Challenges in Advanced Computing and Functionalities
International Cooperation on Semiconductors

Presentation of the preliminary ICOS results on International Technology Highlights on Advanced Functionalities

Markus Pfeffer, Fraunhofer IISB, Prototype Fab Management

Contributions by VTT, U-Ghent, IMEP-LaHC, KTH

Outline

- Overview of current trends and challenges
- Deep Dive
  - Sensors
  - Semiconductor-based photonics
  - Energy harvesting
  - Power devices
- Short Screening of research activities in other areas of advanced functionalities
- Conclusion and first ideas for potential fruitful research collaboration

Overview of current trends

Trends and drivers

- **Digitalization**, analogue measurement results are immediately digitized on-site
- **Wireless connectivity** for IoT devices, easy, low cost installation of sensor devices
- **Autarctic systems,** wireless connectivity and (desired) freedom from disposable batteries increase the need for energy harvesting
- Access to powerful computation **(Edge) AI** increases the usage for data producing sensors
- **Fusion of sensor data** from different sources enable new, improved, smarter data to be available for users
- **Data security and reliability**, data should be accurate and reliable, it should not be available to wrong hands, …
- **Electrification of transportation** and **energy conversion** require efficient **power devices**

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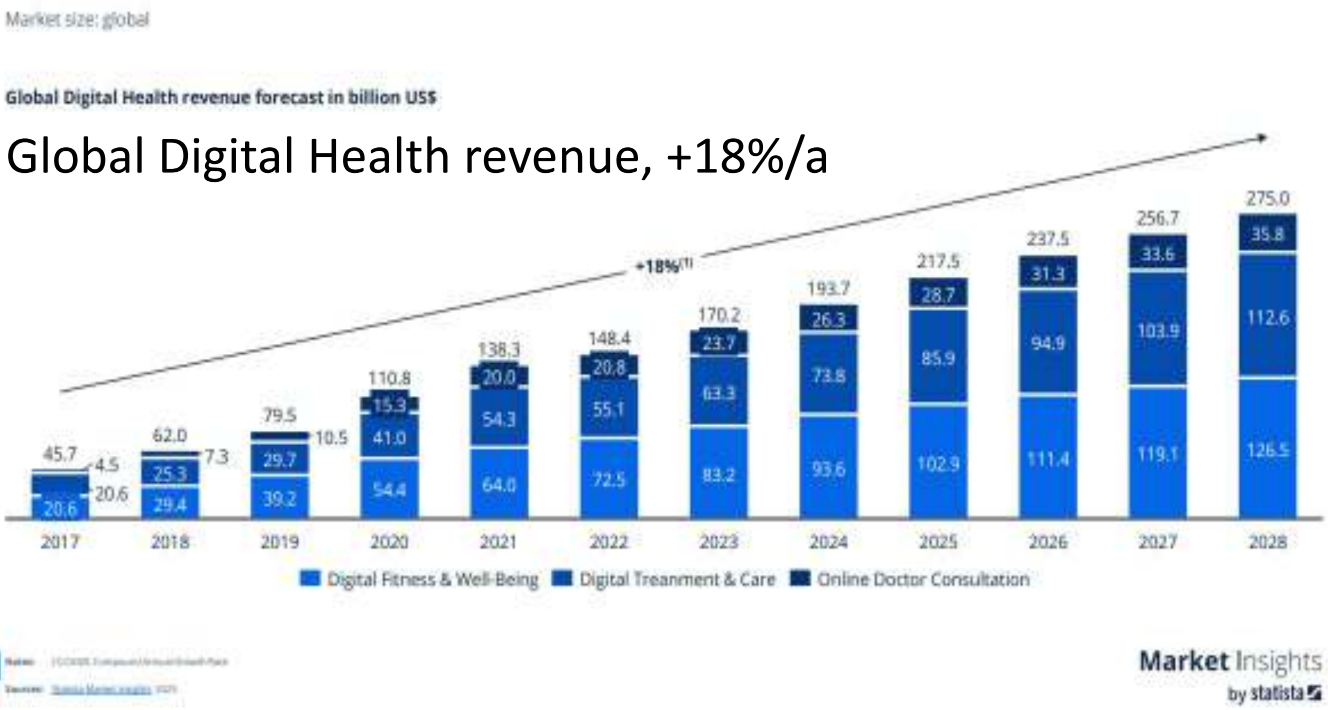
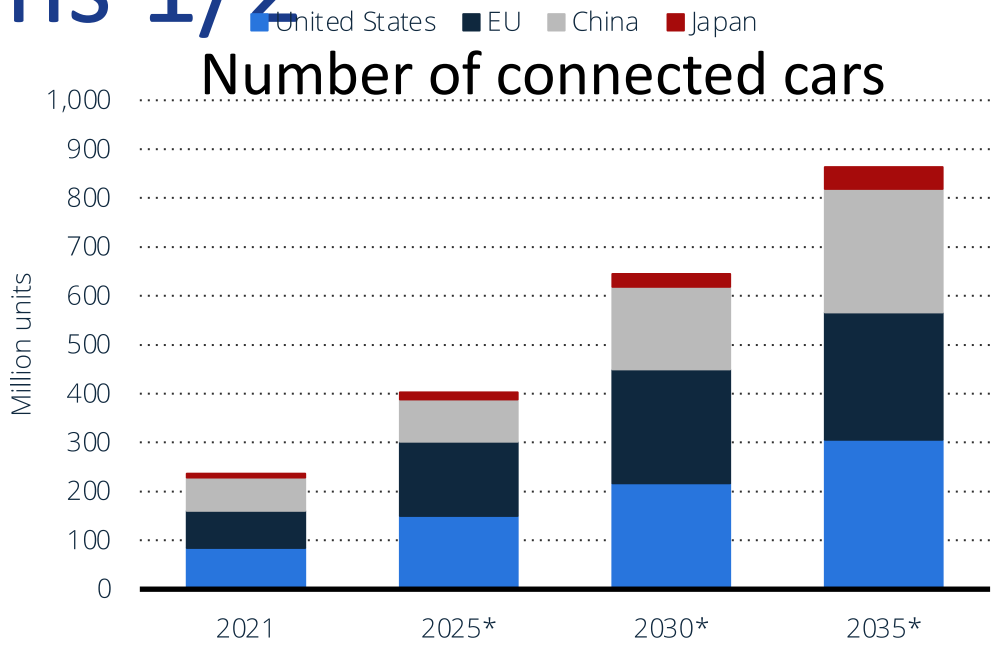
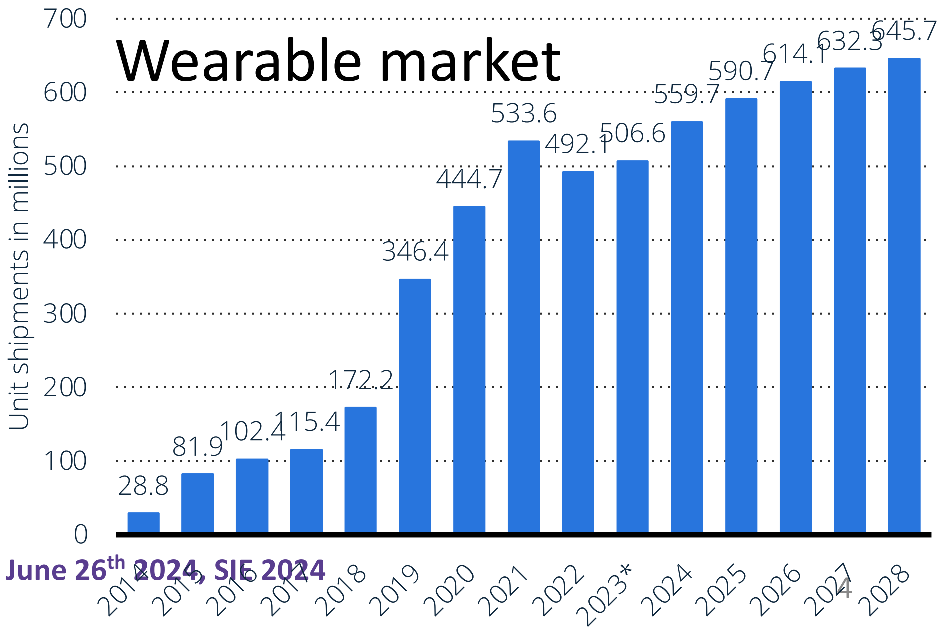
Applications 1/2

- Automotive/Transport (perception)
- Health / Well being / Vital Signs

Global Digital Health revenue, +18%/a

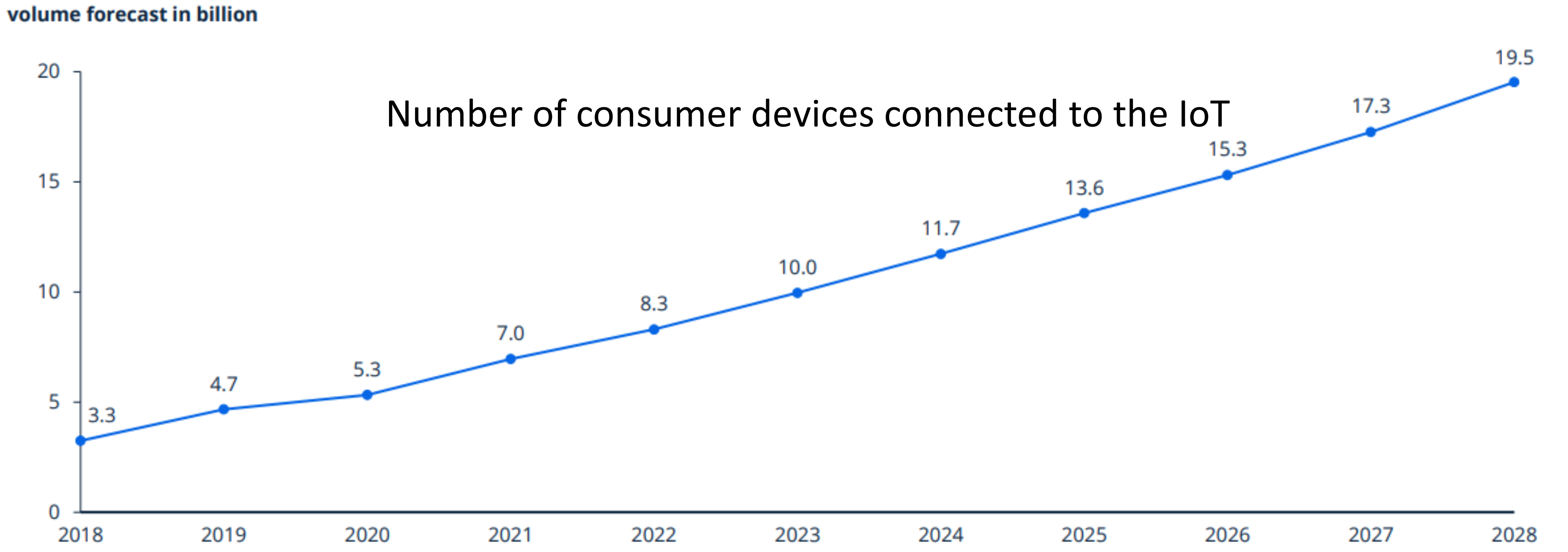






Applications 2/2

- Environmental /Built environment
- Industry / Robotics
- Aerospace/Defense/Security
- Consumer
- IoT



