Next Generation Power Electronics based on WBG Devices - WBG System Integration

Content:

- Introduction (ECPE Network, Roadmap Programme, WBG User Forum and WG)
- Why ´Next Generation Power Electronics´?
- Lead Applications for SiC and GaN
- ECPE Position Paper ´Next Generation Power Electronics based on Wide Bandgap Devices - Challenges and Opportunities for Europe´
  => WBG System Integration

Thomas Harder, ECPE European Center for Power Electronics, Nuremberg
Co-Authors: ECPE WBG Working Group (Prof. N. Kaminski, Univ. of Bremen)
at NEREID Workshop – Smart Energy, 20 Oct. 2016 in Bologna

ECPE – the industry-driven Research Network with 77 Industrial Members

… and 90 ECPE Competence Centres

ECPE Objectives & Mission

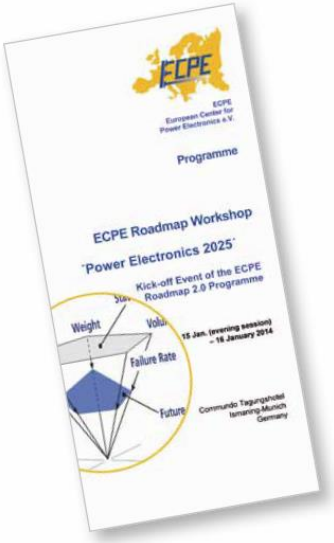
- **Precompetitive Joint Research in Power Electronic Systems**
  - ECPE Projects with focus on automotive & industrial power electronic systems as well as renewable energies and electronic power grids
  - EC or national funded research projects with partners from the Network
- **Education & Advanced Training**
  - Expert workshops and tutorials for engineers in industry
  - ECPE online course ´Power Electronics´
- **Public Relations & Lobbying for Power Electronics**

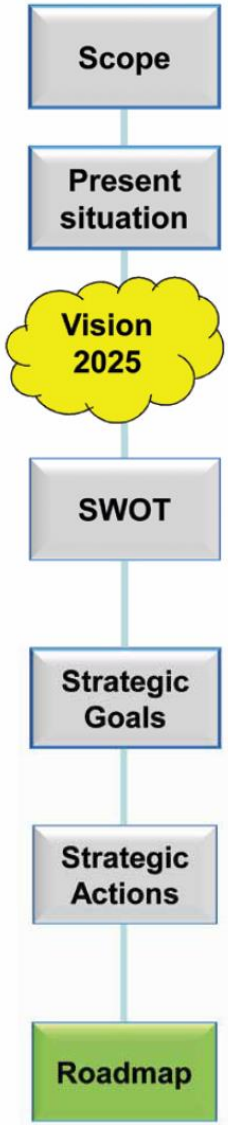
  Have “one strong voice” of power electronics industry to public & politics

ECPE, the Industry-driven Research Network for Power Electronics with more than 160 member organisations in Europe.

A strong voice of the Power Electronics community in Europe to the public and to politics!

ECPE Roadmap Programme ´Power Electronic 2025´





Research and Technology Roadmaps are an important strategic tool to identify and guide a mainstream for medium to long term research. The ´Power Electronics 2025´ Roadmaps will be the key element of the ECPE Strategic Research Agenda.

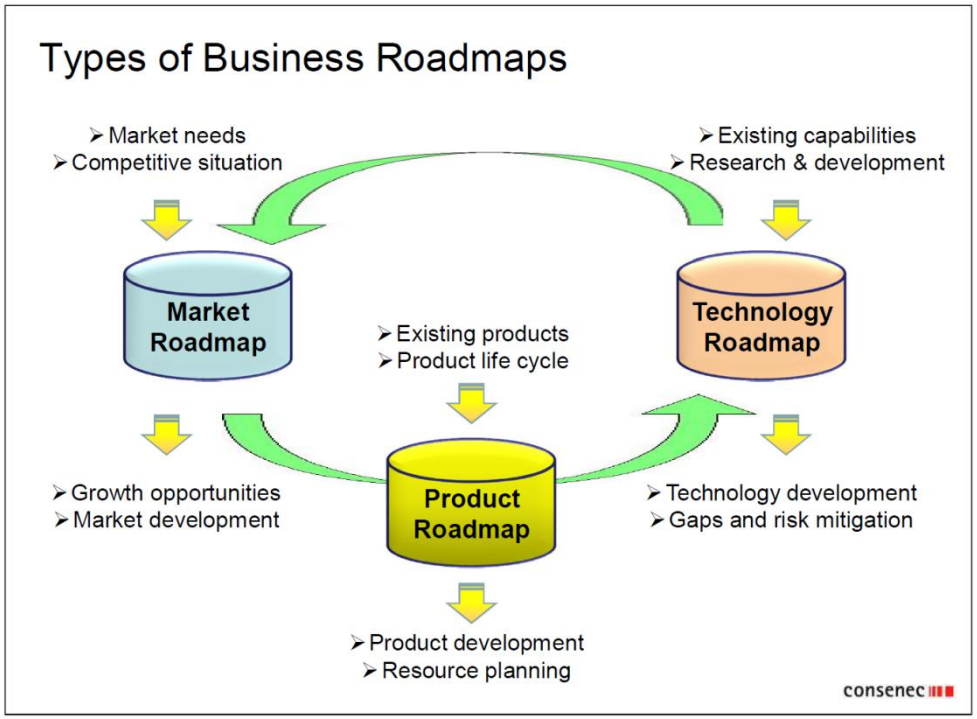
<u>Objectives:</u>

- Provide input and industrial guidance to research programmes on European and on national level
- ECPE Member companies will reflect their own company roadmap vs. the ECPE roadmaps
- ECPE Competence Centre will use the roadmaps when they define new research directions

Structure: three application-related roadmapping teams

- **Power Supplies** (low power)
- **Automotive & Aircraft** (medium power)
- **Electronic Power Grids** (high power)

