# PCIM Europe Insights

Issue April 2019

**GaN / Industry 4.0**
A Small Change that is Revolutionizing the Industry

**E-mobility**
SiC revolutionizes the powertrain

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# Power Semiconductors // Current Research Trends

Achieving a more sustainable use of the limited energy resources available is greatly facilitated by utilizing more efficient power electronic systems. New development leaps in power electronics can only be realized by significantly reducing, or altogether eliminating, parasitic component properties. Compared to the silicon power semiconductors that enjoy widespread use today, semiconductors with higher band gaps such as GaN and SiC boast exceptionally good properties for developing efficient power devices. SiC and GaN devices have already been launched to the market and are now being used in power electronic systems. These are just initial steps, however, as research on power semiconductor devices continues. To this end, new developments and trends will be presented at the Fraunhofer IAF expert forum. While SiC devices are based on vertical current-carrying device concepts such as power MOSFETs and IGBTs, the GaN devices currently available feature a lateral design. With these devices, let-through current flows in an AlGaN/GaN boundary layer near the surface of the device. This lateral design makes it possible to position and wire several components in a row using a single chip. Such monolithic integration allows systems to be compact and avoids high external wiring inductances as well as associated costs as compared with current discrete power modules. Today, entire circuit parts – including gate drivers, simple logic, sensors and power topologies – can be monolithically integrated. The entire system with control loop and power components can then be realized in GaN technology [1]. In the future, this development will produce elegant and cost-effective single-chip solutions.

> » New semiconductor technologies pave the way to development leaps in power electronics «

To further increase the performance capabilities of GaN technology, an innovative material known as AlScN (aluminum scandium nitride) is currently being researched at Fraunhofer IAF. AlScN/GaN bonds generate more free charge carriers in the boundary layer than previous AlGaN/GaN bonds. This, in turn, leads to higher let-through currents and lower forward resistances and, thus, to more efficient devices. Promising new developments have also been achieved with vertical device concepts. With GaN technology, for example, vertical power devices can be developed that realize higher blocking voltages and current densities than the lateral GaN devices that have already been established. Research groups worldwide are currently working on very different vertical component concepts in order to fully exploit the potential of the GaN material.

Diamonds have an even higher band gap than GaN and SiC (considerably higher), not to mention the fact that they are noted for their outstanding thermal conductivity. These desirable properties are the motivation behind the ongoing research activities pursued in developing diamond-based power semiconductors. In this context and at an early stage in research, Fraunhofer IAF has already demonstrated the operative function of a diamond power diode as used in an LED buck converter [2].


[1] M. Basler et al., »A GaN-on-Si-Based Logic, Driver and DC-DC Converter Circuit with Closed-Loop Peak Current-Mode Control,« in Proc. PCIM-Europe 2019

[2] R. Reiner et al., »Diamond Schottky-Diode in a Non-Isolated Buck Converter,« in Proc. PCIM-Europe 2019


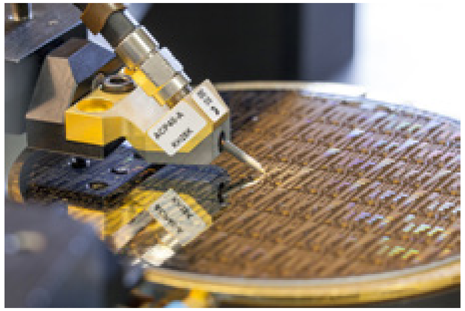

Fig. 1: AlScN/GaN wafers for on-wafer characterization

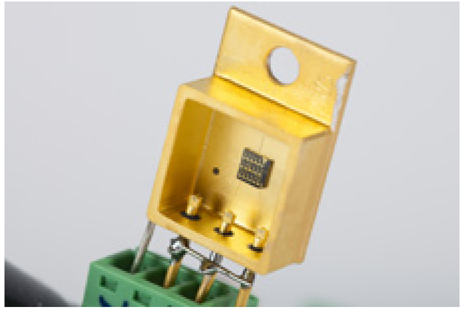

Fig. 2: Diamond power diodes on monocrystalline diamond substrates

**Richard Reiner,**
Fraunhofer IAF

# GaN / Industry 4.0 // A Small Change that is Revolutionizing the Industry

In Industry 4.0, the long history of the Industrial Revolution is merging with the ever-evolving capabilities of the Information Revolution. Flexible design of intelligent industrial spaces that are capital cost conscious and energy-efficient is the new aspirational standard for markets as diverse as automotive and consumer packaged goods. Hardware innovation plays an important role in of the hundreds of millions of motor drives used in Industry 4.0, along with the robots that need to be increasingly autonomous and precise.