Notes: (1) CAGR: Compound Annual Growth Rate

Sources: Statista Market Insights 2023

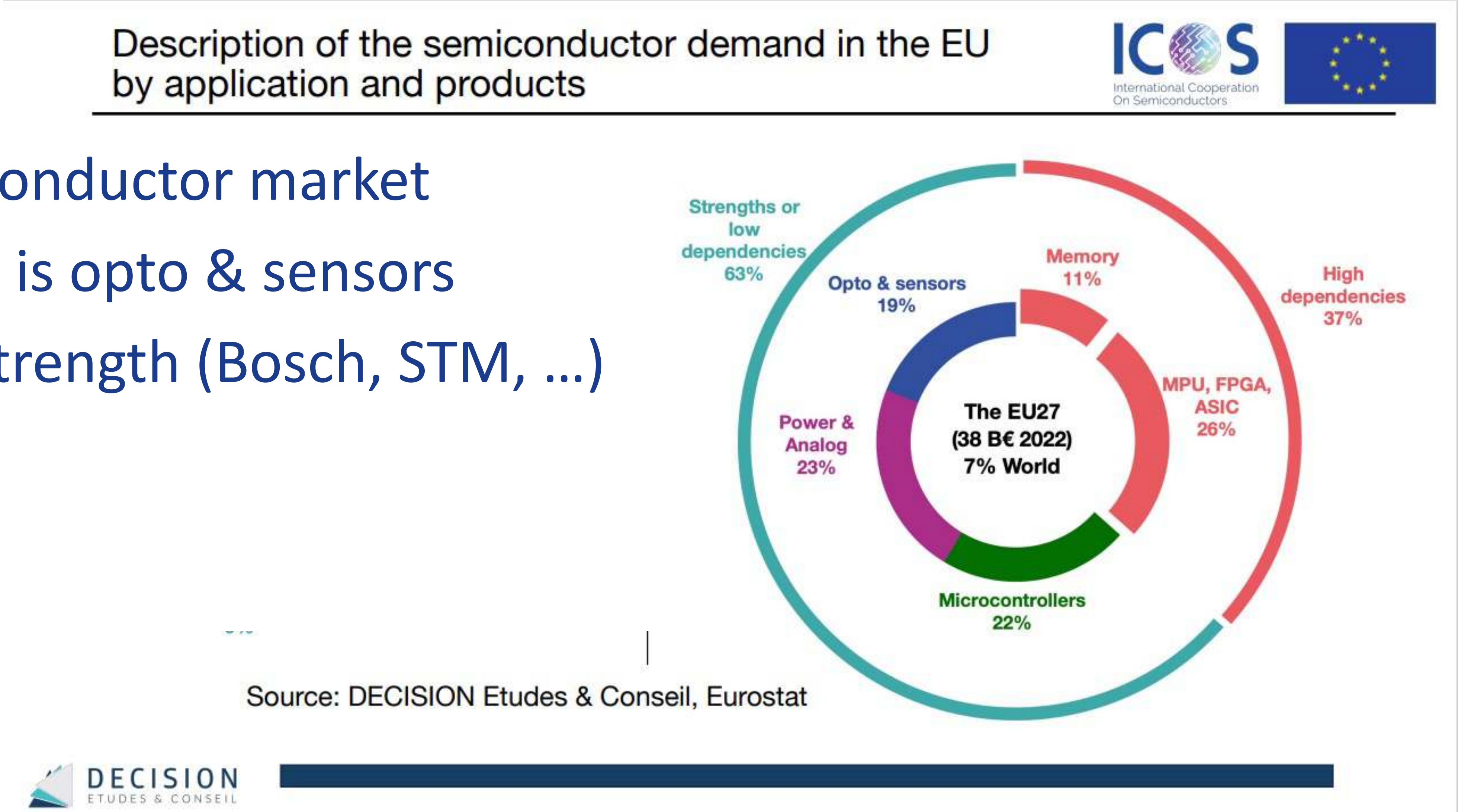
Market Insights by statista

Sensors

- Inertial sensors (accelometers, gyroscopes)
  - Bosch, STM, Murata
- Acoustics (microphones, loudspeakers, ultrasonic transducer)
  - Piezoelectrically driven MEMS are emerging
- Photonics/imaging (camera, spectral sensing, hyperspectral, lidar, …)
- RF (radar, JCAS)
- Others (temperature, pressure, flow, …)

EU market

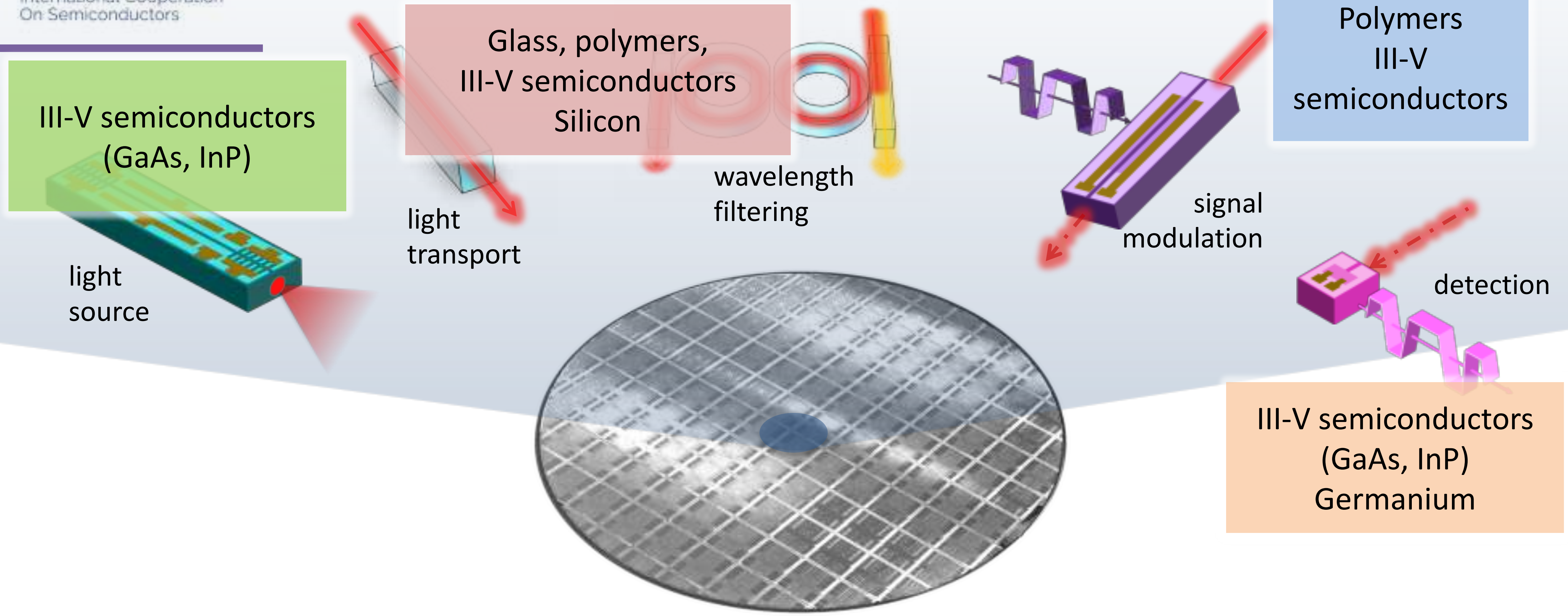
- 38B€ semiconductor market
- 19% of that is opto & sensors
- European strength (Bosch, STM, …)



