ESSERC 2024

SiNANO-ICOS-INPACE Workshop

“Emerging technologies in Advanced Computation, Advanced Functionalities, Ground-breaking Technologies: Impact on International Cooperation”

Innovative materials for power devices

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Outline

Our Great Societal Challenge

Global Warming

Energy Conservation

Renewable Energy

Improving the Efficiency

Electrical Conversion

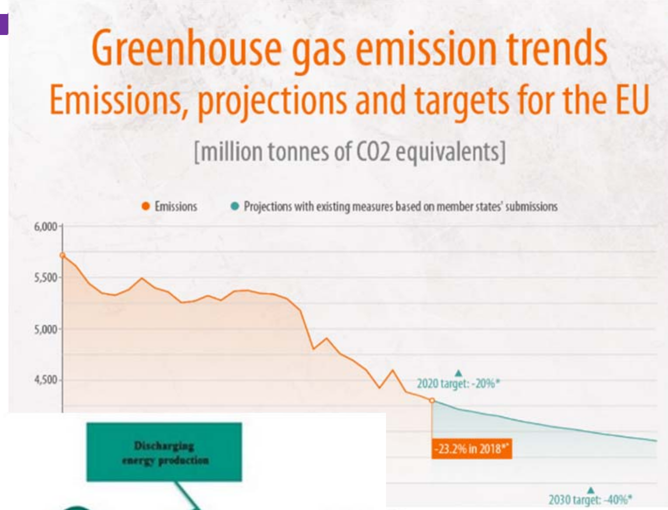
Power Devices

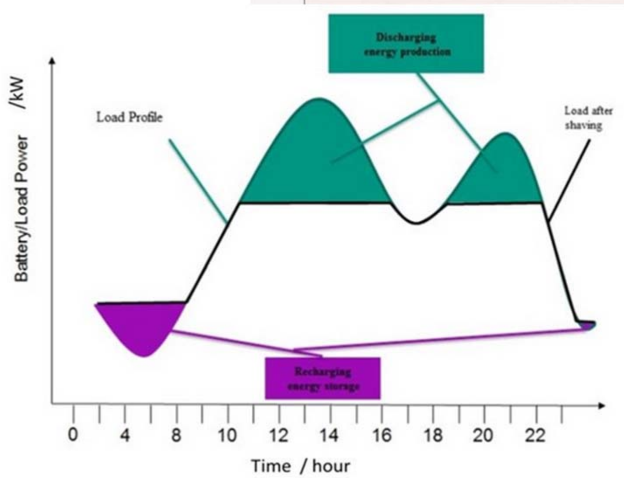
At least 50 % of the electricity used in the world is controlled by Power Devices.

Power Devices - Introduction

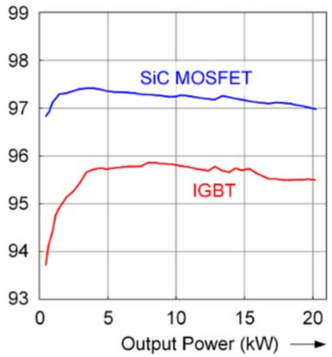
- Energy efficiency contributes to EU's CO_2 goals
  - Ecological and economical implications
    - Laws and regulations (compare Monitors)
    - Prestige and responsibility for companies

- SiC (WBG) converters offer excellent partial load properties
  - Up to 10% more efficiency compared to silicon topologies
  - Every time energy is transferred
    - Generation
    - Storage (Recuperation)
    - Consumption
  - Applicable to any source of electrical energy consumption (broad range)