ECPE Roadmap Programme ´Power Electronic 2025´

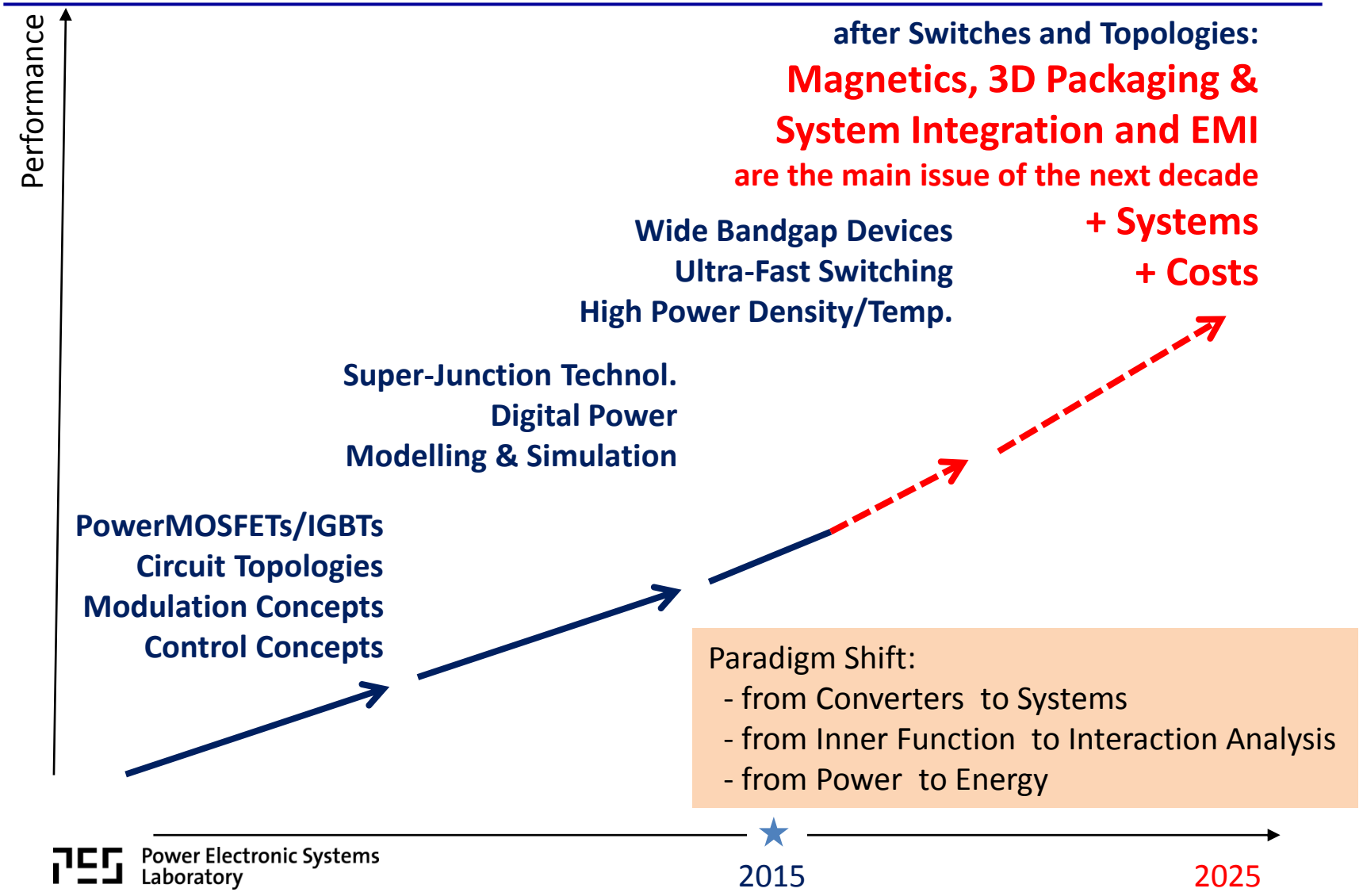


ECPE Roadmap Workshop,
26 March 2015 in Munich

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ECPE Roadmap Programme ´Power Electronic 2025´

Technology Milestones



Power Electronic Systems Laboratory

Source: J.W. Kolar, ETHZ and T. Harder, ECPE

ECPE SiC & GaN User Forum, Working Group ´Wide Bandgap Power Electronics´

ECPE European Center for Power Electronics e.V.

SiC User Forum – Potential of SiC in Power Electronic Applications

in the frame of the ECPE Annual Event 2006

14 – 15 March 2006
Süd-West-Park Conference Centre, Nürnberg, Germany

in cooperation with Otto-von-Guericke-Universität Magdeburg

1st Meeting of the

ECPE Wide Bandgap Technical Committee (TC)

(WBG Working Group)

Date: **Tuesday, 10 February 2015, 10.00 – 16.00 h (CET)**
Location: **Commundo Tagungshotel Ismaning, Room no. S 036**
Seidl-Kreuz-Weg 11,
85737 Ismaning/Munich, Germany

Draft Agenda

9.30 h **Registration / Welcome Coffee**

10.00 h Start of the TC Meeting

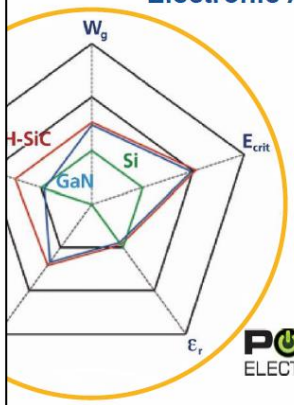
- **Welcome, Introduction and Motivation**
  L. Lorenz, President ECPE
- **Wide Bandgap Power Electronics – Status and Trends in Japan, US and Europe** (results of an ECPE study)
  N. Kaminski, University of Bremen
- **Discussion of the Draft Programme of the 6th SiC & GaN User Forum** on 20-21 April 2015 in Warwick/Birmingham, UK
- **Open Expert Discussion on WBG Power Electronics in Europe**
  - present status in Europe
  - is Europe fit for leading WBG technology in the future?
  - GaN: new ways of system integration, medium power applications necessary materials development (sc, packaging), reliability
  - SiC: switch technologies, high voltage devices, identify system benefits, packaging technol./thermal management, reliability
  - further WBG candidates e.g. Galliumoxide, diamond
- **Strategic ECPE Position Paper for Europe on ´WBG Power Electronics´** for European (and national) public funding authorities
- **Next Steps/Actions**

ECPE
European Center for Power Electronics e.V.