Semiconductor-based photonics

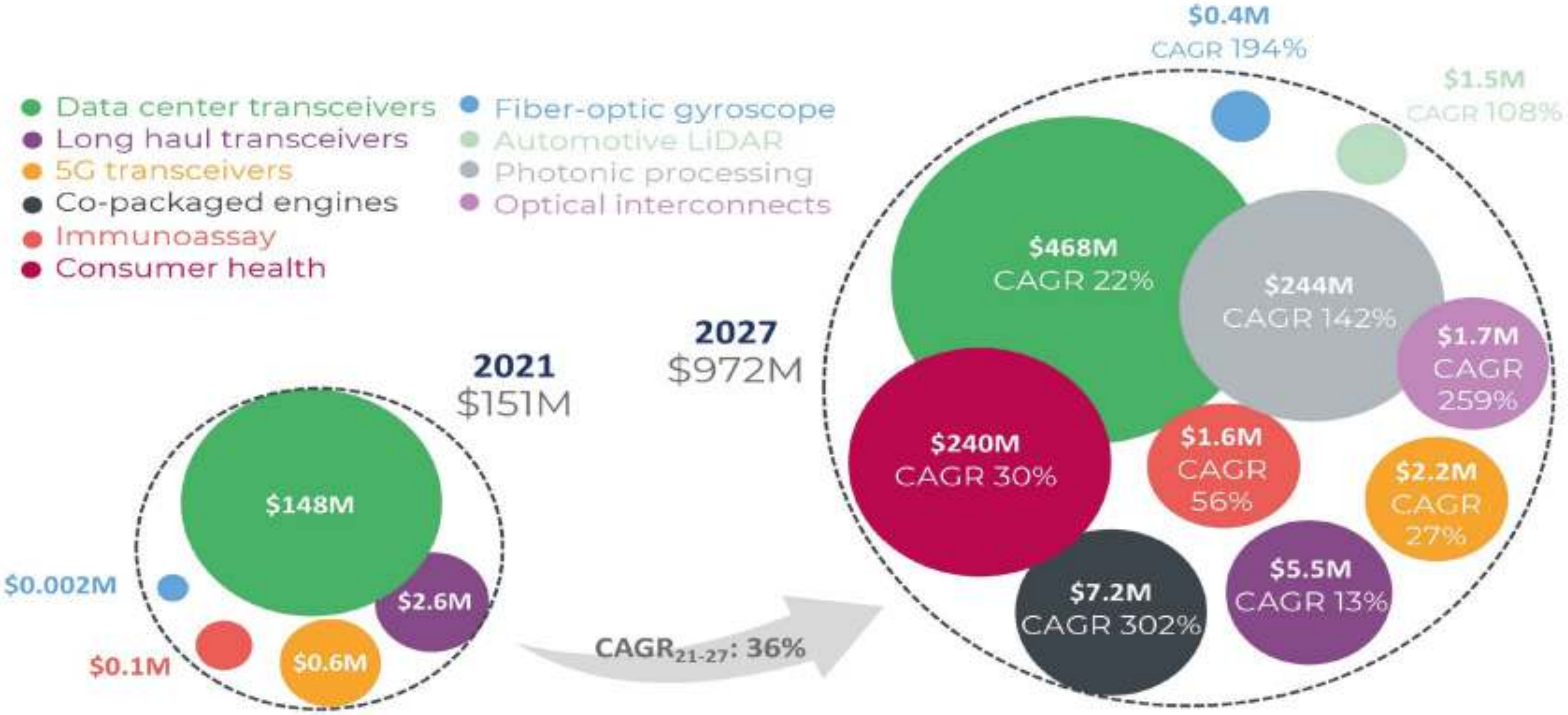
Wim Bogaerts (U Ghent)

Photonic Integration: A mix of materials



2021-2027 SILICON PHOTONIC DIE FORECAST BY APPLICATION

Source: Silicon Photonics 2022 Report, Yole Intelligence, 2022



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Summary

- Silicon photonics rides on the developments of CMOS
- The main driver today is transceivers (mostly US and Asia)
- No high-end, high-volume foundries in Europe
- Europe has great R&D, design tools, packaging, …
- Performance needs are driving heterogeneous integration

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Energy Harvesting: review of the main EU and international activities and technologies

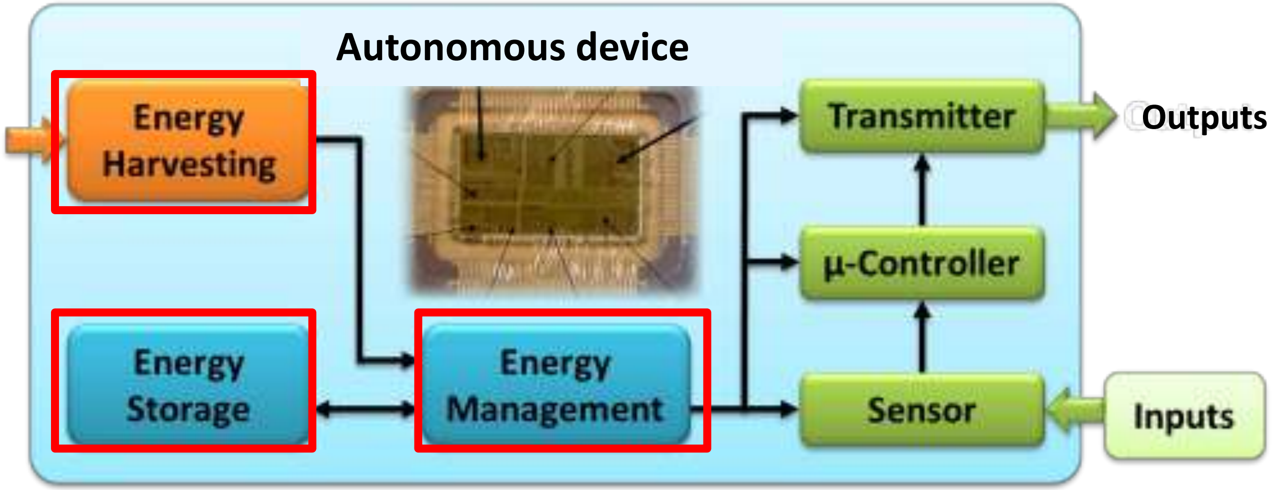
Gustavo Ardila (IMEP-LaHC)

ICOS WORKSHOP – June 26th 2024, SIE 2024

Energy Harvesting - Importance

- Market growth on connected devices : IoT (estimated 40 billion devices by 2025), healthcare, wearables, home automation…
- Energy supply is essential (<mW, tens of µW) → Energy Harvesting
- EH is important in applications with specific requirements : simple battery is not enough, cords would increase the cost / complexity, too many devices, harsh environment, implants…

➢ **Mechanical**
➢ **Electromagnetic**
➢ **Thermal…**



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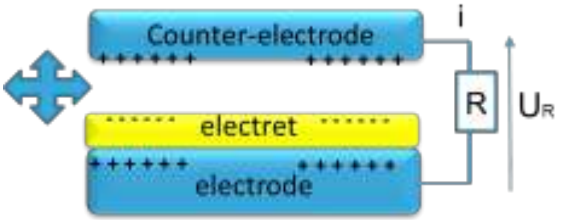
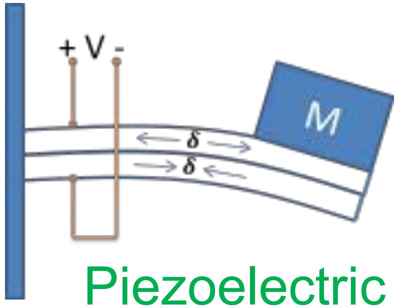
Energy Harvesting – Possibilities

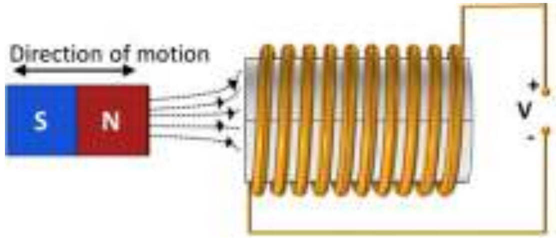
Mechanical EH



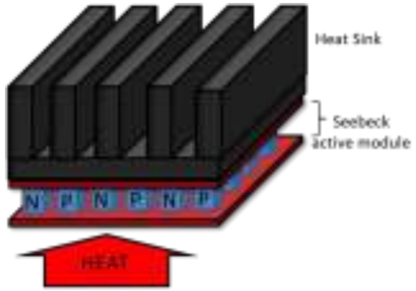
Electrostatic



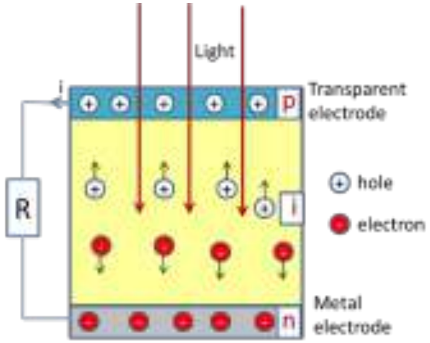
Piezoelectric



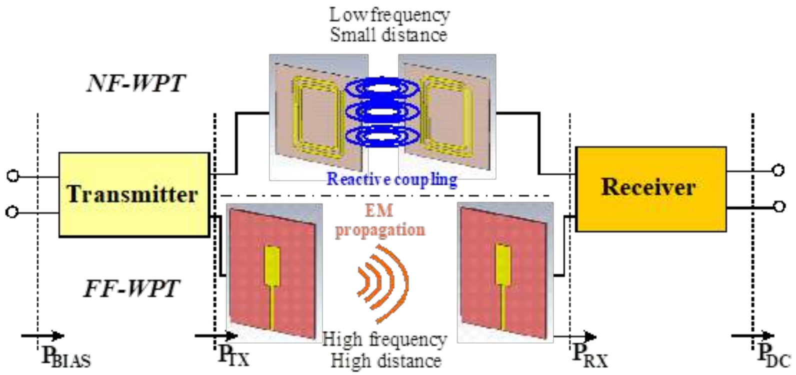
Electromagnetic



Thermal EH



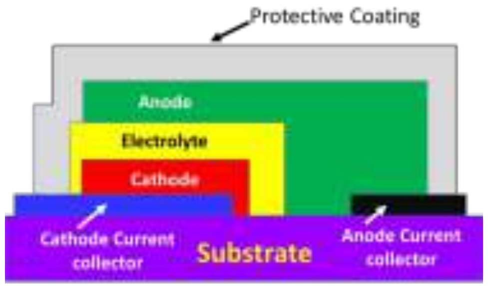
Solar EH



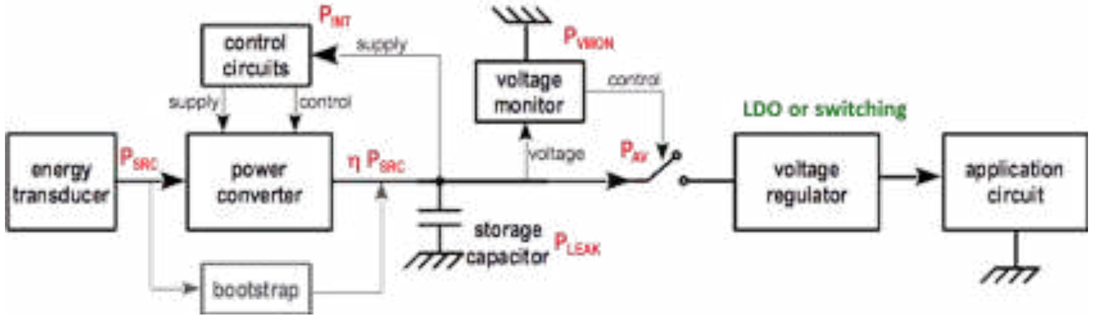
RF EH / wireless power transfer

IEEE Advancing Technology for Humanity

IRDS



Energy storage (µbatteries)



Micro power management

Funded by the European Union

Energy Harvesting - Summary

- The improvement of the EH performance/efficiency is as important as the development of "green" materials. Replacing toxic/rare materials used nowadays (lead based piezoelectrics, Bi_2Te_3 for thermoelectrics, NdFeB - neodymium, for electromagnetic conversion).
- The use of nanotechnologies is foreseen to increase the performance of all the concepts in general.
- Flexible and low cost approaches for wearable applications (i.e. e-health) should be developed as well.
- The comprehensive system design combining all aspects of the fabrication process, harvester structure, power conversion circuits and storage will be the potential solution for increasing the power generation efficiency.