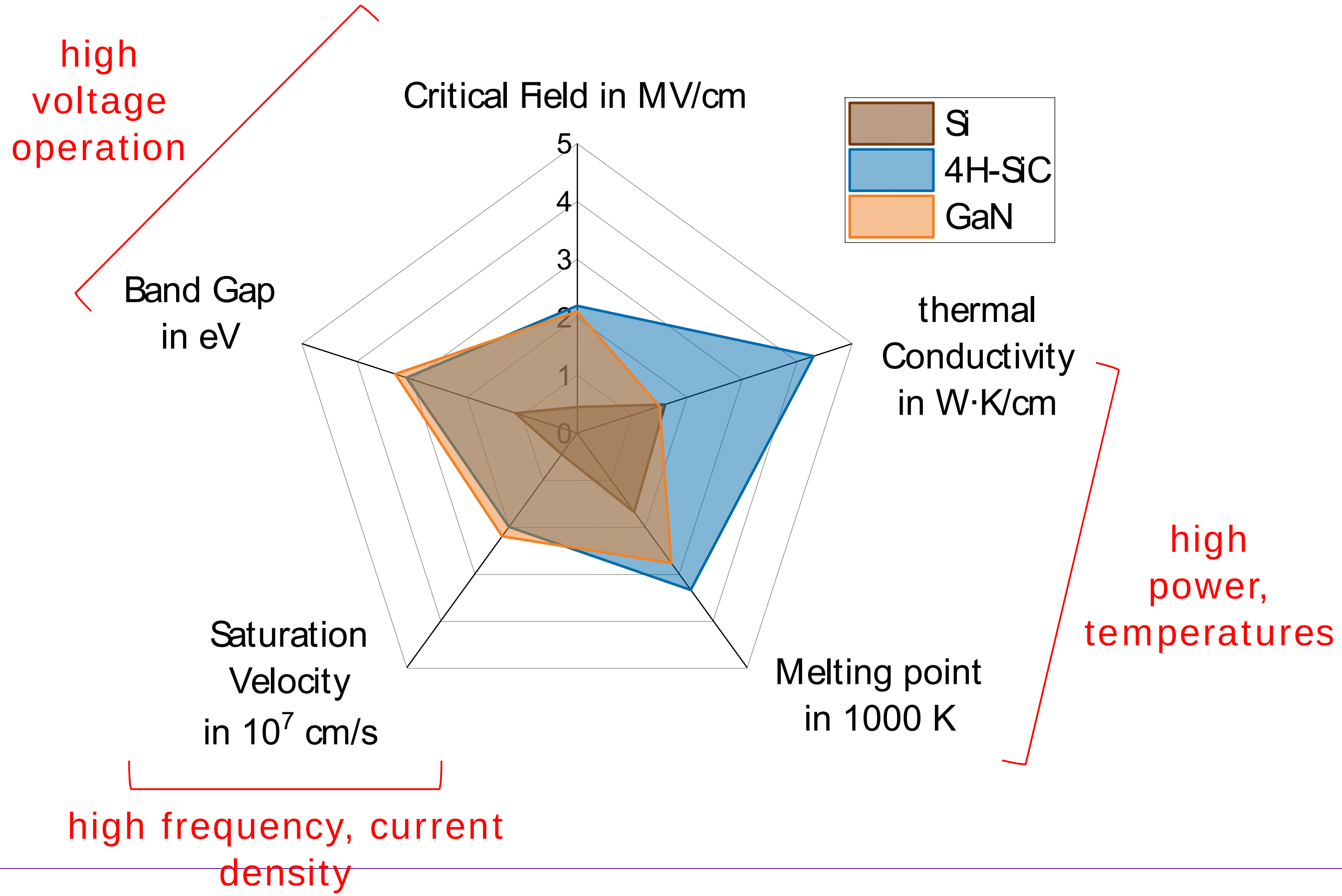


Boyouk N. et al., ISGT-Europe 2018, Sarajevo



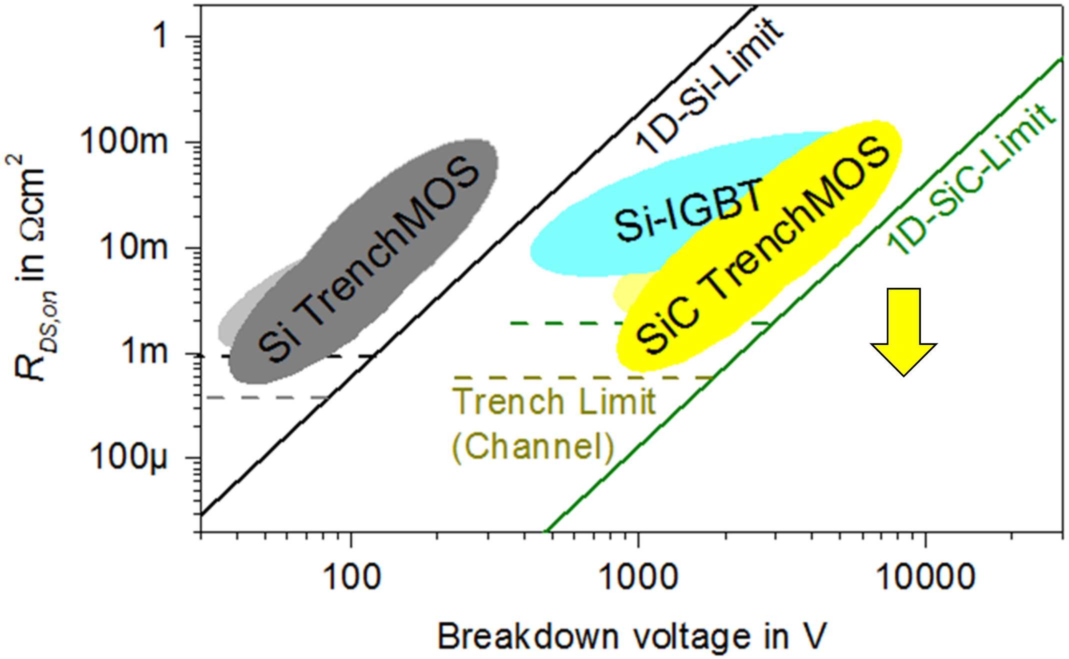
M. Nitzsche et al., PCIM 2019, Nuremberg

Materials Properties of WPG Material



Evolution of Power MOS Technology

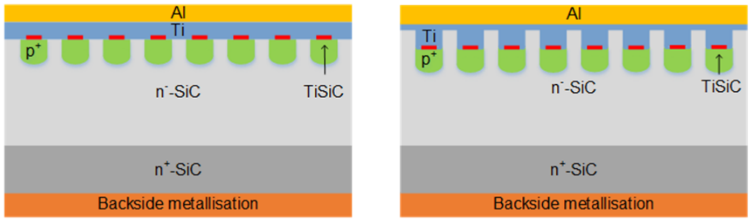
- Task 1: Reduction of On-State resistance to minimize die size/cost
  - Technology development depends on voltage rating