Programme Flyer

ECPE SiC & GaN User Forum

Potential of Wide Bandgap Semiconductors in Power Electronic Applications



20 – 21 April 2015
University of Warwick
Coventry, UK

in cooperation with

nmi Semiconductors to Systems

POWER ELECTRONICS UK

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

THE UNIVERSITY OF WARWICK

ECPE

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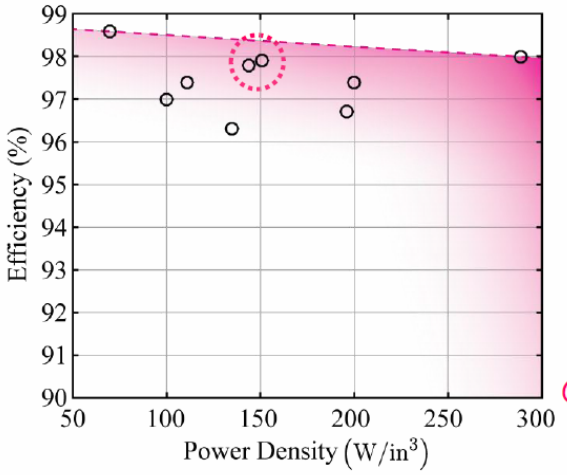
Google/IEEE Little Box Challenge 2015/16

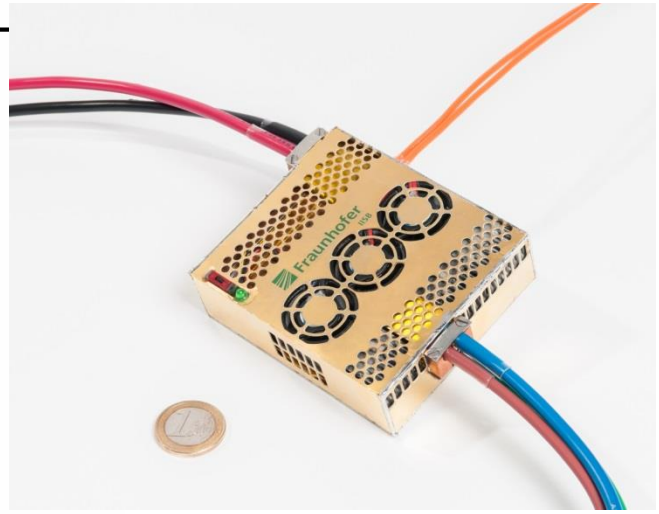
Finalists - Performance Overview

- 18 Finalists (3 No-Shows)
- 7 Groups of Consultants / 7 Companies / 4 Universities



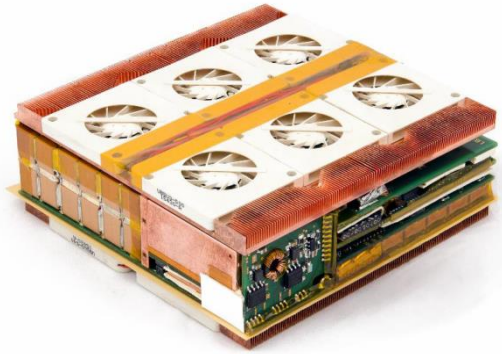
@ Rated Power

- 70…300 W/in³
- 35 kHz…500kHz…1 MHz (up to 1MHz: 3 Teams)
- Full-Bridge or DC/|AC|Buck Converter + Unfolder
- Mostly Buck-Type Active Power Pulsation Filters (Ceramic Caps of Electrolytic Caps)
- GaN (11 Teams) / SiC (2 Teams) / Si (2 Teams)



Finalist FhG IISB

★ 135 W/in³



Finalist ETHZ/FhG IZM

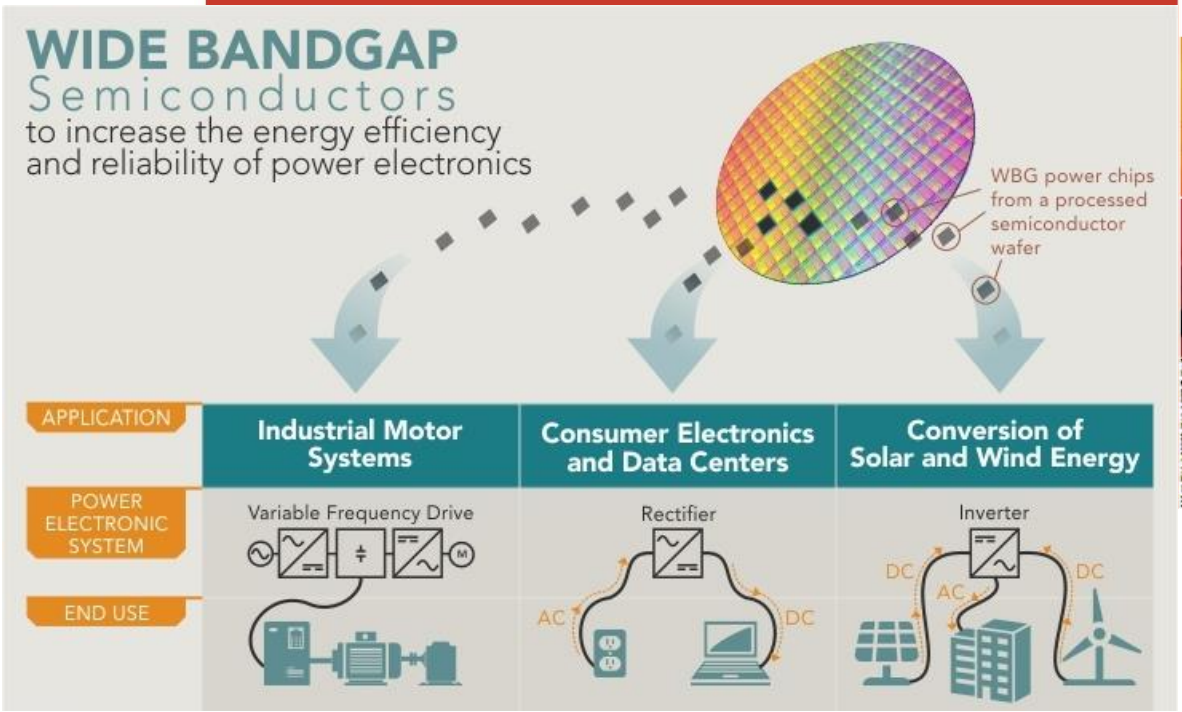
Source: J.W. Kolar et al., CIPS 2016, Nuremberg