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Power Devices: review of the main EU and international activities and technologies

Mikael Östling KTH Royal Institute of Technology, Markus Pfeffer Fraunhofer IISB

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Our Great Societal Challenge

Global Warming

Energy Conservation

Renewable Energy

Improving the Efficiency

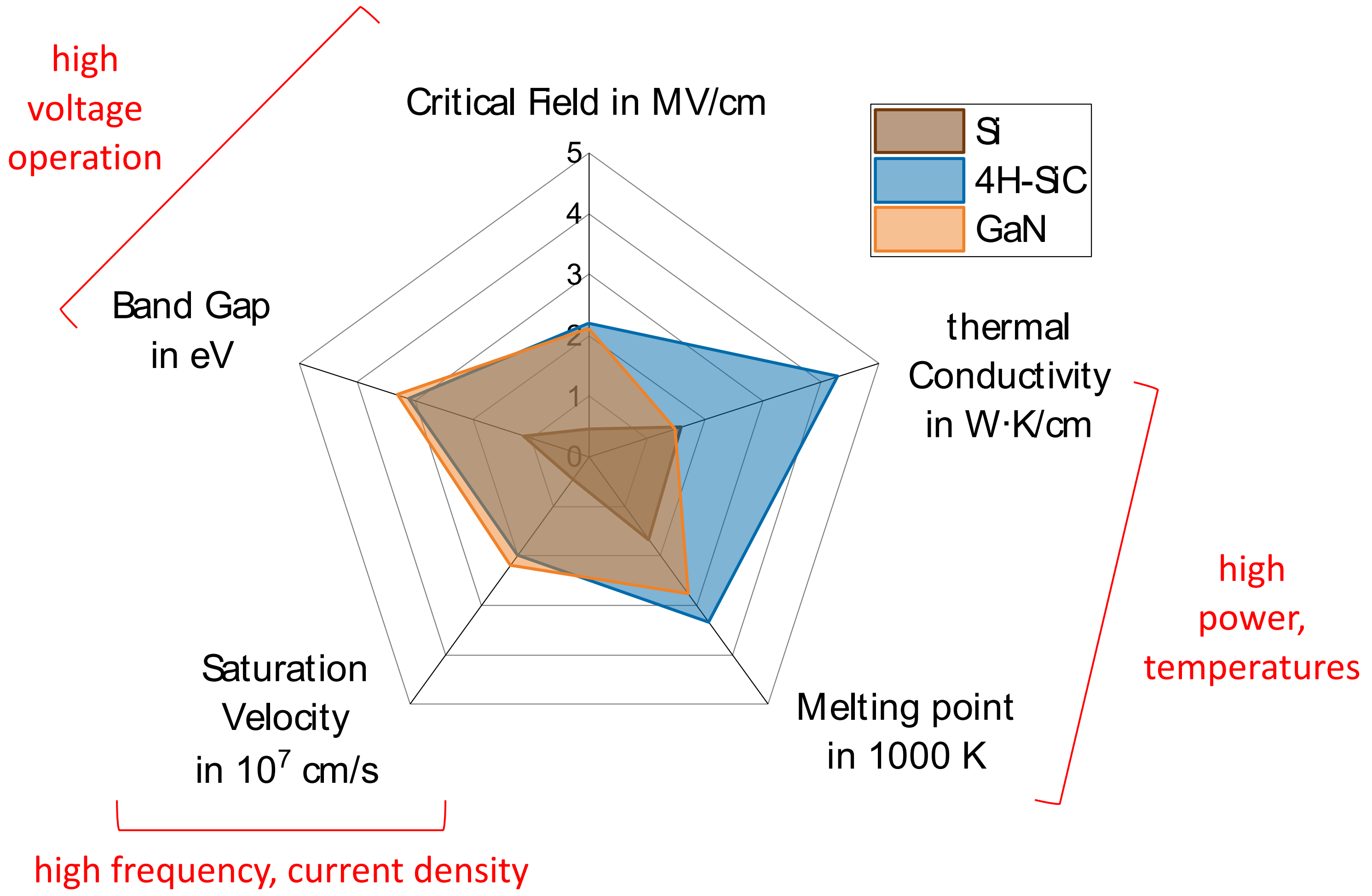
Electrical Conversion

Power Devices

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

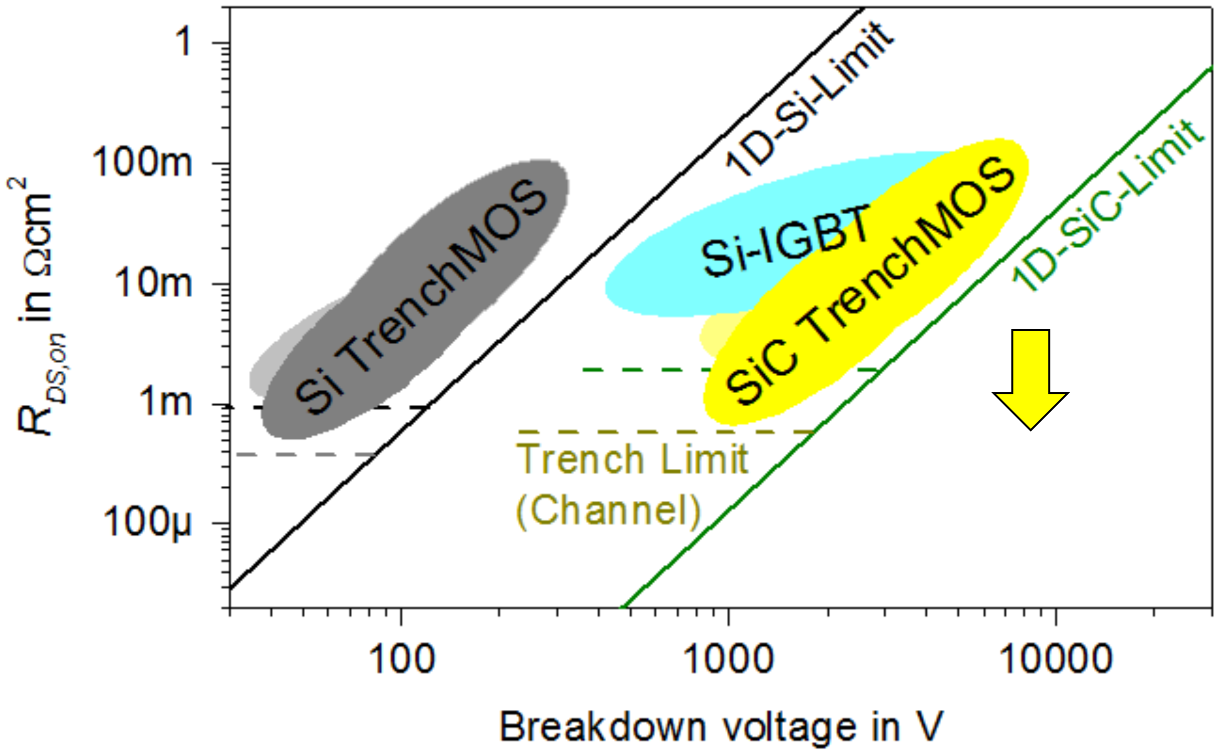
B.J. Baliga, Advanced High Voltage Power Device Concepts, Springer

Materials Properties of SiC



Evolution of Power MOS Technolog

- Task 1: Reduction of On-State resistance to minimize die size/cost
  - Technology development depends on voltage rating

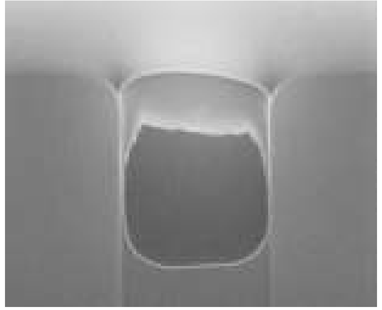


Power Devices on SiC

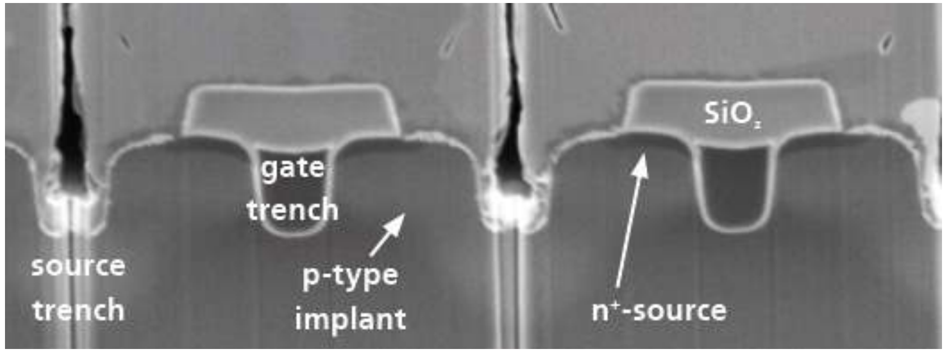
- Advanced Trench Technologies

1.2 kV TrenchMOS

Devices on wafer



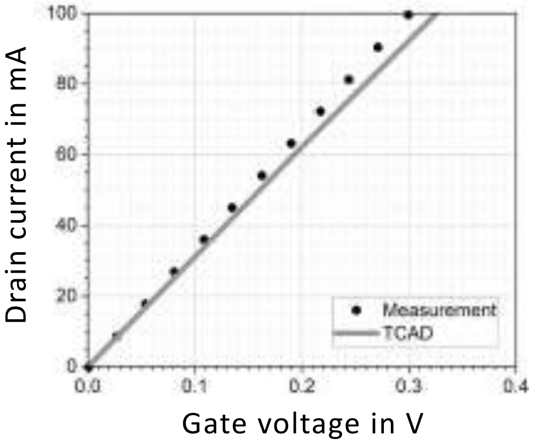
Poly-Si-plug with oxidation



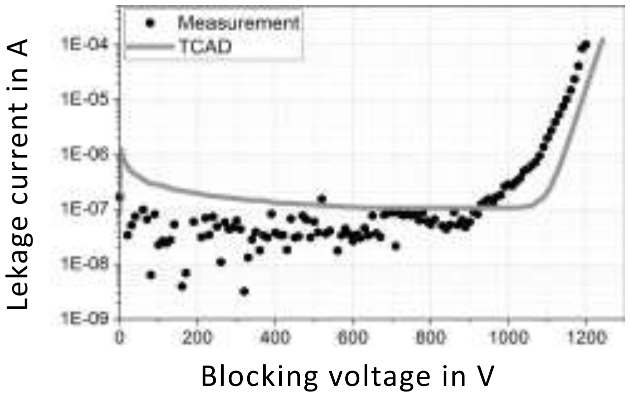
FIB cross-section of active area

Electrical Performance

Transfer characteristics (lin.)



