SiNANO-NEREID Workshop:

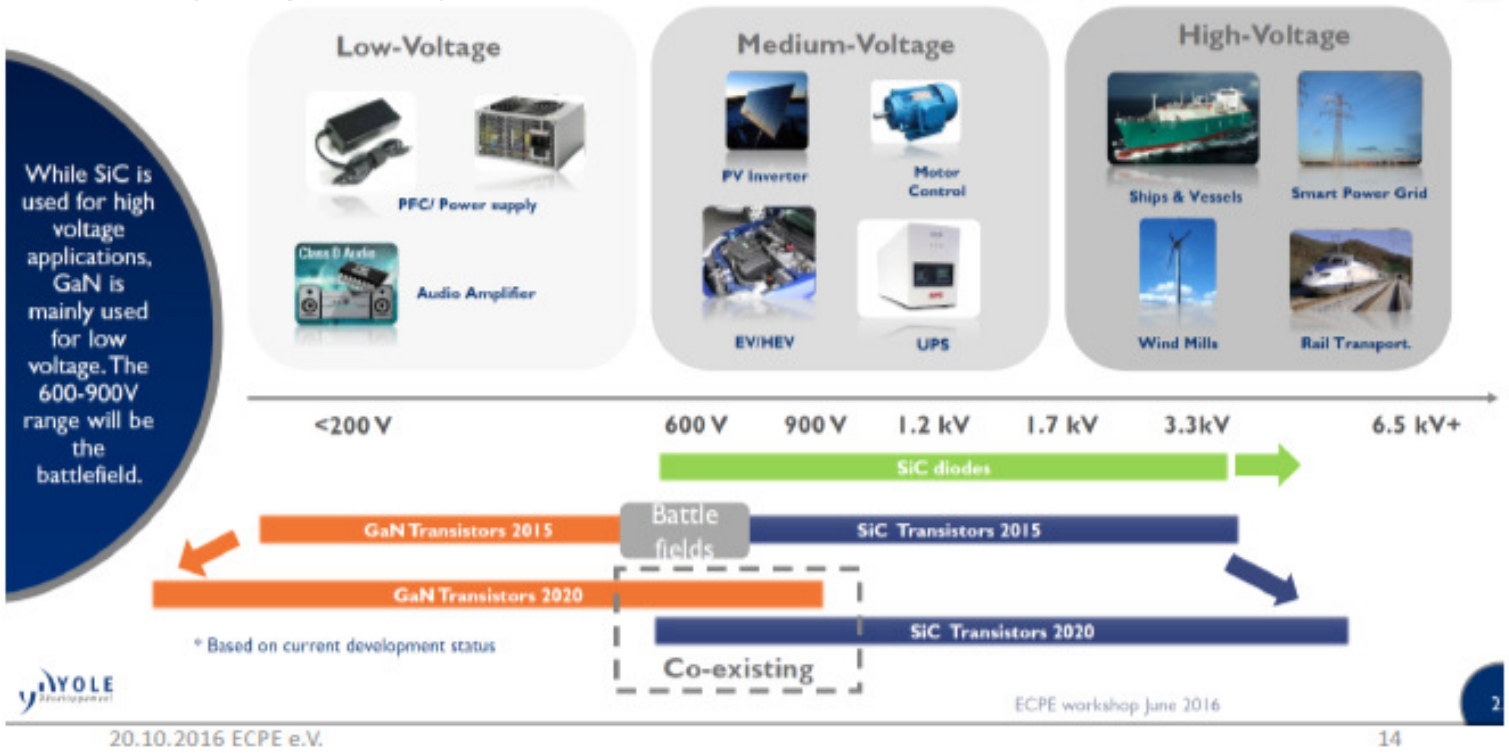
Towards a new NanoElectronics Roadmap for Europe

Leuven, September 11th, 2017

WP4/Task.2

Introduction: Technologies/concepts covered by the Roadmap SMART Energy

- Power semiconductors
  - SiC
  - GaN
  - Si
- Packaging and passives for advanced power semi-conductors (high power & speed)
- System-level: Topologies for power conversion & control



Summary

- 1. Introduction
  - Societal challenges
  - Potential for power semi-conductors
  - General trends in power electronics
  - Technologies & applications
- 2. Selection of technologies & applications
- 3. Key figures of merit of devices
- 4. Challenges & issues
- 5. Roadmap
- 6. Current trends
- 7. Conclusions

Introduction

- These technologies, falling under the denomination of “More than Moore”, do not scale simply with geometrical size, and are widely diversified; **therefore new metrics will have to be identified for the roadmap**. It includes two main Tasks:
- T4.1 Smart Sensors
- **T4.2 Smart Energy**
  - **Europe has a lead in this area. Two of the three leading power companies are European**
    - **Infineon (#1), STM (#3)**
    - **On-Semi (#2) has branches in Europe**