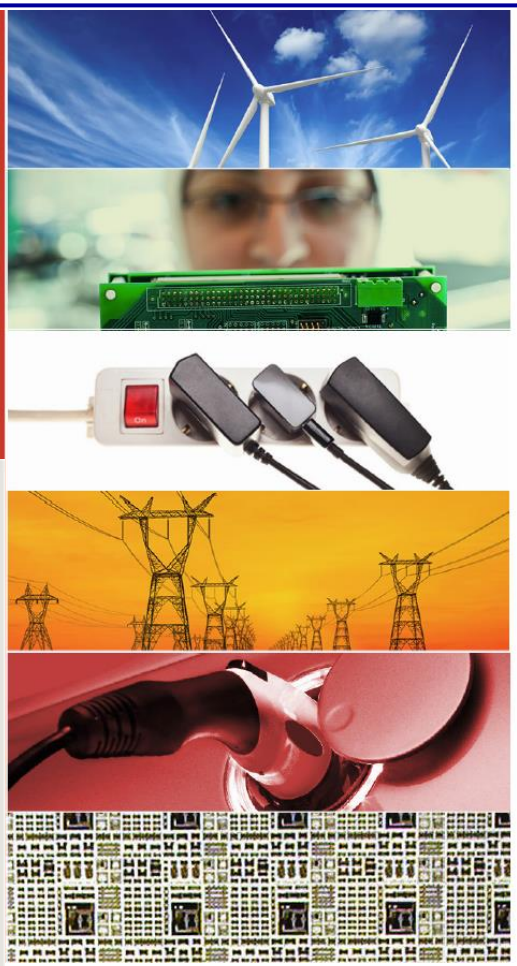
US: Next Generation PE Manufacturing Innovation

NC STATE University

PowerAmerica

Next Generation Power Electronics Manufacturing Innovation Institute





https://www.nist.gov/sites/default/files/documents/el/msid/18_rIvester.pdf

Japan: SIP on Next Generation PE

SIP (Cross-ministerial Strategic Innovation Promotion Program)

Next-Generation Power Electronics

【Objective】 Dramatically cutting power loss for more energy-efficient and downsized power electronics systems by developing capable next-generation power devices until 2020.

【Duration】 Five years (2014 - 2018)

【Budget】 ¥2.3 Billion (for FY2016)

■ Targets:

Integrating next-generation semiconductors into highly efficient and downsized power electronics systems through comprehensive development from materials to systems.

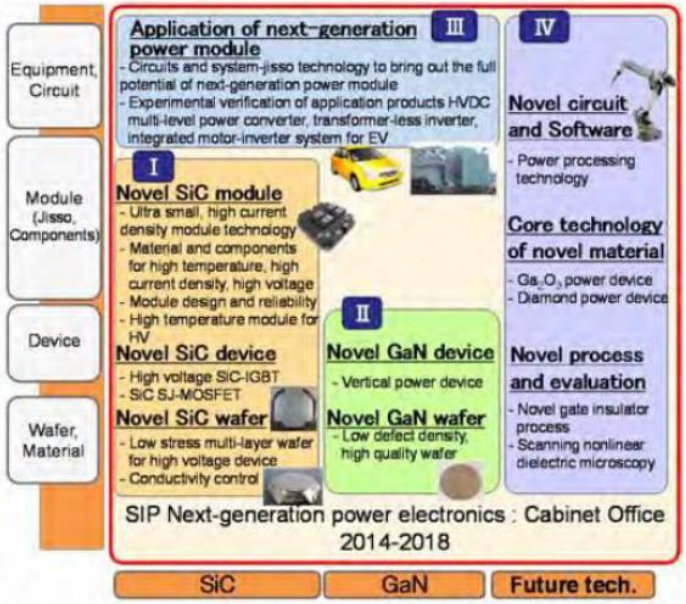
■ Contents:

I. Development of fundamental basic technologies regarding SiC
(higher voltage ratings, downsize, smaller loss and higher reliability)

II. Development of common fundamental technologies regarding GaN
(improvement of wafer and development of vertical power devices)

III. Basic research and development regarding applications of next-generation power modules *(circuit, control …)*

IV. Basic research and development for the future power electronics
(new materials and structures)



■ Strategies

- Consider and formulate a strategy for activities toward creating an ideal society in 2030
- Prove performance using prototypes to demonstrate successful development of technologies that meet requirements
- Conduct standardization and other activities to promote the adoption of program results