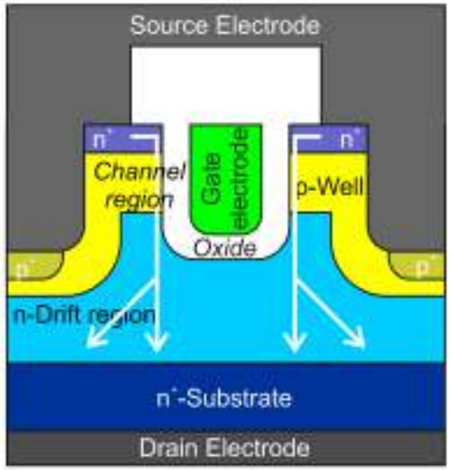
Reverse operation



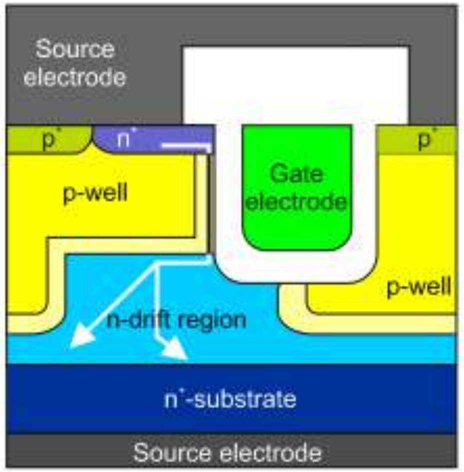
Evolution of Power SiC MOS Technolog

- Task 1: Reduction of On-State resistance
  - Implementation of trench gates
    - Increased channel mobility along (1 1 -2 0) orientation
    - Vertical channel → Pitch reduction compared to VDMOS
  - Shielding of trench bottom oxide vital!

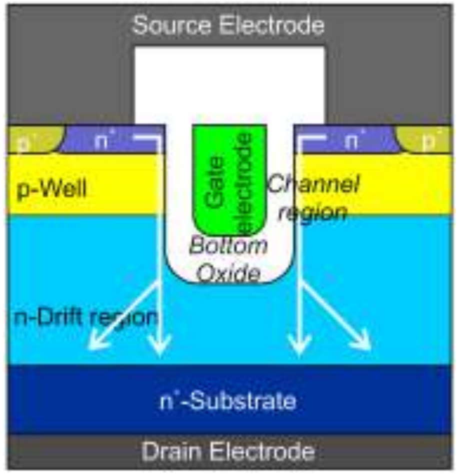
Examples of practical SiC Trench MOS concepts



Rohm / MaxPower Double Trench

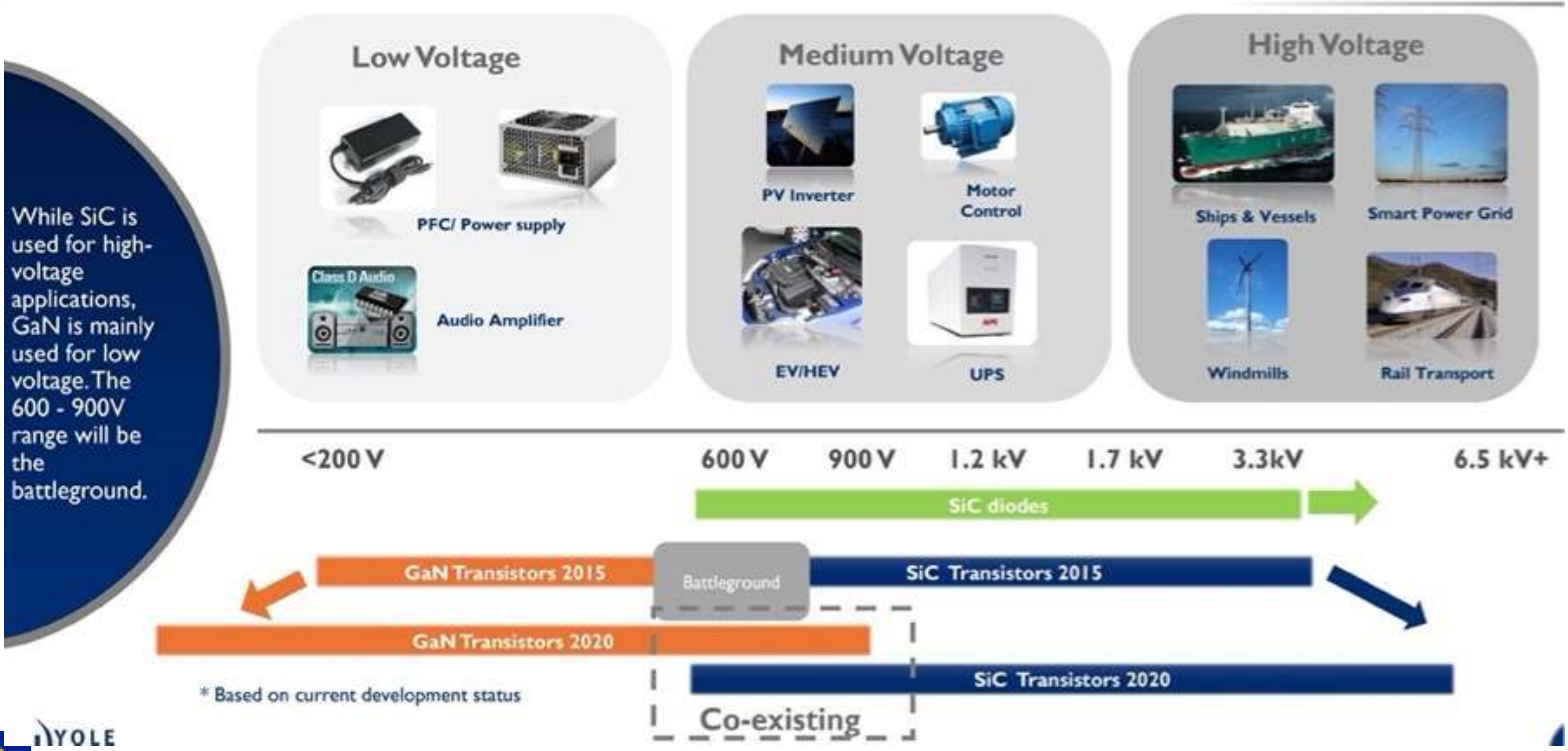


Peters et al., Power-Mag 3 (2017)

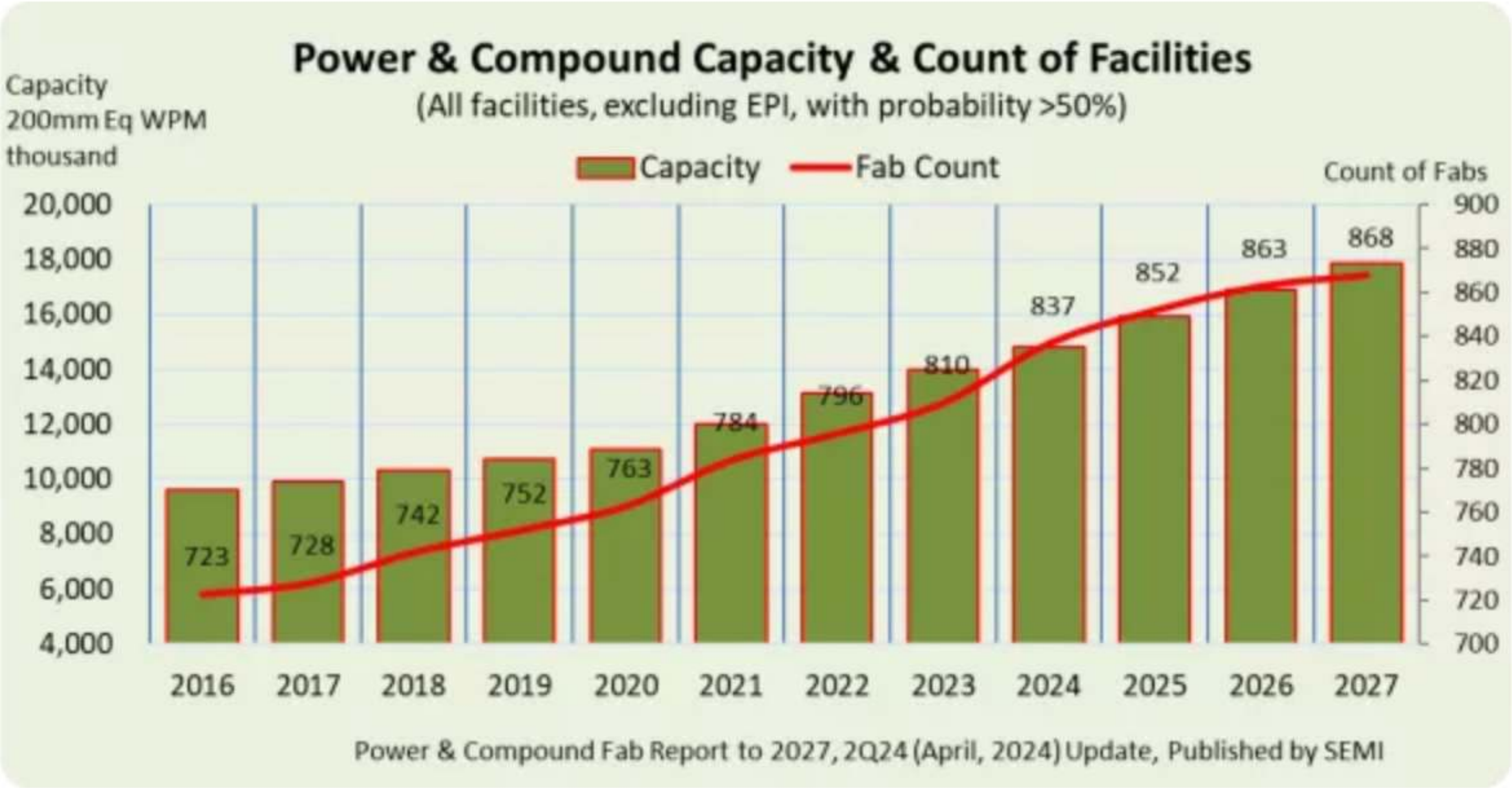


Banzhaf et al. MSF 858 (2016) 848-851

The WBG Device Landscape



Market Outlook



SEMI

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Annoucements (some examples)