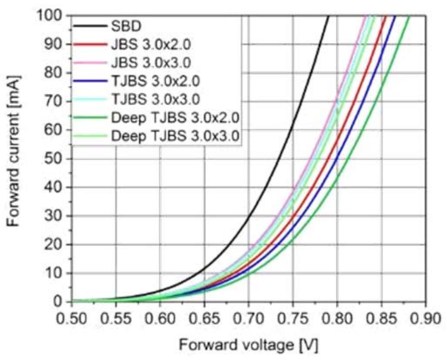


Power Devices on SiC

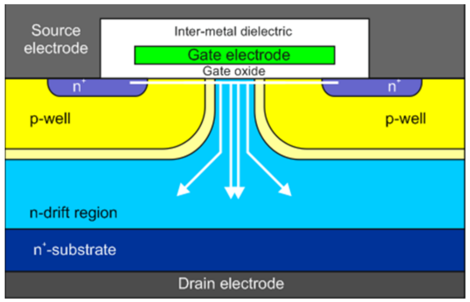
- Bipolar and MOS Power Devices

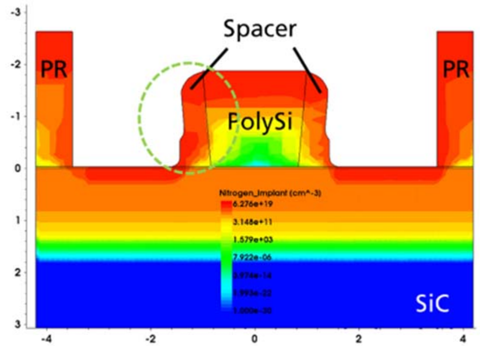
Merged Schottky/pn Diodes

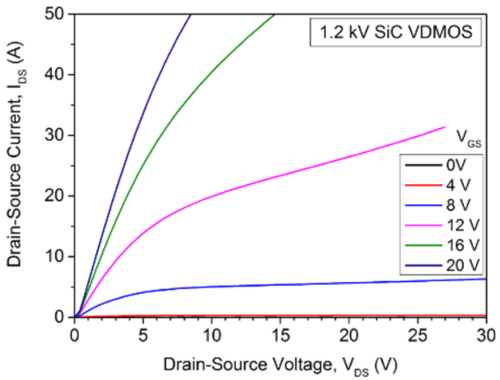


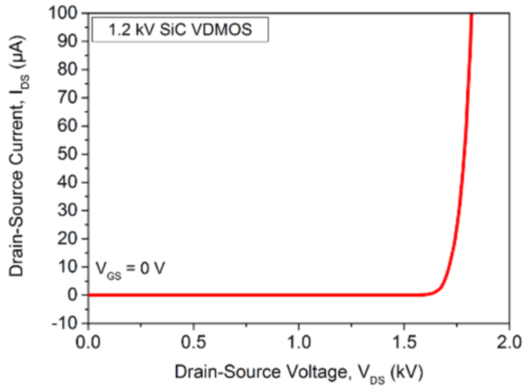


1.2 kV VDMOS (planar)