Source: http://www8.cao.go.jp/cstp/english/sip/elevenissues.pdf

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- **Lead Applications for SiC and GaN (killer applications)**
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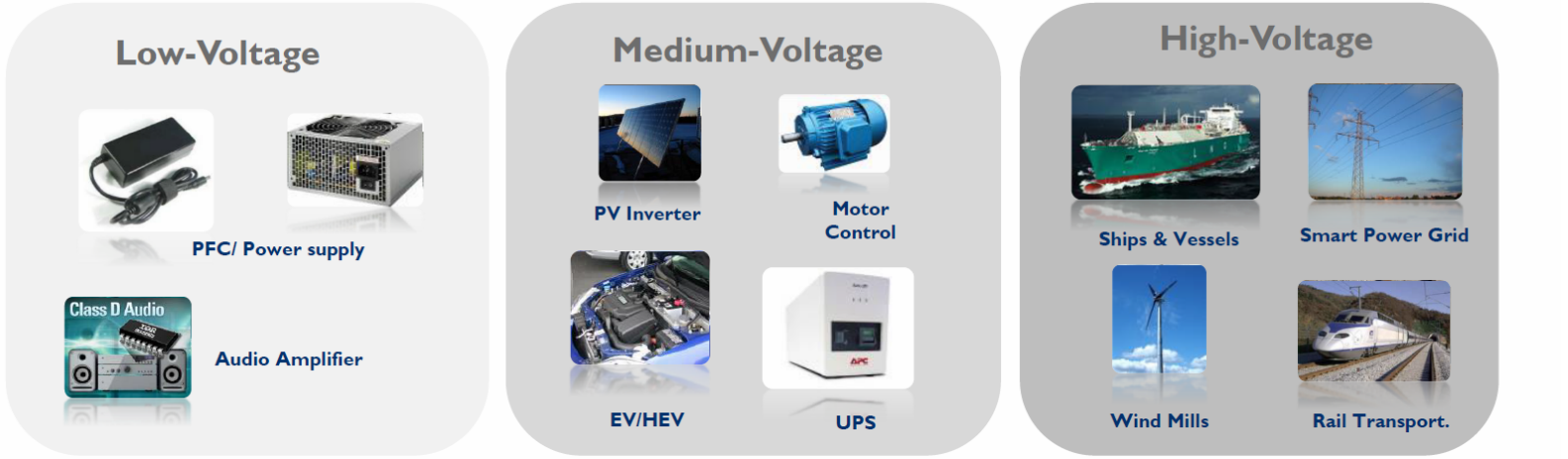
Lead Applications for SiC & GaN

WBG MARKET SEGMENTATION AS A FUNCTION OF VOLTAGE RANGE

Current status and Yole's vision for 2020*

While SiC is used for high voltage applications, GaN is mainly used for low voltage. The 600-900V range will be the battlefield.

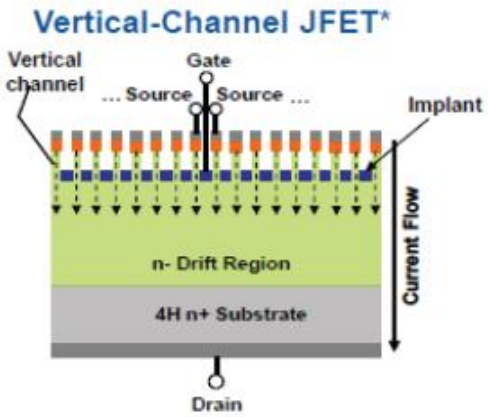


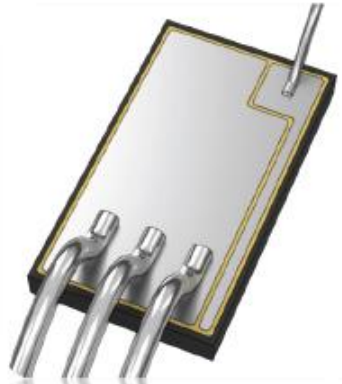
* Based on current development status

YOLE Développement

PV Systems with SiC Transistors

- A short ride through the experience of getting the first SiC transistor design win in a production PV Inverter program.
  - SJEP120R100 Enhancement-mode SiC JFET from SemiSouth
  - SMA Solar Technology AG (SMA) Sunny Tripower 20000TLHE-10
  - 20-kW, grid-connected, transformerless three-phase inverter
  - 99.2% efficiency
  - 580-800 VDC input range





Heinz Neuenstein and Matthias Krause, "The inverter with a plus," Photon International, http://www.photon.info/upload/Musterbericht_aus_PI_12_2011_3241.pdf

Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Energy Systems

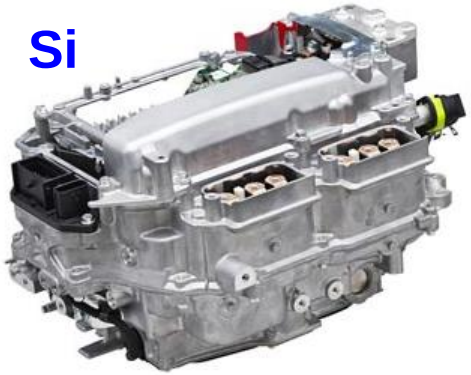
- Every kWh is cash!
  - Back of an envelop calculation
    - how much more expensive is the converter
    - how much efficiency do I gain
    - how much is the payback
  - True for large systems and for everybody's PV-installation
- Market!
  - Market for large systems is small
  - Market for home-systems is under extreme pressure
    "why should I buy an even more expensive converter to gain in the future, if I can buy a cheaper from China and safe in the first place already?"
  - As subsidies (feed in tariffs) getting smaller
    efficiency is less of an argument

Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Mobile Systems: Automotive

- Any mobile system should benefit
  - Higher efficiency is higher range or smaller storage
  - Smaller volume and lower weight of the converter and cooler
  - By leverage effect even smaller volume and lower weight of the storage
- Good example is Toyota
  - 10% fuel savings targeted, 5% achieved on prototypes already
  - Power control unit down to 20% of volume, weight from 18kg down to 4kg
  - On the market in 2020