Corporate Manufacturing

STMicroelectronics to build integrated Silicon Carbide substrate manufacturing facility in Italy

Oct 5, 2022 Geneva, Switzerland

STMicroelectrincs

Infineon to build the world's largest 200-millimeter SiC Power Fab in Kulim, Malaysia, leading to total revenue potential of about seven billion euros by the end of the decade

Aug 3, 2023 | Business & Financial Press

Infineon

Corporate, Power

Wolfspeed Announces Plan to Construct World's Largest, Most Advanced Silicon Carbide Device Manufacturing Facility in Saarland, Germany

Feb 01, 2023

Wolfspeed

TOKYO, Japan, May 17, 2022 — Renesas Electronics Corporation ("Renesas", TSE:6723), a premier supplier of advanced semiconductor solutions, today announced that it will conduct a 90-billion-yen worth investment in its Kofu Factory, located in Kai City, Yamanashi Prefecture, Japan. While the Factory was closed in October 2014, Renesas intends to reopen the fab in 2024 as a 300-mm wafer fab capable of manufacturing power semiconductors.

Renesas

TOKYO, March 14, 2023 - Mitsubishi Electric Corporation (TOKYO: 6503) announced today that it will double a previously announced its investment plan to approximately 260 billion yen in the five-year period to March 2026 mainly for constructing a new wafer plant to increase production of silicon carbide (SiC) power semiconductors.

Mitsubishi

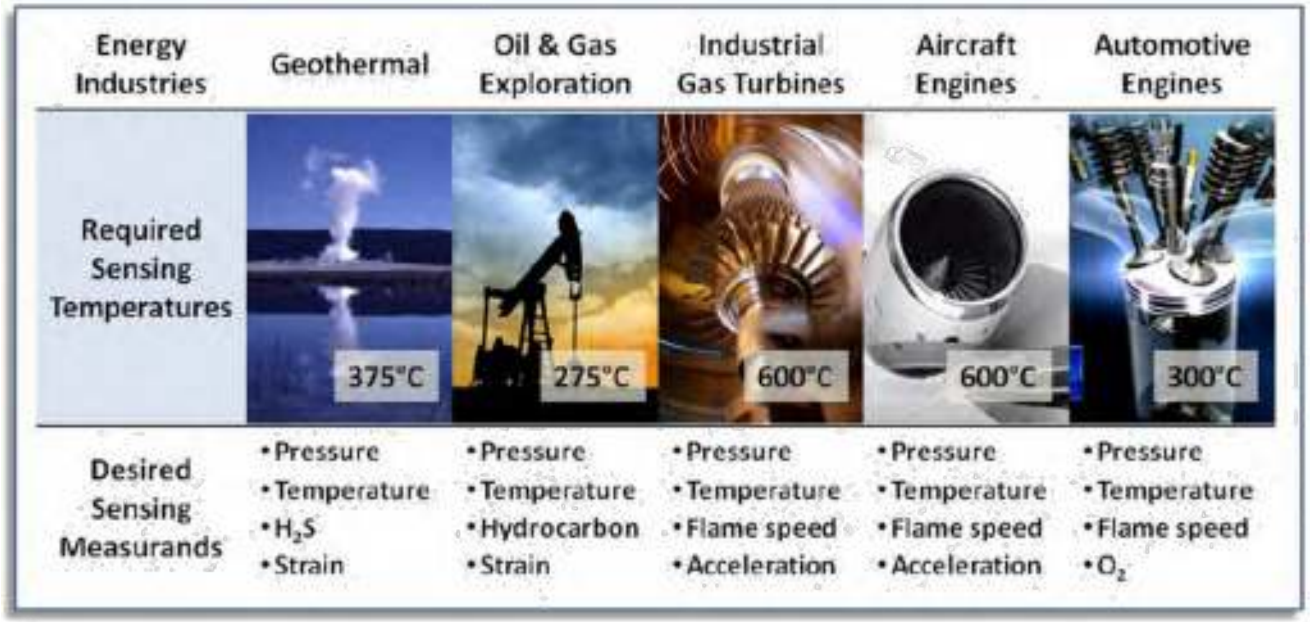
Bosch investing €3bn in semiconductor business by 2026
an extra 1000m2 has already been added to the cleanroom space at the Bosch wafer fab in Reutlingen in 2021. Another 3000m2 will be added by the end of 2023. Production will be using 200 mm SiC wafers using extension also in Dresden.

Research activities in other areas

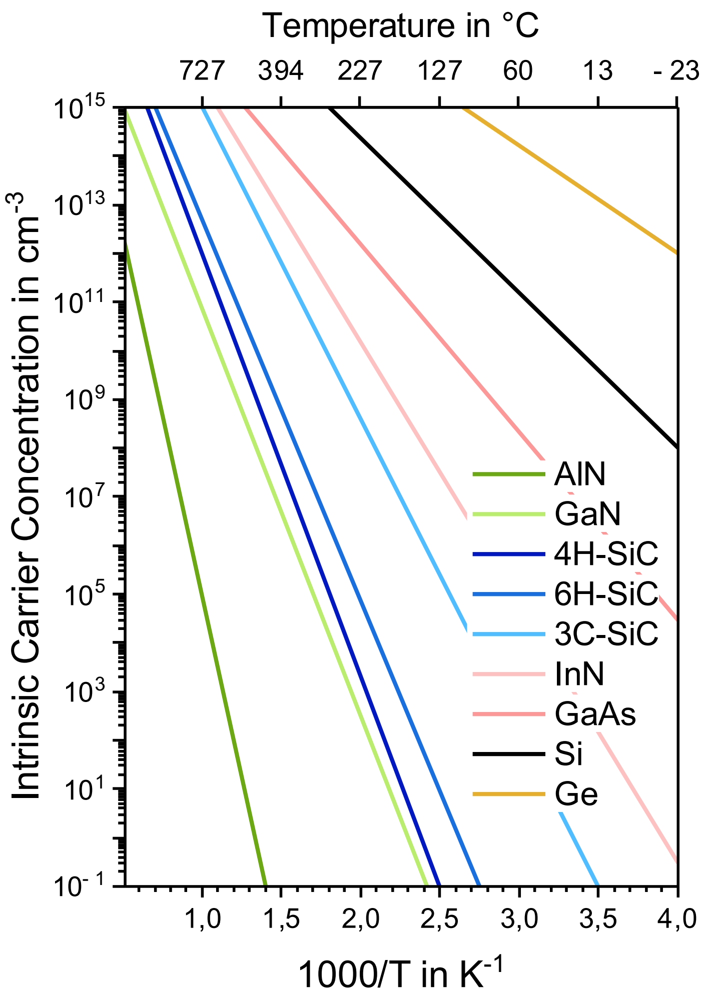
- SiC CMOS Technology for harsh environments
- EU Chips Act – Pilot Line(s)
- Ultra Wide Band Gap semiconductors (UWBGs)

High-Temperature SiC Circuits

- Operation > 500°C



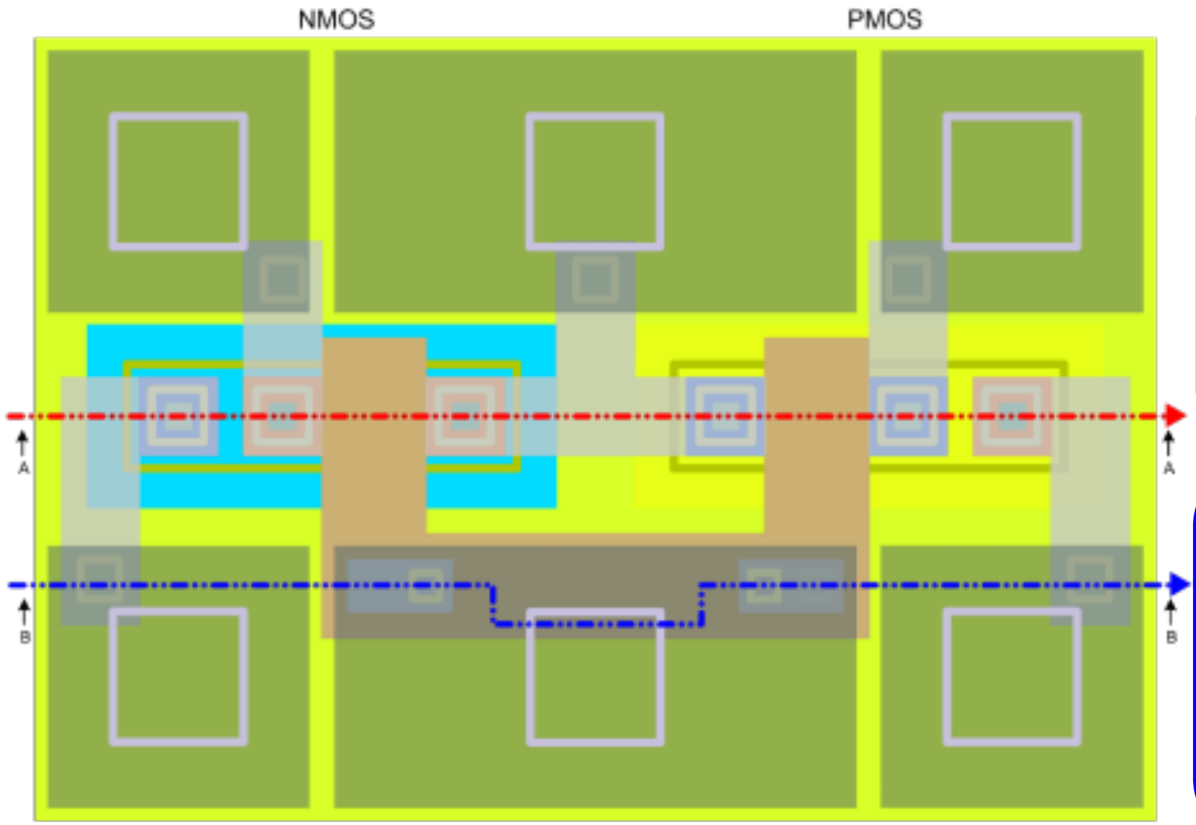
Harsh Environment Sensor Cluster, University of California, San Diego