The story…

Global Warming

Energy Conservation

Renewable Energy

Improving the Efficiency

Electrical Conversion

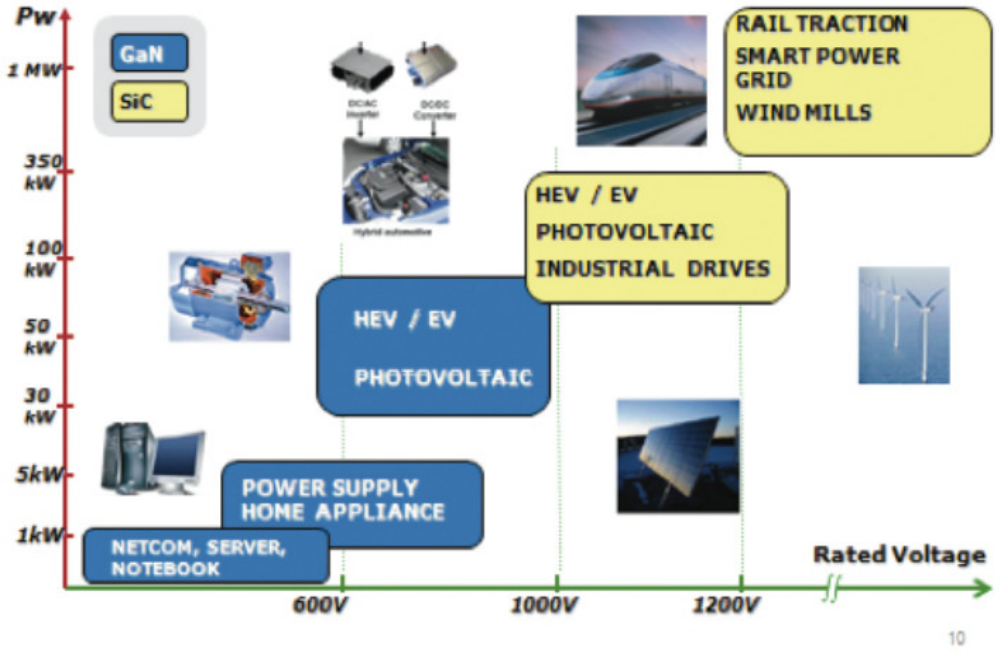
Power Devices

At least 50 % of the electricity used in the world is controlled by Power Devices.

B.J. Baliga, Advanced High Voltage Power Device Concepts, Springer

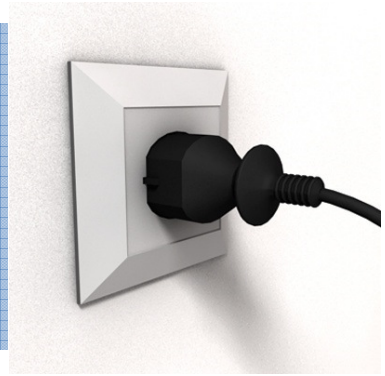
Introduction

- Global challenges require a rethinking of the energy infrastructure
- Integration of renewables on the grid
- Electrification of transport sector
  - Smart control of power supply & demand to integrate renewables in the grid
  - Tighter integration of control logic with power electronics
  - Increase overall efficiency of our energy distribution system

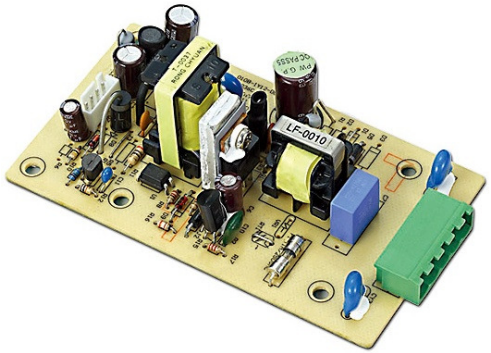


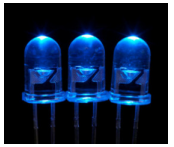
Energy conversion and management...