Si



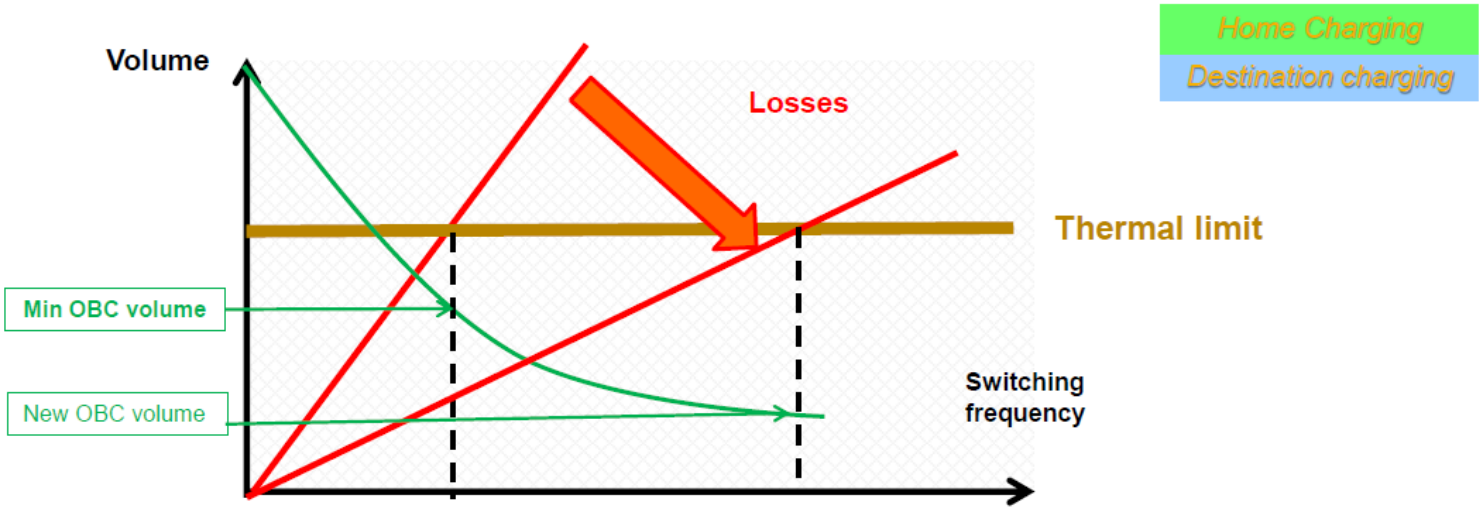
SiC

Source: Toyota

Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Automotive / EV Application: On-Board Charger

WBG push OnBC advantage versus OffBC => increase POWER and decrease COST and VOLUME.



GaN or SiC benefits:

GaN : Gallium Nitride
SiC : silicone Carbide

- **High Efficiency & switching frequency**

➔ high power density

- **High temperature resistance**

➔ Air or hot water cooling

GaN or SiC challenges:

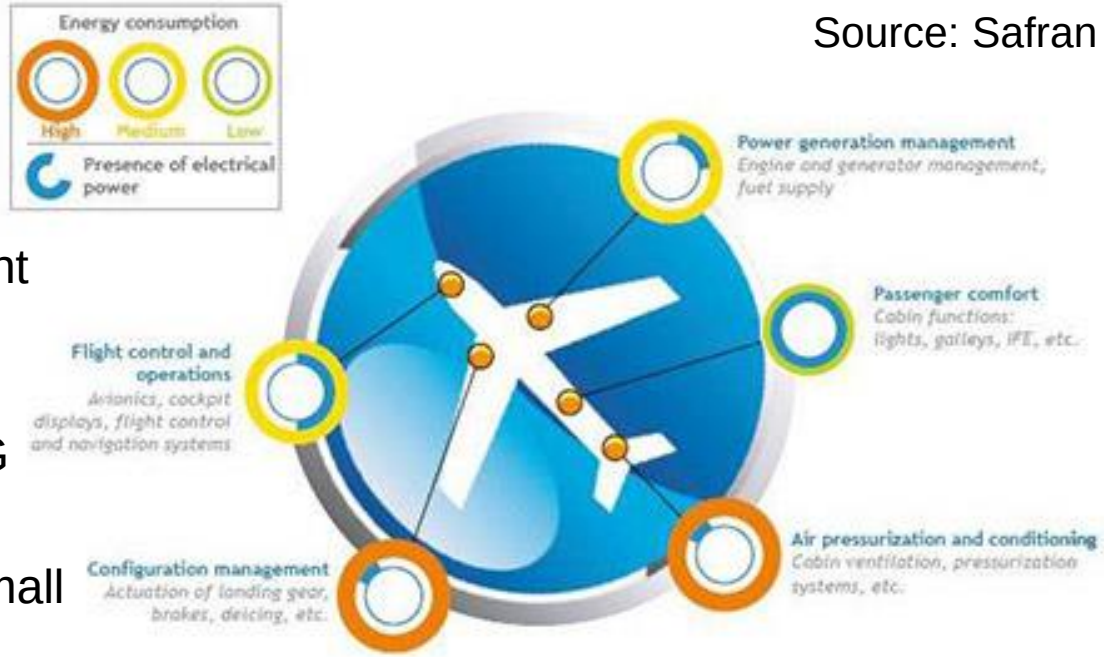
➔ All OnBC layout to be restudied
➔ All OnBC components to be requalified
(new passive components needed)

Source: R. Lassartesses, Renault @ ECPE Workshop ´PE for e-Mobility´, 22-23 June 2016

Mobile Systems

- Aviation
  - Higher efficiency even more beneficial
  - Lower volume and weight even more beneficial
  - Reliability requirements extremely high (no WBG rel. track record yet)
  - Market volume rather small

Source: Safran



- Handheld
  - SiC-Schottky did a great job in switched-mode power supplies
  - At low voltages silicon is good (enough) and really cheap
  - In general, too short lifecycle
  - Price pressure

Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Lead Applications for SiC & GaN

Possible Lead Applications …

… for SiC:

- Automotive: on-board charger, DC/DC converter
- Railway traction
- MV grid applications: wind power, PV, SST, circuit breaker
- MV application in medical technology
- New applications (not replacing Si in existing fields) e.g. hybrid airplane
- ?

… for GaN:

- PFC/Power supplies with very high frequency
- Automotive: on-board charger, DC/DC converter
- Industrial automation and robotics
- PV home systems
- ?

