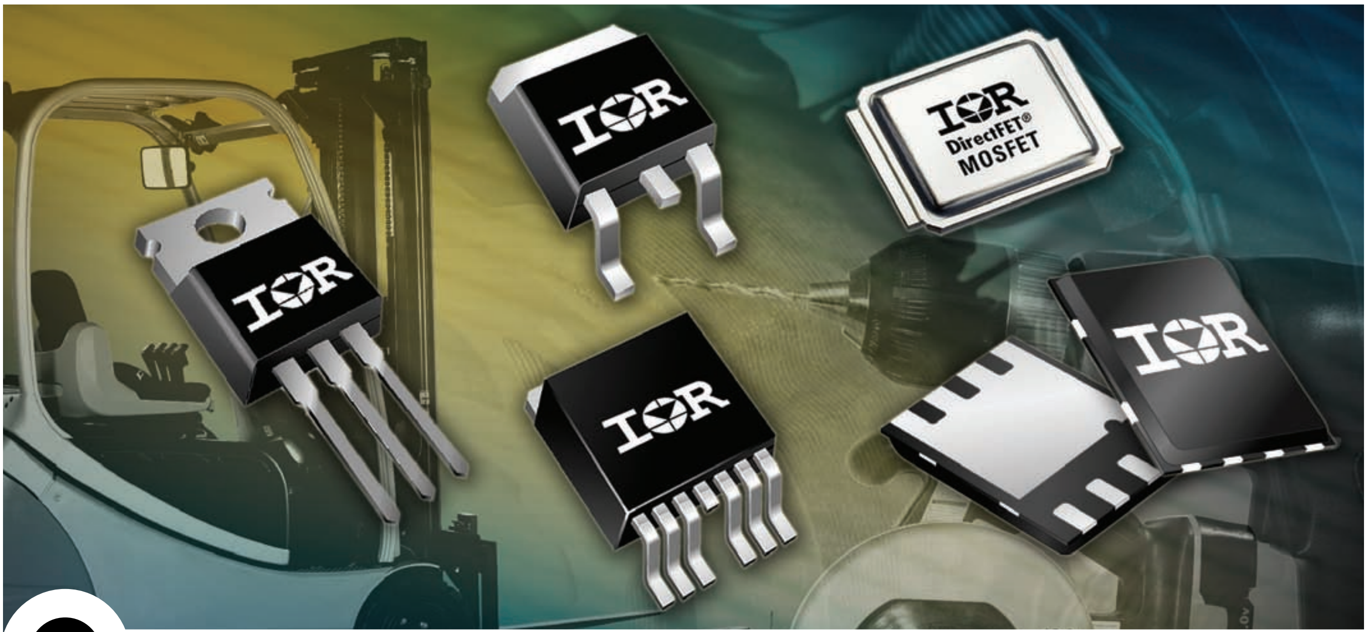

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IRFS7440TRLPbF	40 V	120 A	2.8 mΩ	90 nC	D²-Pak
IRFS7437TRL7PP	40 V	195 A	1.5 mΩ	150 nC	D²-Pak 7pin
IRFR7440TRPbF	40 V	90 A	2.5 mΩ	89 nC	D-Pak
IRFB7430PbF	40 V	195 A	1.3 mΩ	300 nC	TO-220AB
IRFB7434PbF	40 V	195 A	1.6 mΩ	216 nC	TO-220AB
IRFB7437PbF	40 V	195 A	2 mΩ	150 nC	TO-220AB
IRFB7440PbF	40 V	120 A	2.5 mΩ	90 nC	TO-220AB
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