Input power

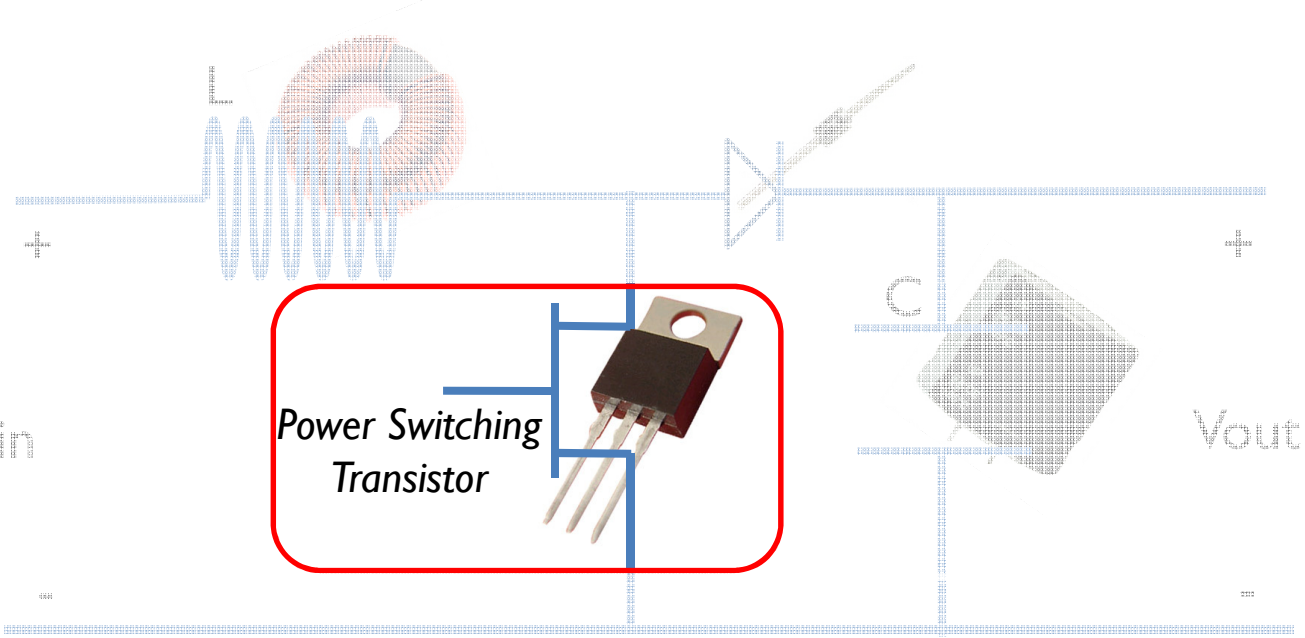


Convertor

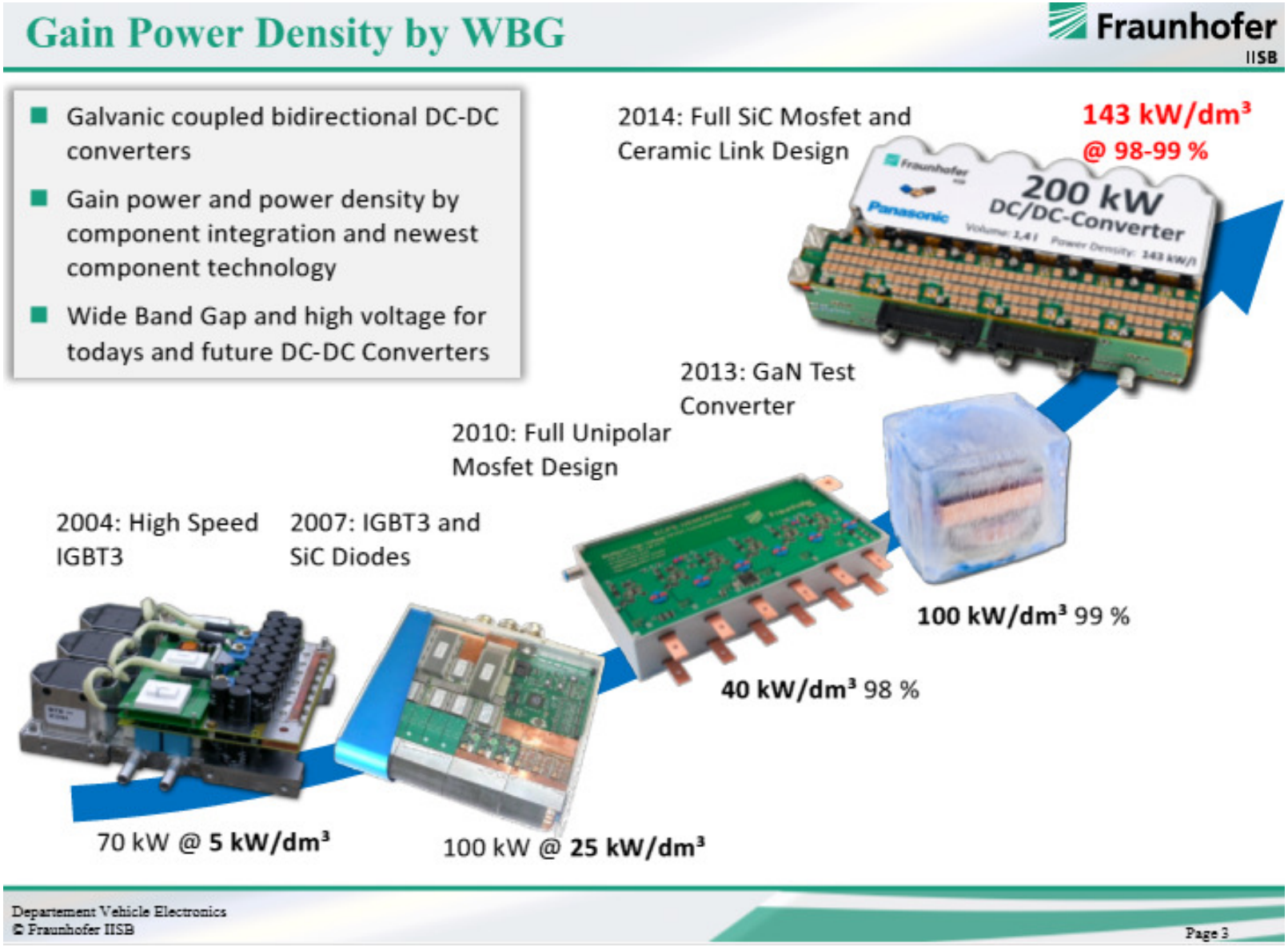




Output Power



The potential …



System benefit …

Mobile Systems: Automotive

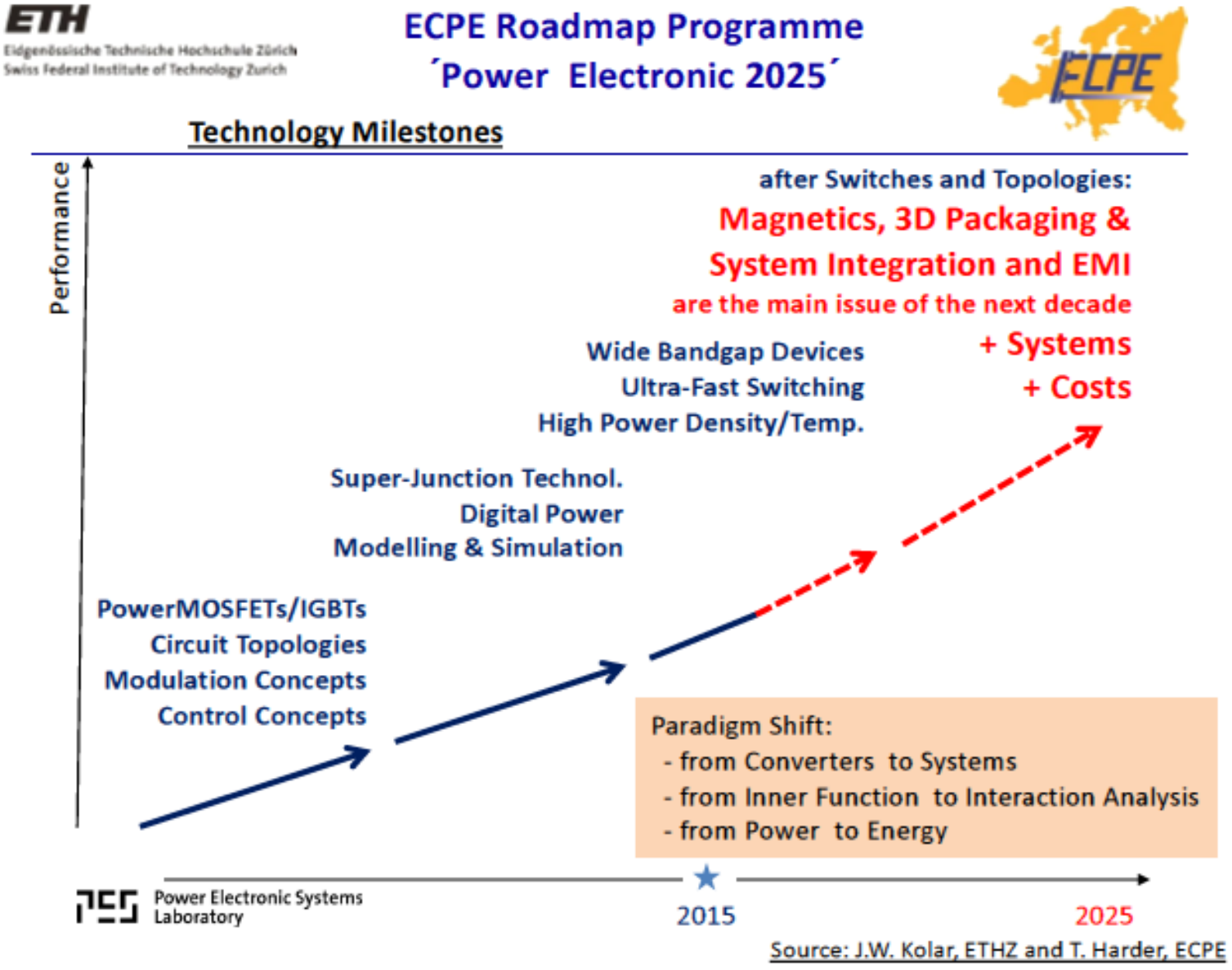
- Any mobile system should benefit
  - Higher efficiency is higher range or smaller storage
  - Smaller volume and lower weight of the converter and cooler
  - By leverage effect even smaller volume and lower weight of the storage
- Good example is Toyota
  - 10% fuel savings targeted, 5% achieved on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