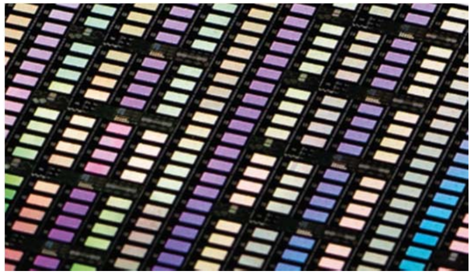


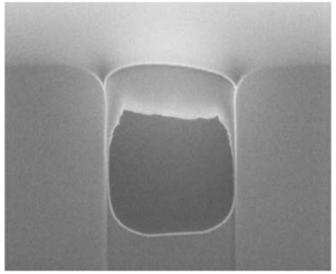


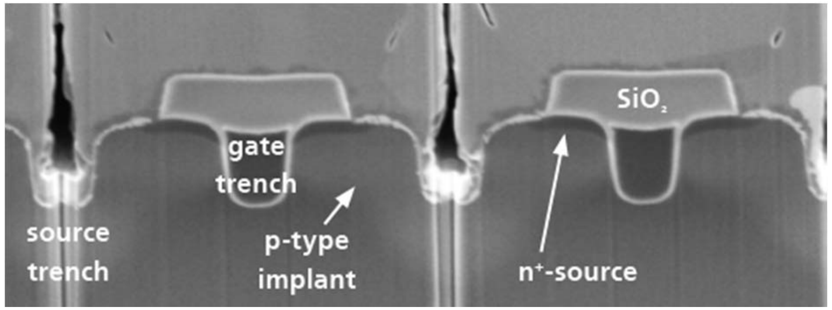
Power Devices on SiC

- Advanced Trench Technologies

1.2 kV TrenchMOS


Devices on wafer

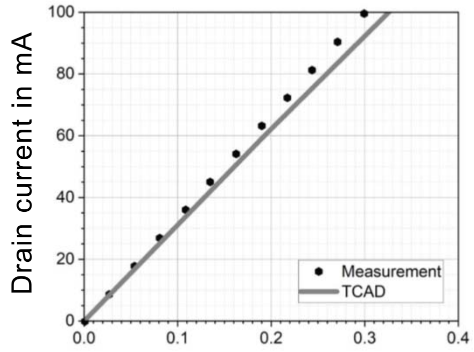

Poly-Si-plug with oxidation



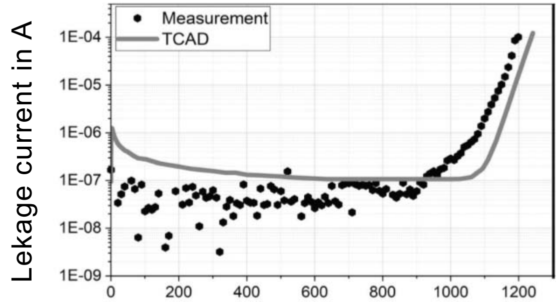
FIB cross-section of active area

Electrical Performance

Transfer characteristics (lin.)



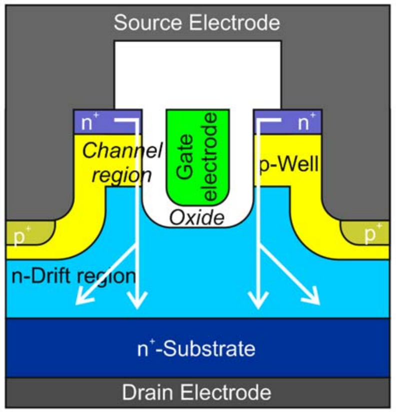
Reverse operation



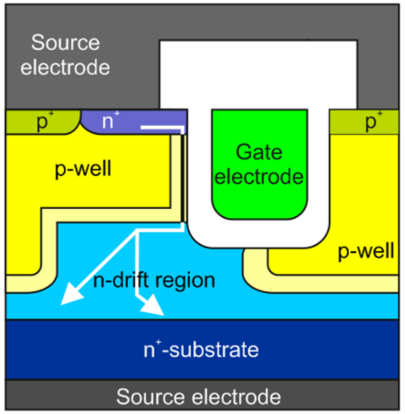
Evolution of Power SiC MOS Technolog

- 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!

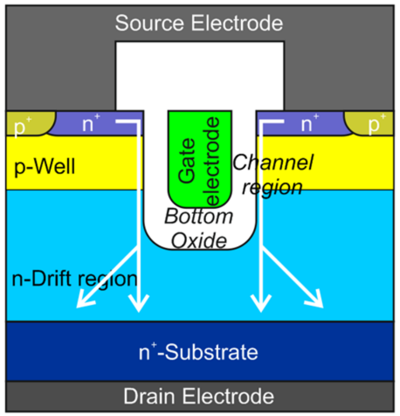
Examples of practical SiC Trench MOS concepts



Rohm / MaxPower Double Trench



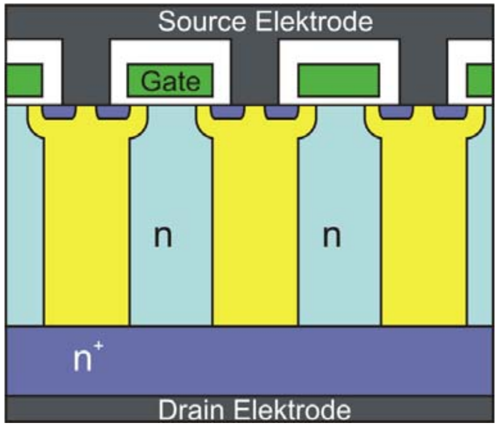
Peters et al., Power-Mag 3 (2017)