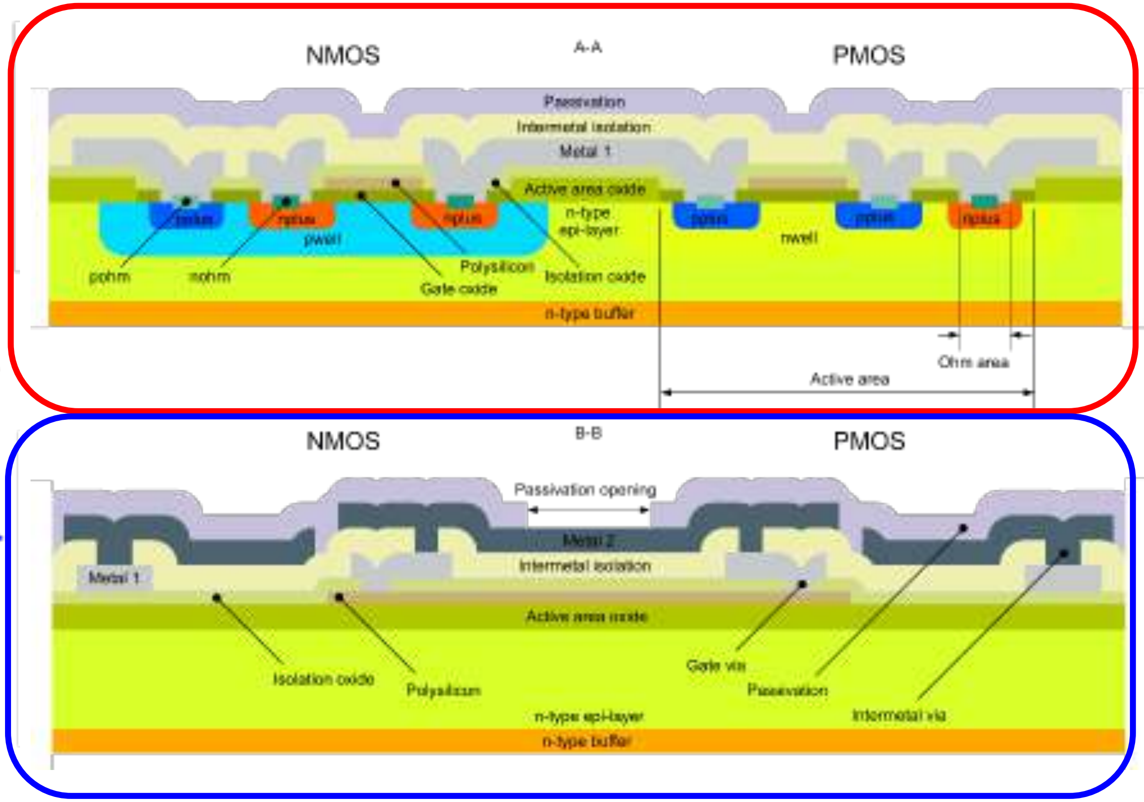


High-Temperature SiC Circuits

- Technology overview

Top View of Circuit Blocks



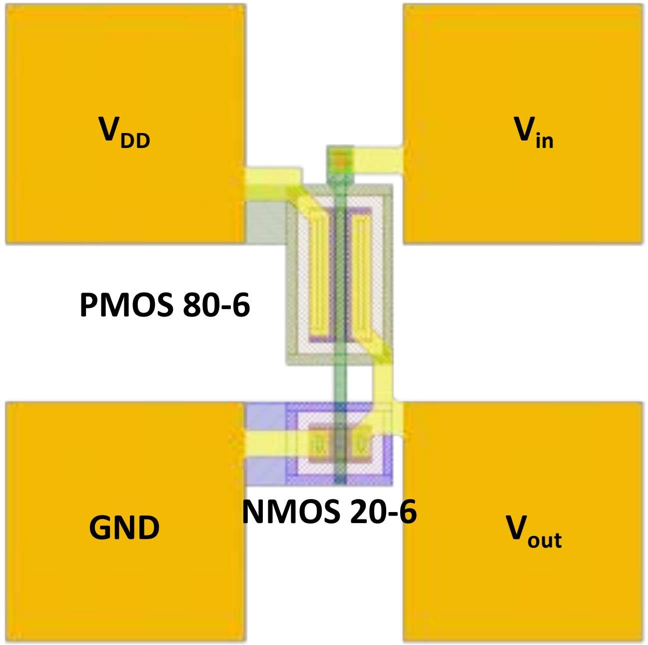


Circuit Cross-Cuts

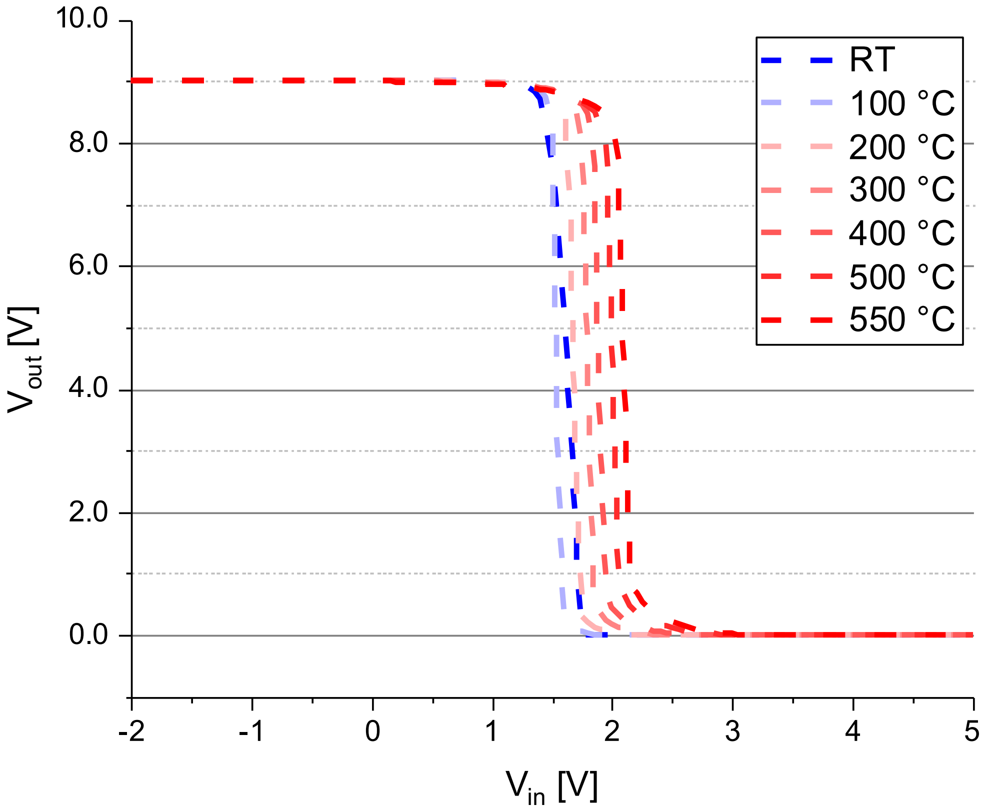
High-Temperature SiC Circuits

- CMOS inverters up to 550 °C

Inverter Layout

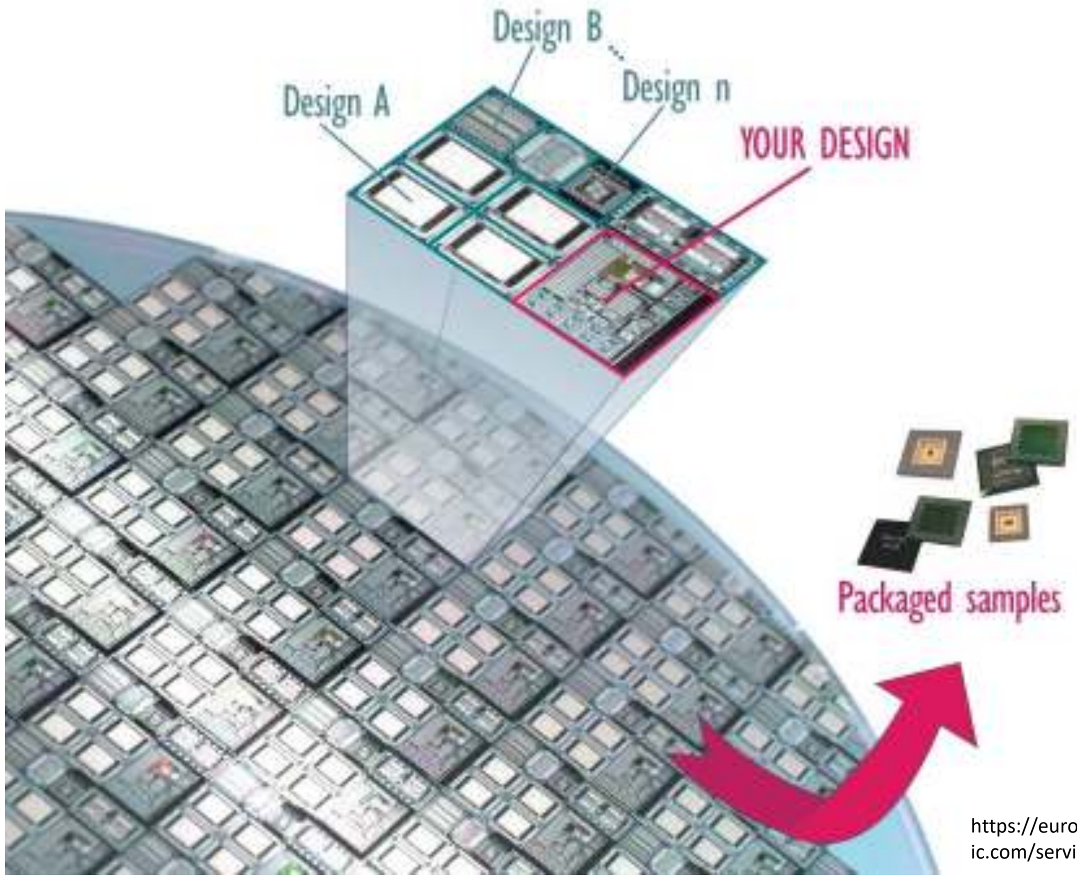


Temperature Dependence of Transfer Characteristics



High-Temperature SiC Circuits

- Access
  - Customer designs are combined in a mask set and processed jointly
  - Process cost are distributed according to areal share
  - Each customer gets delivered single chips of their layout
  - Allows for participation in CMOS process flow starting from approx. 5% of total processing cost



https://europractice-ic.com/services/fabrication/

EU Chips Act – Pilot Line(s)