**Motor Drives and Motors – Energy efficiency and facility layout flexibility**

Industrial use currently accounts for 40-50% of global electricity demand, with two-thirds of that used in the 300M industrial motors in the world – from robotic arms to conveyor belts. Unfortunately, 30-60% of the energy consumed in the motors is wasted through equipment and motor efficiencies.

Historically, companies only focused on ways to cut operating costs or increase production line output with little thought to increasing energy efficiency. Those days are over. This change comes not only from the increasing impact of energy cost on the bottom line, but also from the pressure generated by government on global pollution levels resulting from increased energy production.

> » In the age of industry 4.0, hardware innovation plays a key role in the design of motor drives – as do robots. «

GaN power semiconductors used in motor drives deliver some of the needed changes around the efficiency, durability and flexibility requirements of Industry 4.0. Using GaN reduces energy losses by 50% and increases power density 5 fold, while simultaneously doubling the lifespan of power electronics through decreased thermal stress. And because GaN motor drives can support longer length cables, there is increased flexibility in floor layout and power drop locations within industrial spaces.

**Autonomous Robots and Robotics – Precision, efficiency, and wireless charging**

Increased motor precision and performance, small and efficient physical designs, and the integration of wireless charging are the needed parameters of change for industrial robotics. Industry 4.0 robotics require faster response times, higher precision positioning, and real-time control and coordination of multiple motors. With GaN power semiconductors, motor drives can run at higher operating frequencies and efficiencies that deliver the increased control bandwidth that, for example, reduces or eliminates mechanical vibration.

Today, power conversion and motor drive components of robotic arms can be so large that they are often located in separate cabinets far from the assembly line. GaN enables the design of smaller motor drives that can be directly incorporated into robotic arms.

For mobile robots to work efficiently, flexibly, and without interruption – they need wireless charging to achieve true autonomy. GaN power semiconductors, operating at high frequency, enable several wireless charging advantages. These include high power capability (1kW+) with the spatial freedom (large air gaps) needed in the design of charging systems that require no human intervention.

**GaN and Industry 4.0's Near Future**

To move toward fulfilling the potential of Industry 4.0, the challenges of new hardware design and energy efficiencies must be addressed. GaN technology is an important part of the needed hardware evolution in Industry 4.0 for the hundreds of millions of motor drives and robots that will be needed to make Industry 4.0 a reality.

**Jim Witham,**
GaN Systems

# E-mobility // SiC revolutionizes the powertrain

As the automotive industry moves towards zero-emission transportation, auto manufacturers are swiftly ramping up their electrification programs. Most OEMs plan to be ready to supply large volumes of battery electric vehicles (BEVs) as well as hybrid electric vehicles (HEVs) worldwide by 2025.

> » SiC offers practical advantages over silicon-based components and will bring a cost benefit to car buyers. «

Since 2010, various aspects of the available silicon carbide products have undergone extensive investigations in numerous research and development projects. Today, the benefit of SiC is undisputed. Despite price differences between SiC and Si semiconductor devices, the integration of SiC at system level pays off. In addition, SiC has reached a degree of maturity that has led to SiC being treated as a potential solution for power electronics systems in applications with high reliability requirements – such as in the automotive sector. Interest in SiC is therefore growing very rapidly at the present time.

One of the potential applications for SiC is the power train inverter in electric vehicles. To analyse the advantages of SiC in the powertrain, in 2016 Rohm launched a partnership with the motor racing team Venturi for the Formula E championship series.