Source: Toyota

Universität Bremen

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

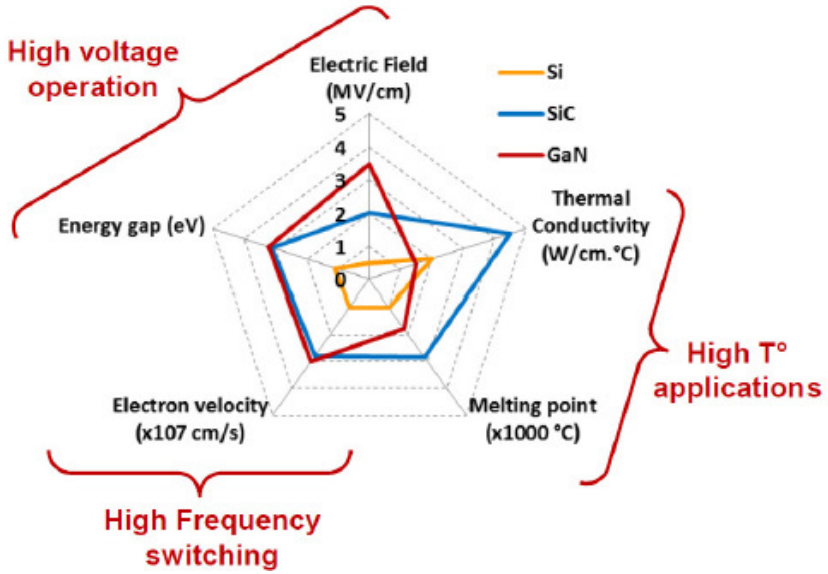
Trends…


ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
ECPE Roadmap Programme
´Power Electronic 2025´
ECPE
Technology Milestones
Performance
after Switches and Topologies:
Magnetics, 3D Packaging &
System Integration and EMI
are the main issue of the next decade
Wide Bandgap Devices
Ultra-Fast Switching
High Power Density/Temp.
+ Systems
+ Costs
Super-Junction Technol.
Digital Power
Modelling & Simulation
PowerMOSFETs/IGBTs
Circuit Topologies
Modulation Concepts
Control Concepts
Paradigm Shift:
- from Converters to Systems
- from Inner Function to Interaction Analysis
- from Power to Energy
Power Electronic Systems Laboratory
2015
2025
Source: J.W. Kolar, ETHZ and T. Harder, ECPE

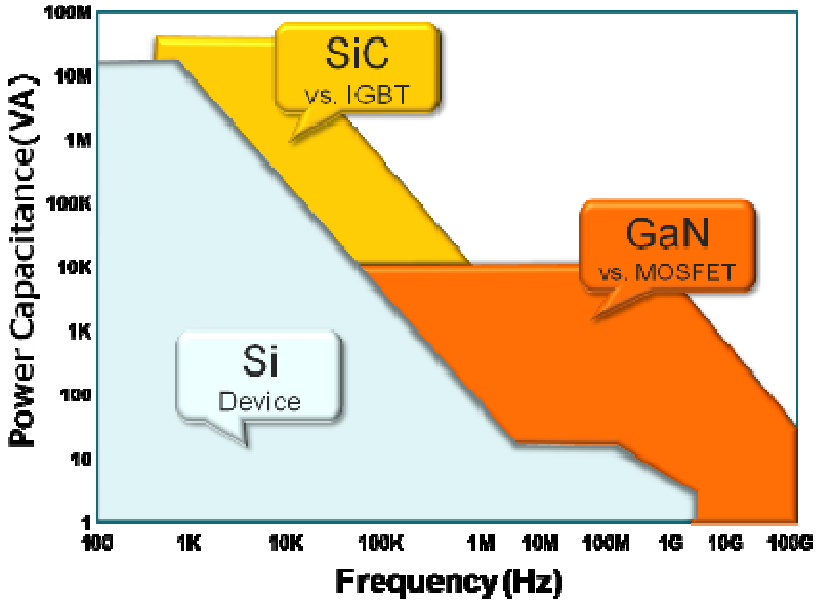
2. Selection of Technologies

- WideBandGap semiconductors will partly replace and extend the market for Si power components
  - SiC & GaN
  - Enablers for breakthrough efficiencies & novel applications