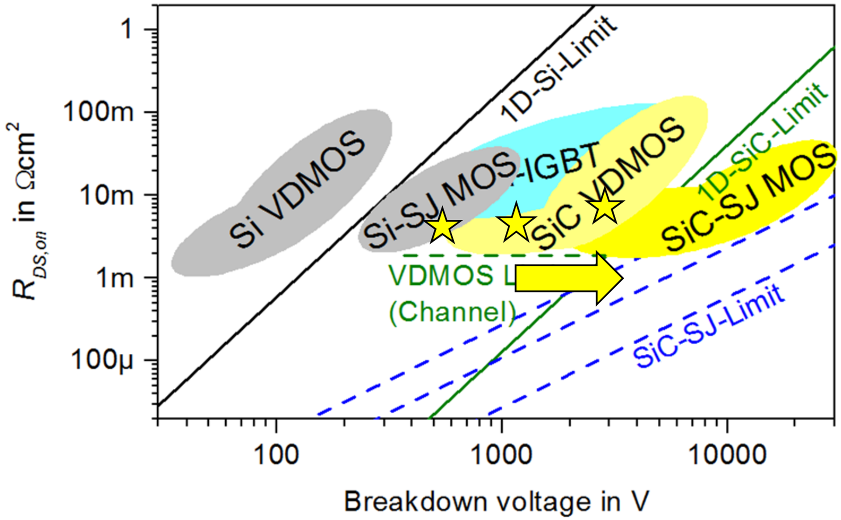


Banzhaf et al. MSF 858 (2016) 848-851

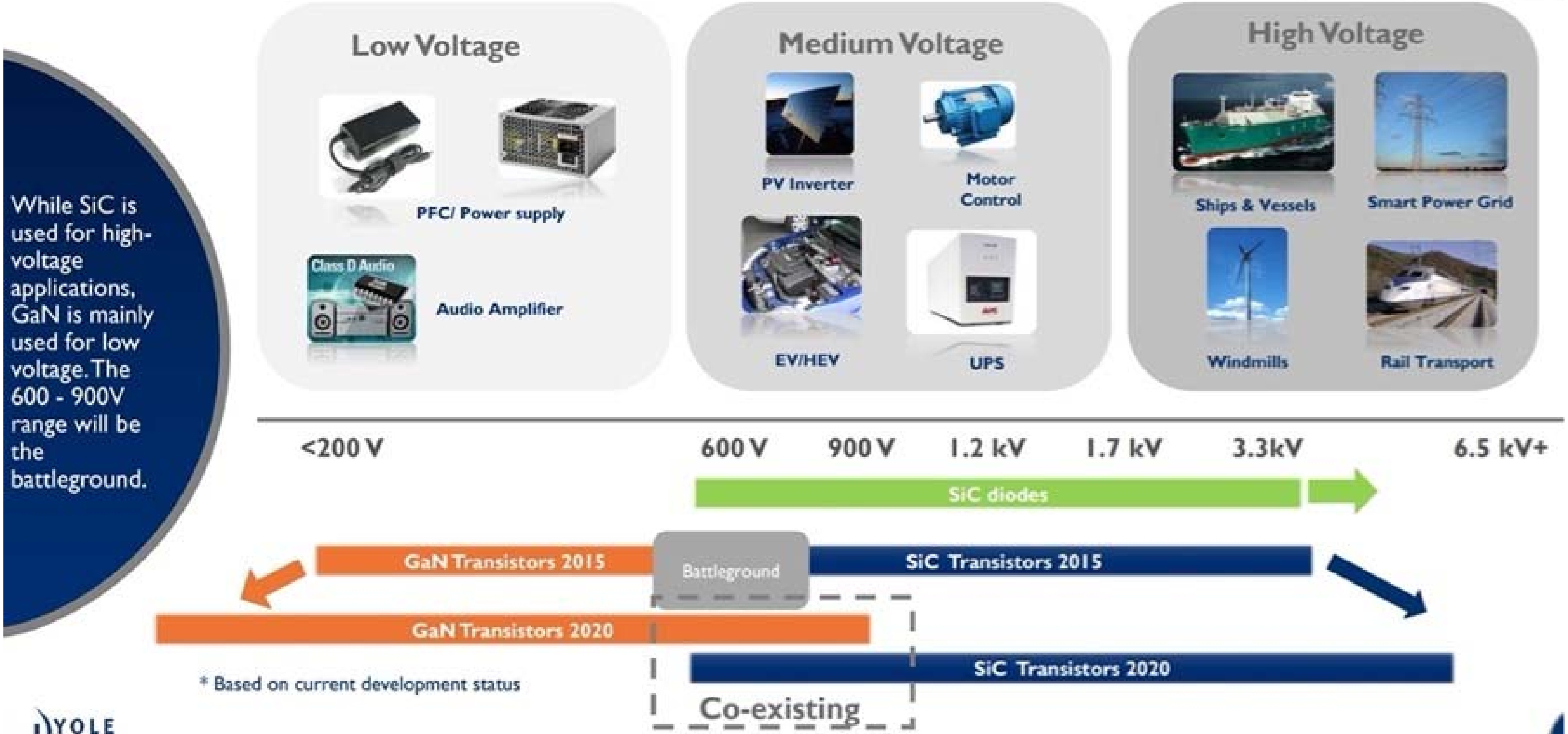
Evolution of Power SiC MOS Technolog

- Challenges for further advancements
  - Unipolar high voltage devices
  - Superjunction device topology using vertical pillar structure (approx. 60µm @ 10kV)
  - Concepts (similar to Infineon / Toshiba solutions in Silicon):
    - Mid-energy ion implantation and epitaxial overgrowth (rinse & repeat)
    - High-energy ion implantation (e.g. filter implantation)
    - Deep trench etching and epitaxial refill