By using SiC devices, it is possible to increase the overall efficiency of the powertrain. Figure 1 shows two power train inverters. The inverter on the left has a rated output power of 200 kW and uses power modules based on Si IGBTs and Si fast recovery diodes (FRDs). The inverter on the right was built using newly developed SiC devices, and has a rated output power of 220 kW. The benefits offered by SiC MOSFETs and SiC SBDs combined with a low-inductance bus-bar design and a compact DC link capacitor allowed a better concept for the motor control strategy to be implemented and resulted in a more compact cooling system. Both inverters are water-cooled and both can be used with battery systems up to 800 V.

Among the various vehicle manufacturers, there is an increasing trend for higher battery capacity. This results from the attempt to solve the problem of battery range in electric vehicles.

In the drive system, losses in both the inverter and electric motor consume a substantial proportion of the energy stored in the battery. So any increase in the efficiency of the powertrain brings benefits. Figure 2 shows the economic benefits of SiC depending on battery capacity in 2025.

Based on the inverter efficiency and a standardized driving cycle for passenger cars – the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) – the possible capacity improvement is up to 5%.

It is, therefore, anticipated that with the same battery capacity, using SiC in the powertrain a BEV will achieve a longer range. Alternatively, a considerable reduction in battery size and hence battery weight as well as cell costs is possible when designing for the same driving range. In this way, efficiency and weight improvements bring cost benefits to car buyers.

Fig. 1: Two power train inverters (left: Si IGBT based 200kW inverter, right: SiC MOSFET based 220kW inverter)

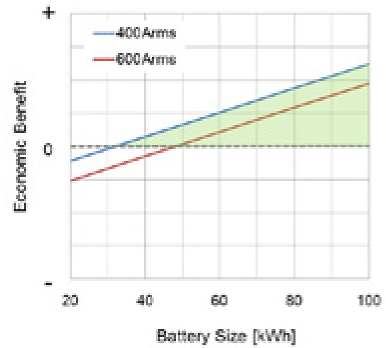


Fig. 2: SiC MOSFET based inverter's economic benefit vs. battery size in 2025

**Aly Mashaly,**
ROHM Semiconductor

# Thermal Management // Liquid-Cooled Power Electronics – New Measurement System for Optimized Thermal Management

Active air flow as employed in power electronics is oftentimes not enough to dissipate heat loss effectively. This is where liquid cooling comes in; the technology, however, requires a more complex infrastructure. Water-glycol mixtures are used as standard cooling media. Oils are also sometimes used, although the material values they offer for transferring heat do not come close to the exceptional performance of water. The key factor to ensuring optimal heat transfer in any case involves optimizing the heat sink structure in the flow channel under the prevailing pressure conditions for the fluid used.

» The new system allows measuring power electronics and their cooling mechanism accurately and close to the application. «

A new measurement system developed at ZFW Stuttgart makes it possible to accurately characterize liquid cooling for power electronics. To this end, the mass flow, pressure conditions and temperatures of the flow are recorded. The measurement uncertainty for the values obtained is typically well below 0.5 percent. During the measuring process, the entire heat path from the junction of the power semiconductor to the coolant is taken into account, whereby the thermal transient method is used to apply a jump function to the semiconductor and quantify the jump response. Calibration produces the thermal response, or Zth curve, which includes all relevant information on the thermal resistances and heat capacities of the individual layers in the heat path. These can be determined accordingly by mapping the heat path using a basic RC model (Cauer model). The thermal resistances and thermal capacities of the individual layers are calculated in reference to the Zth curve by running mathematical conversions [1,2]. Although the heat transfer in the power semi-conductor is relevant, the thermal resistance $R_{th,\alpha}$ between the surface of the heat sink and the cooling medium is of particular interest. $R_{th,\alpha} = 1/(\alpha \times A)$ applies, with the heat transfer coefficient α in W/(m2K) and the heat transfer area A of the heat sink. The heat transfer coefficient α is a function of the material properties of the coolant, geometric conditions, flow velocity and flow type. As the velocity and turbulence of the flow rise, α increases and the thermal resistance between the surface of the heat sink and coolant decreases. More often than not, a clever heat sink design can increase the heat transfer area and heat transfer coefficient without elevating the pressure drop of the flow.

The illustration shows an example IGBT structure with liquid chiller, the Zth curve measured and the structure function calculated based on it. A mass flow (water) of 5, 10 and 15 kg/minute was measured. Thermal resistance decreases as mass flow increases.