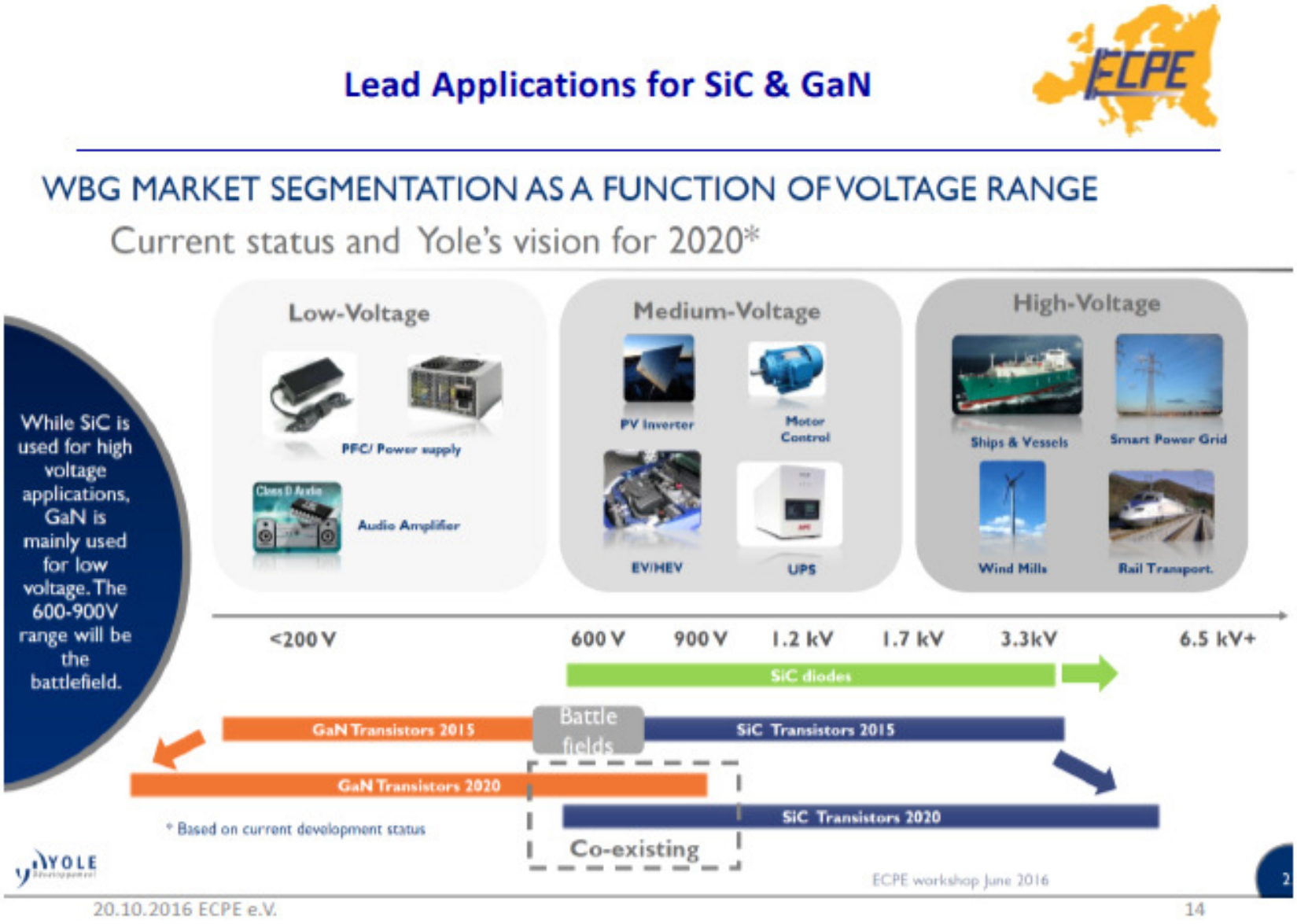
Improved material properties...



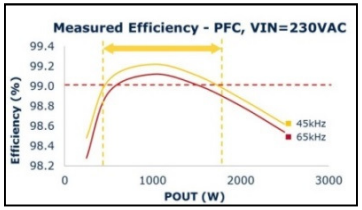
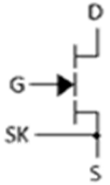
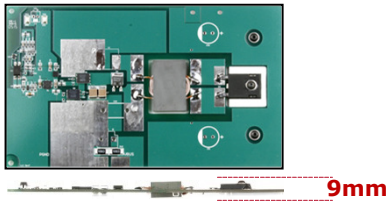
... Leading to improved power switching capabilities



Potential for application



Potential for application (GaN)

What?	How?	Why?	Where?
› **100V and 600V** Enhancement (E) mode GaN HEMT › Single chip, **normOFF** transistor › Robust, **reliable P-Gate concept**	› EMode **600V**, **DSO-20**: sampling prototypes with NDA	› **Efficiency**: very high efficient SMPS	› Example: **>2.5kW SMPS** in where op. cost matters
	 		
	Bottom/Top side Cooling	Highest efficiency PFC	Data centers
 P-Gate Enhancement mode GaN HEMT	› Emode **600V**, **TOLL**: sampling prototypes with NDA	› **Density**: very compact SMPS	› Example: **OLED TV** or other **200-800W SMPS**
			
	Low profile, small footprint	Ultra-thin SMPS	Ultra-thin TV
› **Fastest** normOFF concept available › Can be tailored for high efficiency or high frequency operation › Key for **integration** at chip and/or package level			

100V-200V Emode GaN for Efficiency and Density

3. Key figures of merit devices :

Device level

- Normally off – Vth > 2V
- Low gate leakage at maximum gate voltage
- Breakdown Voltage 650 V, 1200 V devices
- Ron vs Qg (efficiency vs speed)
- Dyn $R_{DS,ON}$ < 20% at maximum voltage
- Reliability/robustness > 20year
- Maximum operating channel temperature

System level point of view:

- Passive components
- Packaging (high power, low inductance, cooling, surface mount, ...)
- Gate drivers

4. Research questions & issues

Technological and **material** issues that need to be solved in order to guarantee a large market penetration of these devices;