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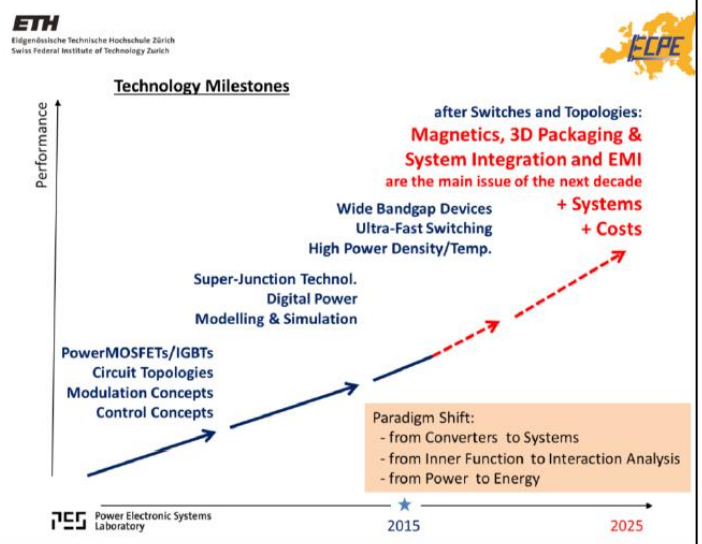
ECPE Position Paper ´Next Generation Power Electronics based on WBG Devices - Challenges and Opportunities for Europe

ECPE Position Paper

on

Next Generation Power Electronics based on Wide Bandgap Devices

- Challenges and Opportunities for Europe



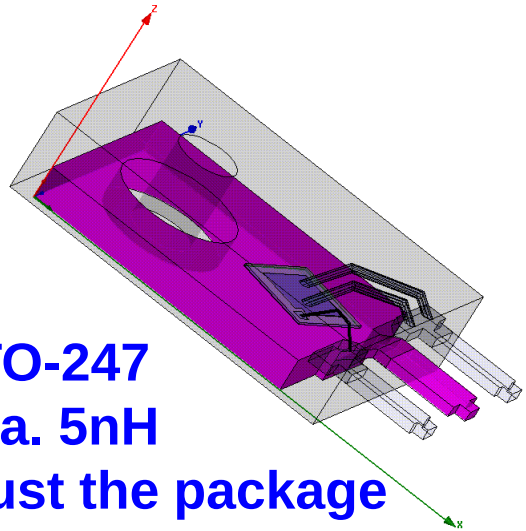
Authors: Core Team from the ECPE WBG Working Group:

- Dr. Peter Friedrichs, Infineon Technologies
- Prof. Dr. José Millán, CNM Barcelona
- Thomas Harder, ECPE
- Prof. Dr. Nando Kaminski Univ. Bremen
- Prof. Dr. A. Lindemann, Univ. Magdeburg
- Prof. Dr. Leo Lorenz, ECPE
- Dr. Lothar Schindele, Robert Bosch
- Peter Ward, Anvil Semiconductors

Index of contents:

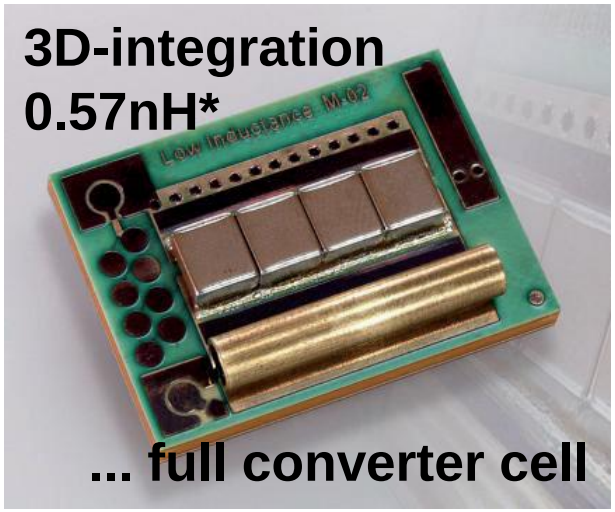
Packaging & Parasitics

- Old boundaries are moving or dissolving
  - traditional chips-package-circuit separation will not work for the future
  - no chance to exploit WBG devices' capabilities due to parasitics
  - package and circuit will merge, no discretes, no explicit package anymore
  - challenge for high current and high voltage even bigger



TO-247
ca. 5nH
just the package

vs.

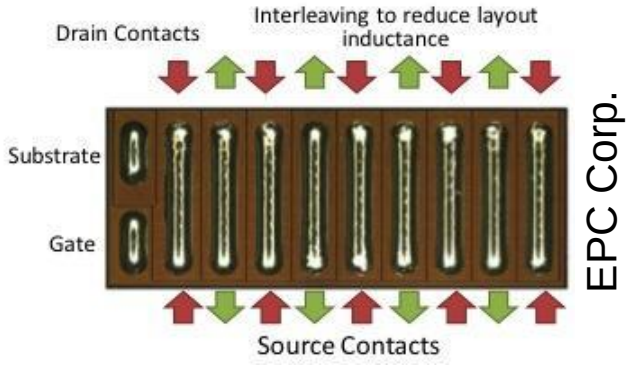


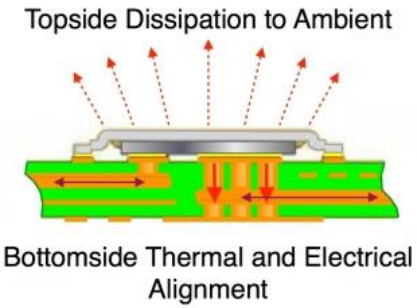
FhG-IZM Berlin, CIPS '14
* plus 0.3nH for the current sensor
(ECPE project demonstrator)

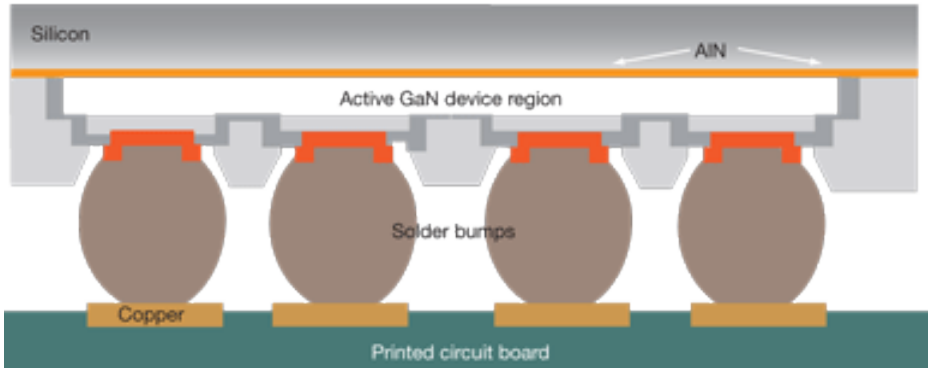
Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Packaging & Parasitics

- Alternative approaches
  - chip-on-board is one possibility (bare die mounting, flip-chip like EPC)
  - insulation requirements vs. inductance
  - is air considered a reasonable and reproducible insulator?
  - cleanliness requirements for circuit integration increasing a great deal
  - for cooling both sides have to be firmly attached ➔ mechanical forces
  - which are reliability implications (mechanics, contamination, corrosion, ...)?