The new measurement system is designed for temperatures ranging from -40 °C to 80 °C and a mass flow of 0 to 20 kg/minute. The main benefit of the new system as compared with conventional methods is that power electronics (such as IGBTs) and their cooling mechanism are accurately measured close to the application utilizing the original design, thereby establishing a solid basis for realizing optimal and cost-effective thermal management.

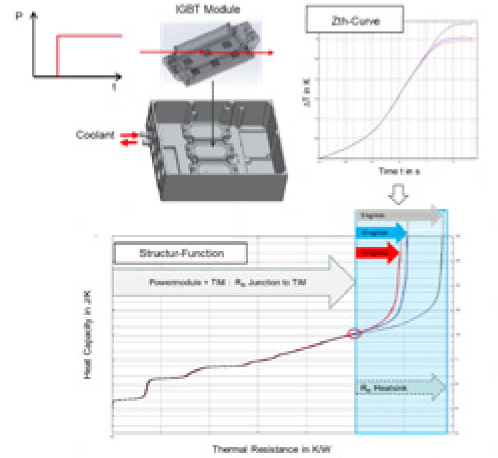


Fig. 1: IGBT structure with liquid chiller and measured Zth curve with structure function.

[1] JEDEC STANDARD JESD51-14 (2010) Transient Dual Interface Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow Trough a Single Path, JEDEC Solid State Technology Association
[2] Griesinger A (2019) Wärmemanagement in der Elektronik, Theorie und Praxis, Springer Vieweg

**Prof. Dr. Andreas Griesinger,**
ZFW Stuttgart

# Power Electronics Optimization // Impact of Core Technology on Grid-Tied Converter

Power electronic systems have a hierarchical structure that includes materials and components that are combined to make systems. The space designed between the layers affects performance in terms of efficiency and the power density in the upper layers. For example, the efficiency of a certain topology is determined by the utilized semiconductors; the weight of an inductor is affected by the winding and core materials. These multiple hierarchical layers lead to a complex design procedure for the final power electronic system. Moreover, as each core technology in power electronics is maturing, the space available for the design is becoming wider, providing more options for the arrangement of topology, semiconductors, cooling, and magnetic components. This imposes considerable challenges on the optimization of modern power electronics systems. Particularly in the renewable energies sector where the market is changing rapidly, finding an optimized solution resulting from this extensive design space within a short time becomes even more challenging. Consequently, the need for a fast systematic design and the need for an evaluation procedure in industrial research is increasing. Recently, multi-objective optimization in power electronics has made significant progress in academia as it aims to create a holistic design perspective. To cope with ever-increasing technical challenges in grid connection, the recent advances in the optimization of power electronics are being applied to industrial research as a backbone for developing grid-tied converters. Currently, the impact of different core technologies on the performance of a grid-tied converter is being explored with the aid of multi-objective optimization for power electronics, which leads to future research directions with new challenges.

» Power electronics optimization is the backbone of developing grid-tied converters «