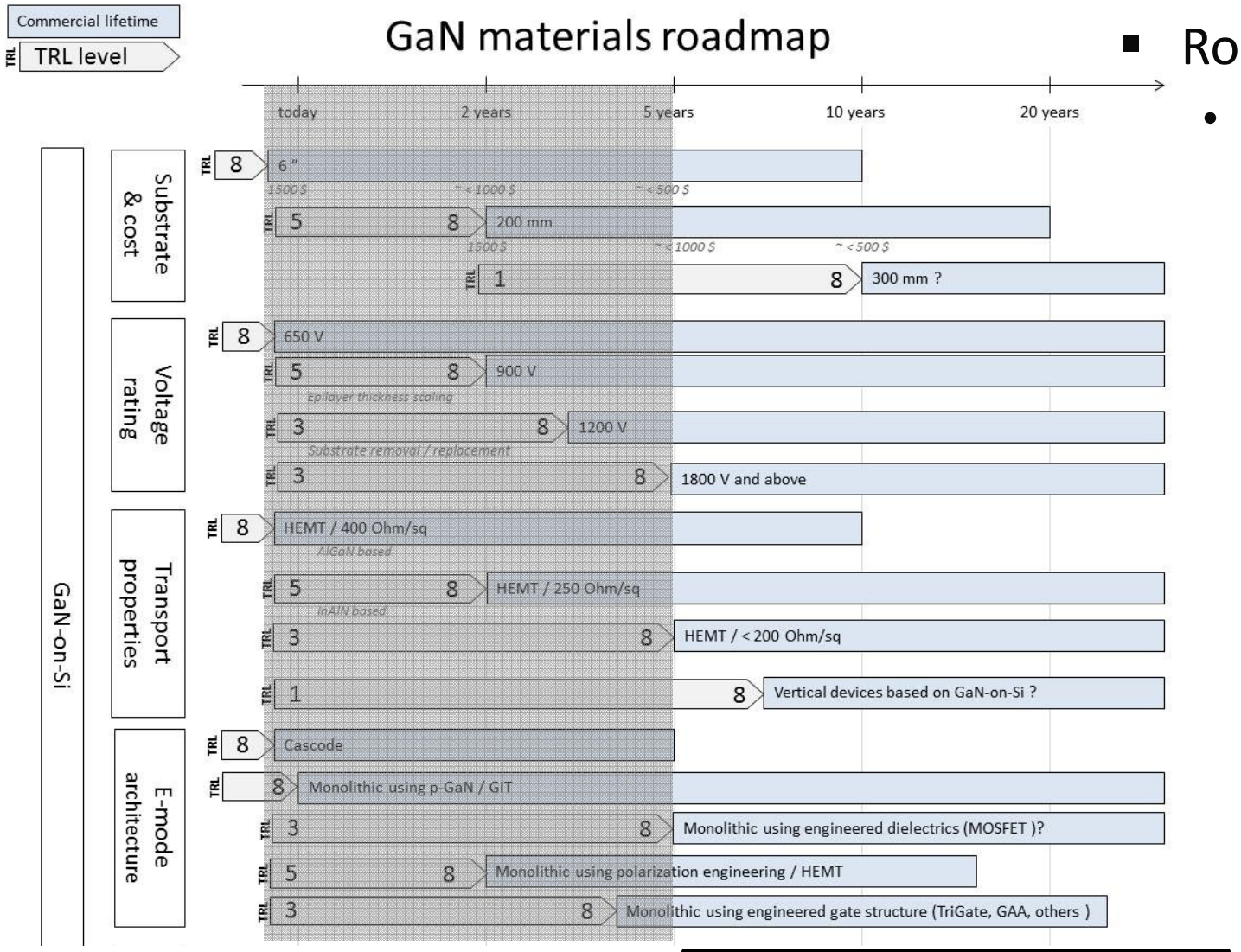
Technological and material issues

- Material (substrates, quality, reproducibility, supply chain, wafer size, maximum thickness for heteroepitaxial growth)
- Processing issues (contacts, gate, isolation)
- Normally off operation (hybrid or intrinsic)
- Isolated gate (MIS) devices
- Sustainable breakdown, Operational (rated) voltage
- Robustness (UIS, short circuit) & Reliability
- Passive components
- Packaging (high power, low inductance, cooling, surface mount, ...)
- Gate drivers
- …….

4. Technology challenges

- Customers want cost parity at the device level
  - Replace e.g. Si SJ device by a GaN device that yields at par or better system efficiency
- GaN-on-Si wafer cost is (too) high
  - Multi-wafer reactors/New concepts
  - Growth on CTE matches substrates (poly-AlN, …)
  - Others….to reduce growth time and Defect Density
  - 150mm versus 200mm (vs 300 mm ?)
- GaN Reliability is different from Si (JEDEC) and is not well enough understood—Need standardisation
  - JEDEC is a minimum requirement, but we need more (GaN specific testing like Dyn Ron, hard switching testing, surge current capability etc)

5. Roadmap for power components



- Roadmap Materials
  - ***GaN-on-Si***

Nereid relevant timeframe

5. Roadmap for power components

SiC Device Roadmap

Going for more compactness for power converters

Going for more technological maturity

Years	Si 4.5 kV IGBT or BIGT	4H-SiC 1.2 - 1.7 kV MOSFET JFET/BJT	4H-SiC 3.3 kV MOSFET	4H-SiC 6.5 kV MOSFET IGBT	4H-SiC 10.0 kV MOSFET IGBT	4H-SiC 15.0 kV IGBT	4H-SiC 20 – 30 kV IGBT GTO	AlN/ Diamond 30 – 50 kV IGBT/GTO
2016	√√√	√√	√	x	x	x	x	x
2018	√√√	√√√	√√	√	x	x	x	x
2020	√√√	√√√	√√	√	√	x	x	x
2022	√√√	√√√	√√√	√√	√√	√	√	x
2024	√√√	√√√	√√√	√√√	√√√	√√√	√√	√

x Fundamental potential exist but technological solution is not ready yet
√ Engineering die samples available. Probably not qualified chip. Complete package solution may not be ready yet.
√√ Qualified chip ready. Complete package solution probably ready to be tested in the field.
√√√ Fully mature and qualified chip is available along with qualified packaged power module to be tested in the field.