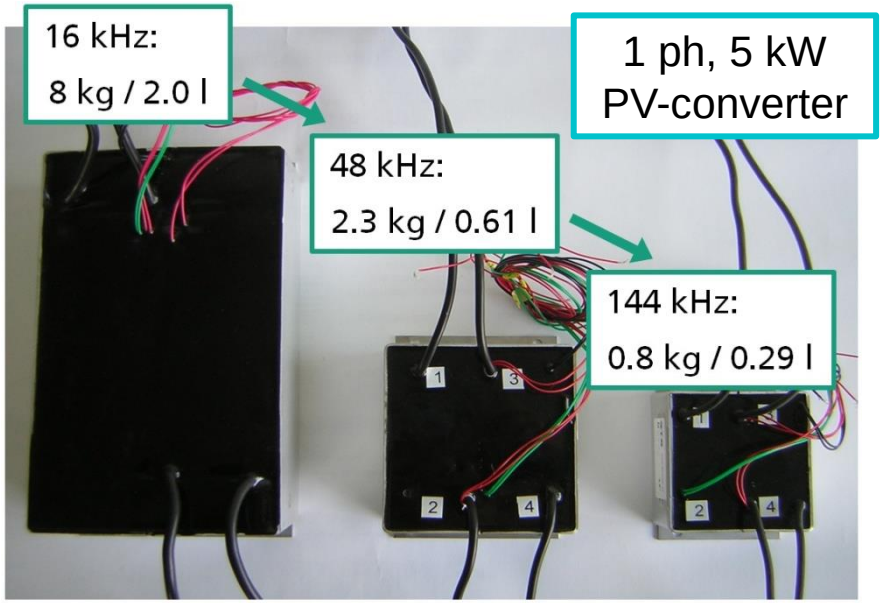




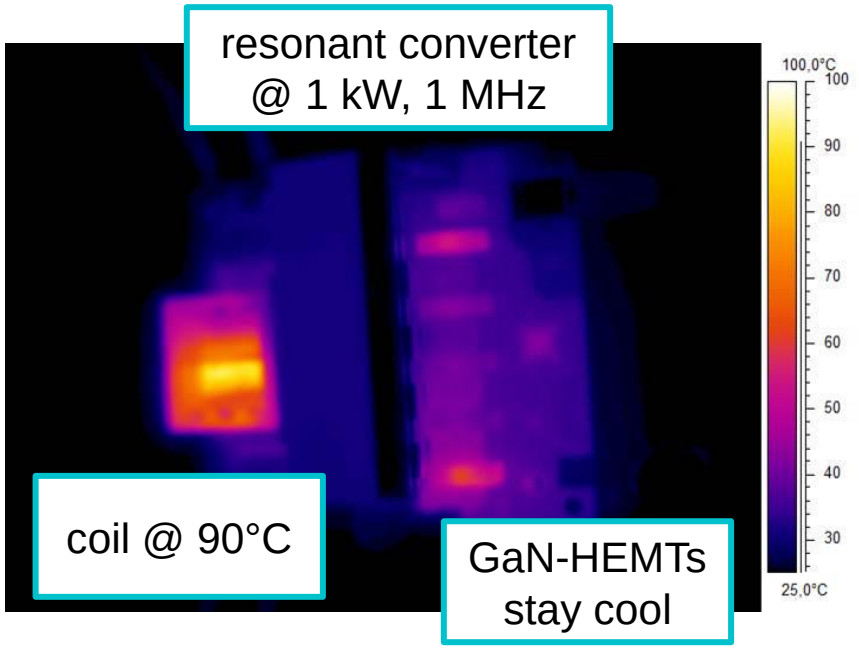
Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

Limitations due to Passives

- Minimisation of passives requires high frequencies
  - Volume and weight about inversely proportional to frequency
  - Every switching cycle causes losses
  - Losses density increases non-linearly



Source: FhG-ISE, Freiburg



Source: FhG-ISE, Freiburg

Source: ECPE Roadmap Workshop ´Power Electr. 2025´, Munich, 26.03.2015

ECPE Position Paper ´Next Generation Power Electronics based on WBG Devices - Challenges and Opportunities for Europe

Key statements:

Apart from WBG device development the WBG system integration is necessary to exploit the potential.

- Packaging and system integration technologies enabling low parasitic inductances to master EMC issues
- Packaging and system integration technologies enabling reliability at higher temperatures
- Handling higher voltages on package/module level and system level**:** SiC in medium voltage (MV) applications e.g. in traction and industry
- Low inductance packaging and integration technologies: powerPCB with chip embedding, system-in-package (SIP), switching cell in a package
- Passive components for fast switching: mainly inductors, reduce losses at high switching frequencies, thermal management of (integrated) passives
- Characterisation, testing, modelling and reliability analysis of WBG packages, modules and converters

Conclusions

After many years of (funded) research in SiC materials and device technology we see more and more devices entering the market from various suppliers in Europe, Japan and US. One might conclude that SiC/GaN is finished as research topic incl. the public funding. But the opposite is true.
Research effort should be increased, as we see this in US with the new SiC programme announced by President Obama. Joint research should be extended from device technology to wide bandgap system integration involving all necessary technology and supply steps along the value chain of WBG power electronics.