EU Commissioner for the Internal Market, Thierry Breton, spoke of Europe's ambitions to be an industry front-runner, with capabilities in advanced technologies as well as in existing strengths. He praised the world-beating 11 billion euros of investment in R&D through the Chips JU, and confirmed the creation of a European cloud-based design platform and four new pilot lines. These lines will bridge the gap from the lab to the fab in four critical and strategic technologies:

- Extending Moore's law to the Angstrom area
- Scaling down towards 7 nm in FD-SOI technology
- *The integration of several heterogeneous technologies and advanced packaging*
- **Next-generation wide-bandgap materials**

Ultra Wide Band Gap semiconductors (UWBGs) are superior to Silicon

due to their physical properties in the field of power electronic applications

		WBGs		Ultra WBGs		
	Silicon	4H-SiC	GaN	Ga2O3	Diamond	AlN
Bandgap E_g [eV]	1.1	**3.26**	**3.45**	4.85	5.47	6.2
Melting Point [°C]	1420	-	-	1795	-	-
Electron Mobility μ_n [cm^2/Vs]	1350	900	1000	150	4000 (th.)	500
Dielectric constant ε	11.8	9.7	9.5	9.9	5.5	9.1
Thermal Conductivity k [W/cmK]	1.56	**3.7**	1.5	0.1	25	3
Critical Electrical Field E_{cr} [10^6V/cm]	0.2	**3.2**	**3.3**	8	10	16.6

Device performance

- Drastically lower transmission losses
- Outstanding dynamic properties
- Potential for higher/lower operating temperatures

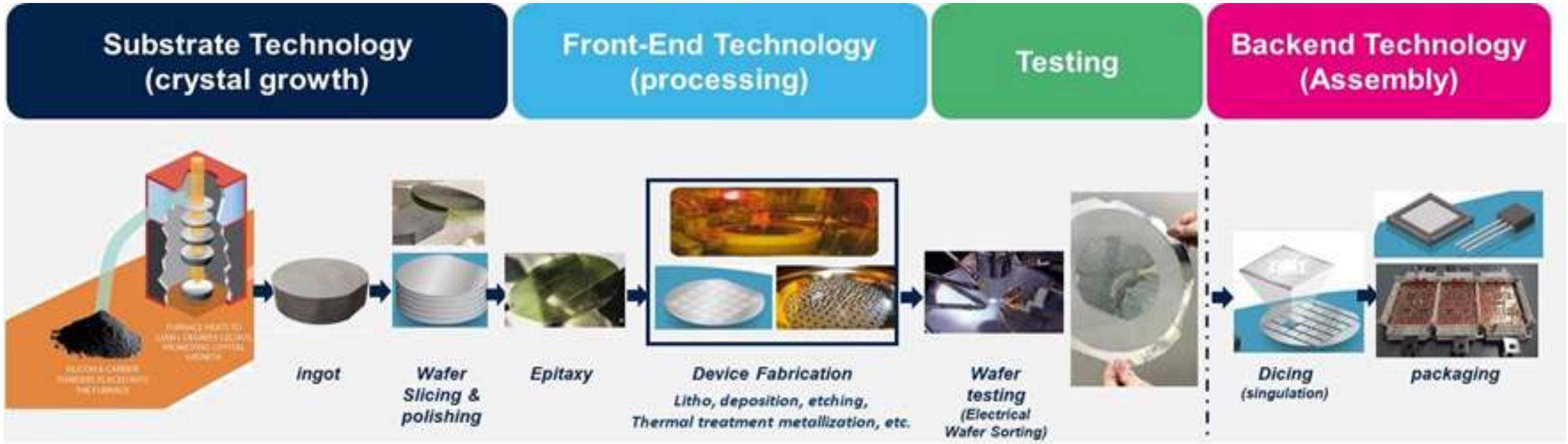
System benefits

- Higher efficiency
- More compact systems including simpler cooling and smaller passive components
- Reduced costs at system level

WBG Pilot Line

Chips-CPL-4: Pilot line on advanced semiconductor devices based on Wide Bandgap materials:
It will focus on two key outcomes:
(i) to extend the maturity level and the impact of ***SiC and GaN technologies***; and
(ii) to ***explore less mature WBG and UWBG semiconductors***, such as cubic polytype of SiC (3C–SiC), low–cost polycrystalline SiC, lattice–matched InAlN or InAlGaN for RF heterostructures, bulk gallium nitride or gallium oxide (Ga_2O_3) or aluminium nitride (AlN).

Vision of the WBG Pilot line:
The R&D activities aim to improve the efficiency and power density capabilities of WBG–based power devices must cover the entire chain, from the crystal growth to the front–end, testing and back–end technology



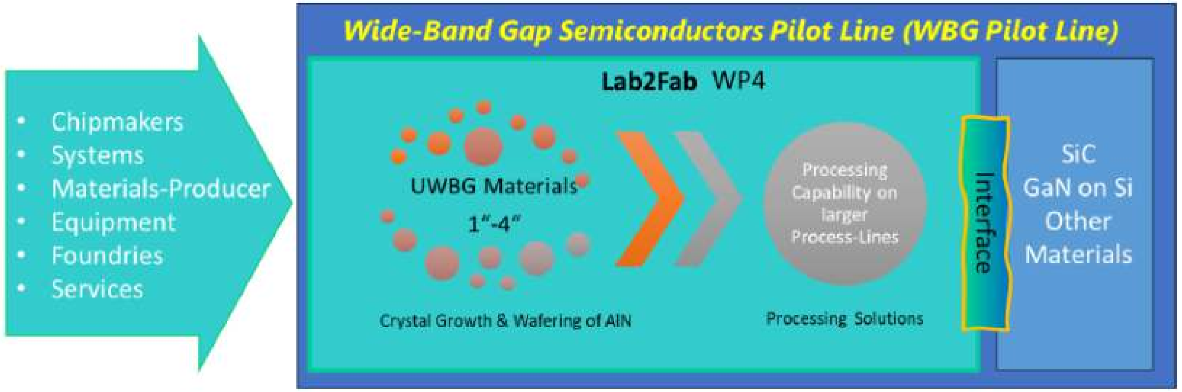
General idea, vision and topical coverage of the WBG Pilot Line

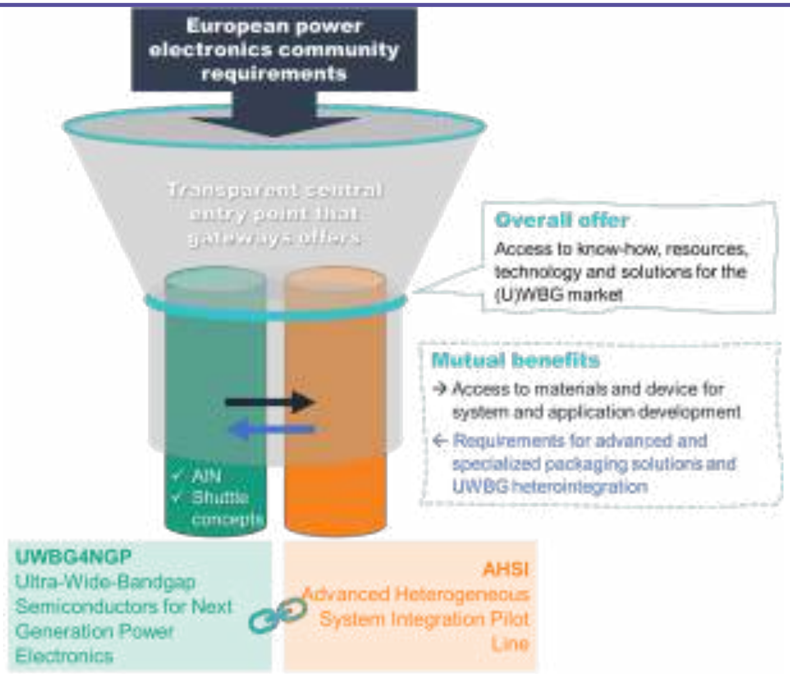
Income prospect of WBG PL business model

WBG Pilot Line - contribution by FhG-IISB

Ultrawide band gap semiconductors for next generation power devices = UWBG4NGP

Lab2Fab initiative for a faster bridging of the „valley of death“





The German contribution aims to fulfil the following targets:

- Creation of synergies within Germany and Europe for AlN but also GaN and Ga2O3 based device supply chains
- Capabilities inside Europe for technology development of power devices based on UWBG materials on low TRL level like AlN, unlock the potential of these new semi-conductors and raise their maturity. → **Lab2Fab**
- **Ensuring the availability of AlN** wafers and related process equipment from within Europe
- Securing **technology autonomy for AlN** and leading the way for Next-Generation Power Semiconductors in Germany

Summary – Power Devices

- Global research and development in the field of advanced power devices
- Investments are on the way
- Market for WBG (SiC, GaN) and UWBG (AlN, Ga_2O_3, diamond)
- Enable Access via Pilot Lines for universities, SMEs and fast followers
- Electronics for harsh environment
  - Available via EUROPRACTICE

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Thank you!

Funded by the European Union