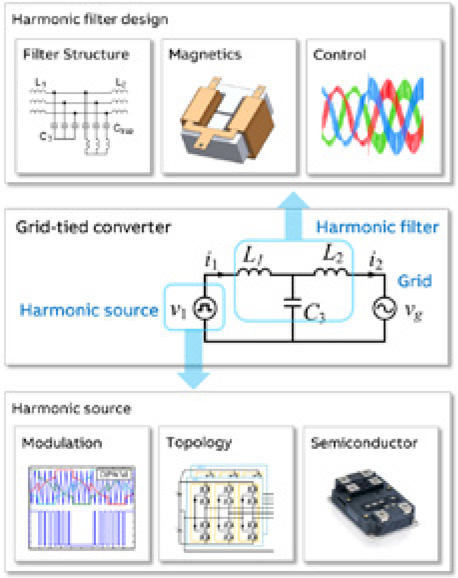


Fig. 1: Power electronic system hierarchy

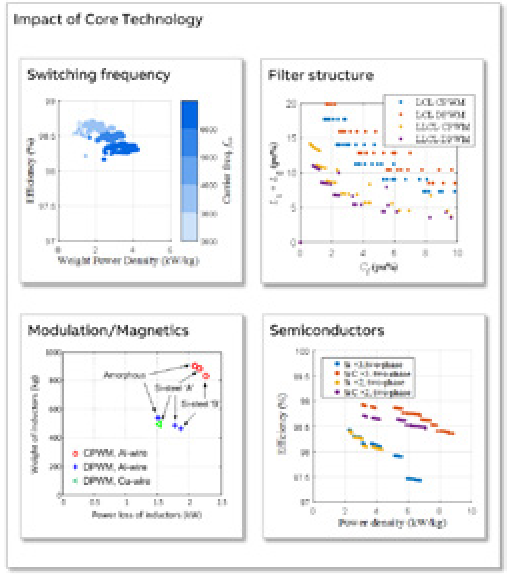


Fig. 2: Core technology breakdown and impact on grid-tied converter

**Ki-Bum Park,**
ABB Corporate Research

# Industry Forum // Platform for knowledge transfer

At the Industry Forum in hall 7 (booth 543), three days' worth of top-quality lectures and presentations await. You may look forward to renowned experts discussing current research and development topics in the field of power electronics.

**The Industry Forum is open to trade visitors at all times.**

Would you like to receive the biannual PCIM Europe Insights automatically? Please send an e-mail to sophie.pfauter@mesago.com

## Complete Program:

**Tuesday, 7 May 2019**

| | | |
|---|---|---|
| 10:15 – 11:00 | Next-Generation Power Electronics by Advanced Semiconductor and Device Technologies | Fraunhofer IAF |
| 11:00 – 11:45 | SiC Power MOSFETs – Application Specific Portfolio Extension | Infineon |
| 12:00 – 13:00 | Get Going with GaN | Power Systems Design |
| 13:00 – 13:30 | SiC and GaN Impact on Traditional Si Power Electronics Industry | Yole Développement |
| 13:30 – 14:00 | New Thinking Leads to Smaller Inductors and High Efficiency at High Frequency | Coilcraft Europe |
| 14:00 – 14:45 | Solutions for Special Measurement Applications (100kA, 100MW, etc.) | DEWESoft |
| 14:45 – 15:15 | Thermal Resistance of Interconnect Layers in Inverter Power Stack Assembly | MacDermid Alpha Electronics Solutions |
| 15:15 – 15:45 | Next Generation of Power Supplies | Virginia Tech |

**Wednesday, 8 May 2019**

| | | |
|---|---|---|
| 10:00 – 10:45 | SiC Power MOSFETs – Application Specific Portfolio Extension | Infineon |
| 10:45 – 12:15 | EV/HEV Transformation of the Power Modules Industry | Yole Développement |
| 12:15 – 12:45 | Automotive Power Module Qualification Guideline AQG324 - The Success Story Continues | AQG 324 |
| 12:45 – 13:15 | A Comparison between NPC and ANPC 3 Level Topologies | Semikron Elektronik |
| 13:30 – 14:30 | SiC – Devices are Mature | A Media, Bodo's Power Systems |
| 14:30 – 15:30 | GaN – Devices are Mature | A Media, Bodo's Power Systems |
| 15:30 – 16:00 | Optimization of Power Electronics for Grid-Tied Converter | ABB Switzerland |

**Thursday, 9 May 2019**

| | | |
|---|---|---|
| 10:00 – 11:00 | SiC Solutions for Industrial and Automotive Applications | ROHM Semiconductor |
| 11:00 – 11:30 | GaN and Industry 4.0 – A Small Change that is Revolutionizing the Industry | GaN Systems |
| 11:30 – 12:30 | Einführung Students Day | ECPE European Center for Power Electronics |
| 12:30 – 13:00 | What is the Impact of Battery, Power Electronics and Electric Motor Global Trends on the EV/HEV Industry? | Yole Développement |
| 13:00 – 13:45 | SiC Power MOSFETs – Application Specific Portfolio Extension | Infineon |
| 13:45 – 14:30 | Next-Generation Power Electronics by Advanced Semiconductor and Device Technologies | Fraunhofer IAF |
| 14:30 – 15:15 | Solutions for Special Measurement Applications (100kA, 100MW, etc.) | DEWESoft |
| 15:30 – 16:00 | Verlosung Students Day | ECPE European Center for Power Electronics |