Source: Dr. Muhammad Nawaz, ABB, ESCDERC 2016 but modified

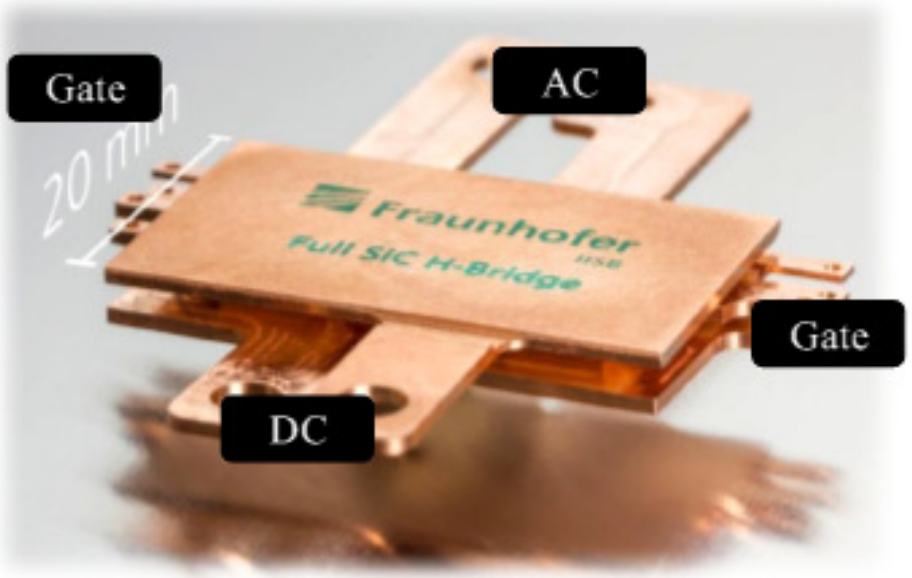
Trends... SiC Packaging

Technical Trends in SiC

Fraunhofer IISB

Innovative Modul Design

- Full Bridge - Busbar SiC-Modul
- Technologies
  - Chip on Busbar
  - Double Side Silver Sintering
- Module Data
  - max. 80A / 600V (1200V)
  - SiC-FETs
  - Silicium Puls Capacitors
  - Ultra Low Inductance
- Concept
  - Modular: H-/Half Bridge
  - Double Side Cooling
  - Small Dimensions

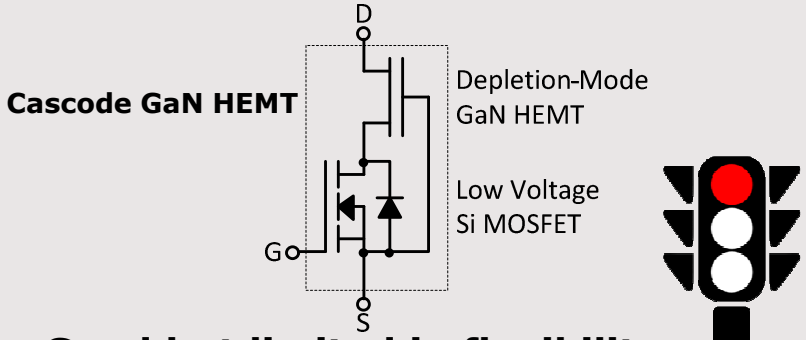


Current trends in industry (Infineon)

GaN HEMTs available configurations

CASCODE GaN

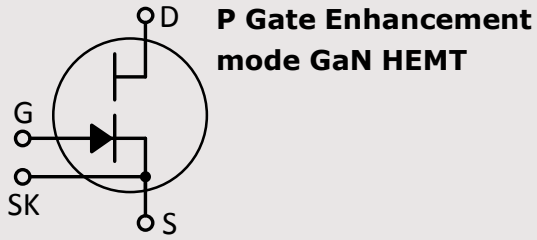
- Suitable for standard gate drivers
- Low Vf body diode
- Not ideally suited for multi-chip solutions
- Not scalable to low voltage
- Complex balance between the two chips



- **Good but limited in flexibility and performance**

ENHANCEMENT MODE GaN

- **Excellent for hard and soft switching topologies**
- **TurnON and TurnOFF optimized**
- **Needed for LV applications**
- **Key for integration at chip and/or package level**



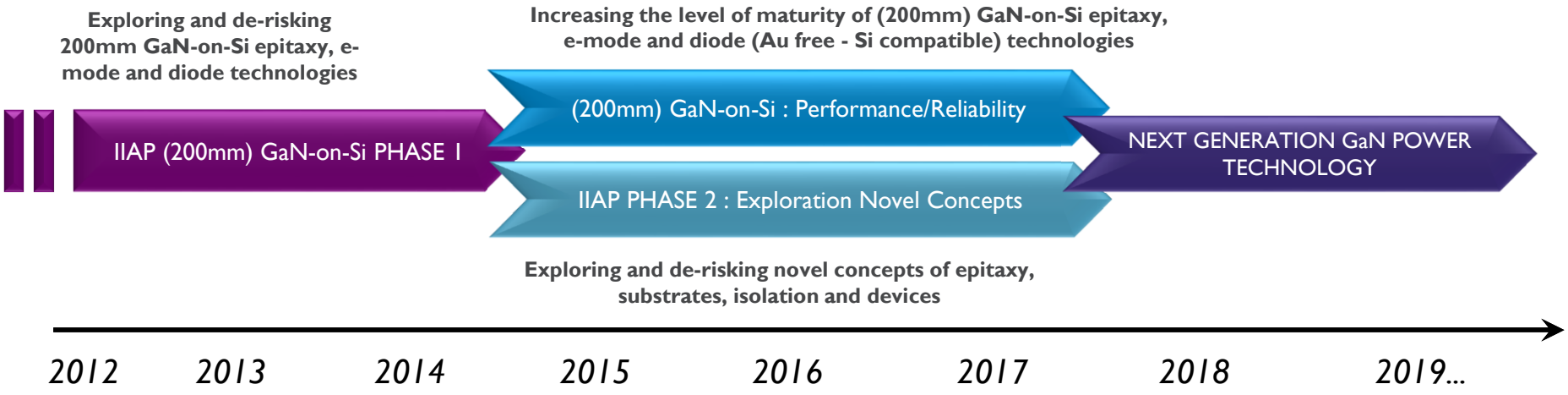
- **The technology for innovative solutions and high volumes**

Infineon is focusing on Emode GaN for all consumer and industrial applications, with the most robust and performing concept in the market

Current trends R&D (imec GaN Program)

HIGH LEVEL PLAN OF GAN TECHNOLOGY AT IMEC

TARGETING SHORT AND LONG TERMS NEEDS OF GAN

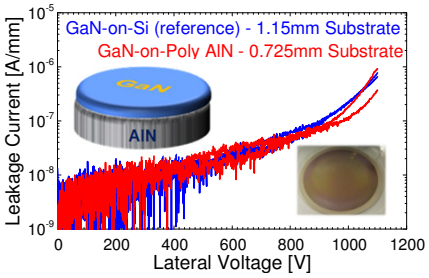


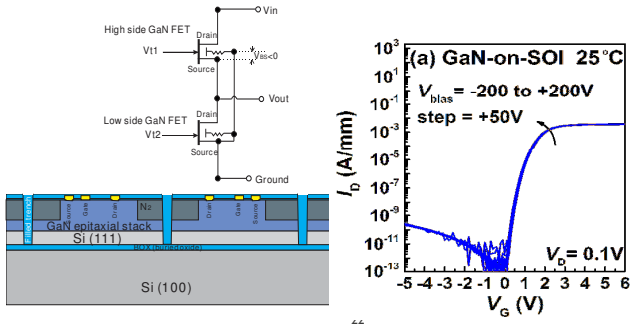
Current trends R&D (imec GaN Program)

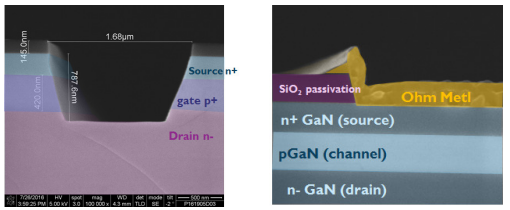
NOVEL CONCEPTS

Advanced substrates	Higher level of integration	Novel device concepts

▪ Advanced substrates
  ▪ Increased yield
  ▪ Reduced defect density
  ▪ Increased buffer thickness
▪ E.g. CTE matched poly-AlN substrates
  ▪ Thinner substrate
  ▪ Equivalent GaN buffer strength
	▪ Integration of high side and low side switches
	  ▪ Further cost reduction of the GaN technology
	  ▪ Reduction of interconnect parasitics (enable higher switching speed)
	▪ High-side/low-side isolation achieved by trench isolation.
		▪ Novel device concepts to improve device performance or enable novel applications for next generation GaN devices.
		▪ E.g. 200mm (semi-)vertical devices.
		  ▪ Preparation of vertical device technology and process modules in a CMOS compatible fab



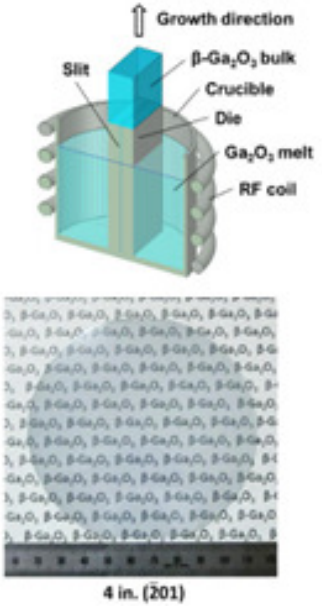


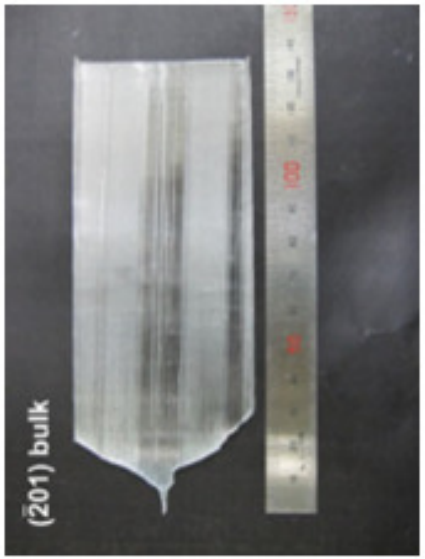


New technologies…

UWBG--Ga_2O_3 : E_c=8MV/cm

- Substrates by Edge Fed Growth idem to Sapphire. The only WBG material that can be grown from the melt (low cost, DD<10^4 cm^{-2}). Low thermal conductivity. No p-type doping.
- Epi by HVPE, MOCVD, MBE (β-Ga2O3) or MIST epitaxy (α-Ga2O3)
- Currently at 2" (cots). Expected 4" in 2018, 6" in 2022.
- Very good n-type doping control with very low resistivity.
- Publications on first 600V Schottky diodes and Transistors





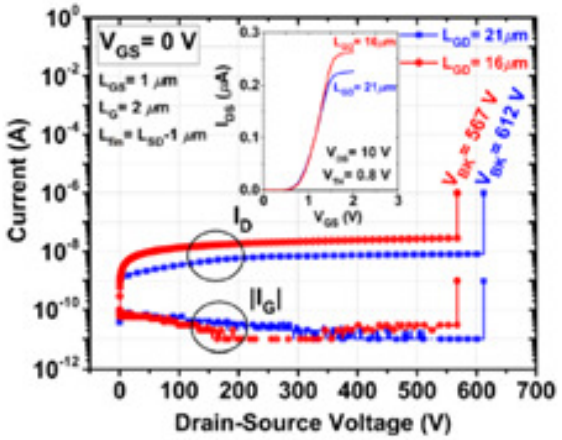


FIG. 5. The breakdown voltages of Ga_2O_3 finFETs with $L_G = 2\,\mu m$ and $L_{GD} = 16,\ 21\,\mu m$ while biased in the off-state at $V_{GS} = 0$ V. The inset shows the transfer characteristics of the same device indicating a $V_{TH} = +0.8$ V.

Conclusions

- Widebandgap semiconductors will cause a paradigm shift in power electronics design
  - SiC is the main contender for high voltage applications
  - GaN for medium voltage (600-1200V)
- System level will need to adapt
  - Novel, low inductive packages with excellent cooling properties
- Higher level of integration of power electronics with control logic
  - Co-integration