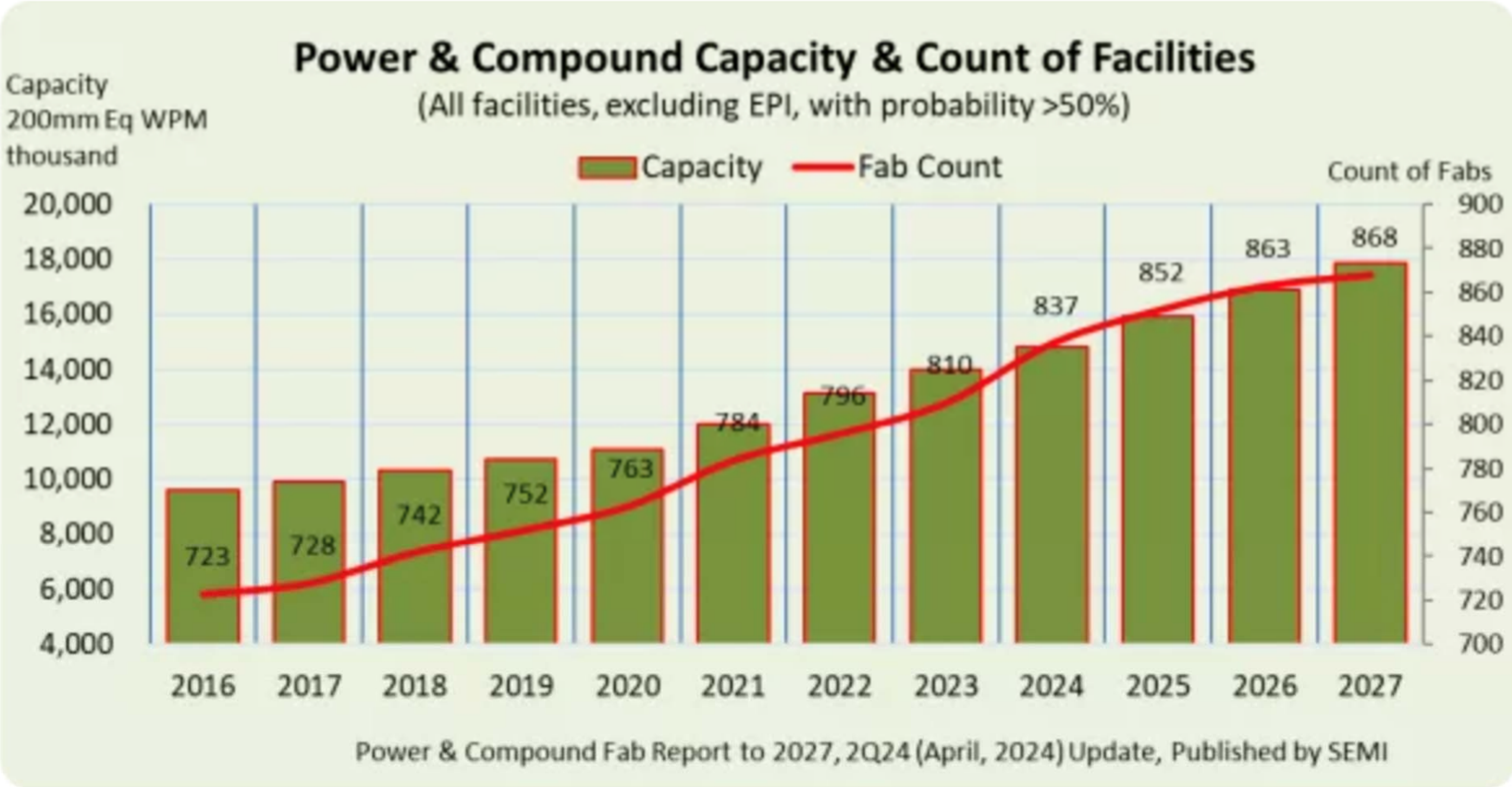




The WBG Device Landscape



Market Outlook



SEMI

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.

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)

		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 [cm²/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

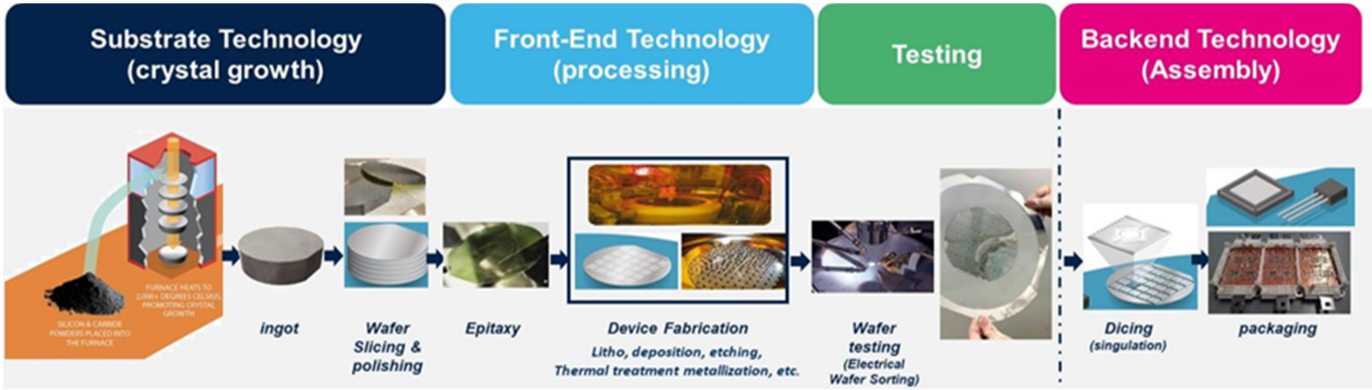
System benefits

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

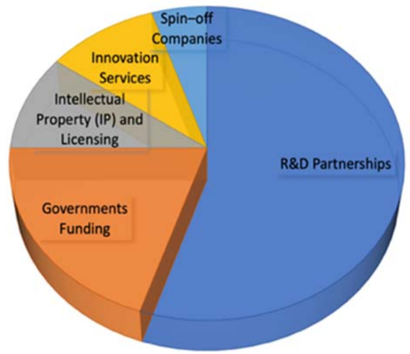
WBG Pilot Line

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

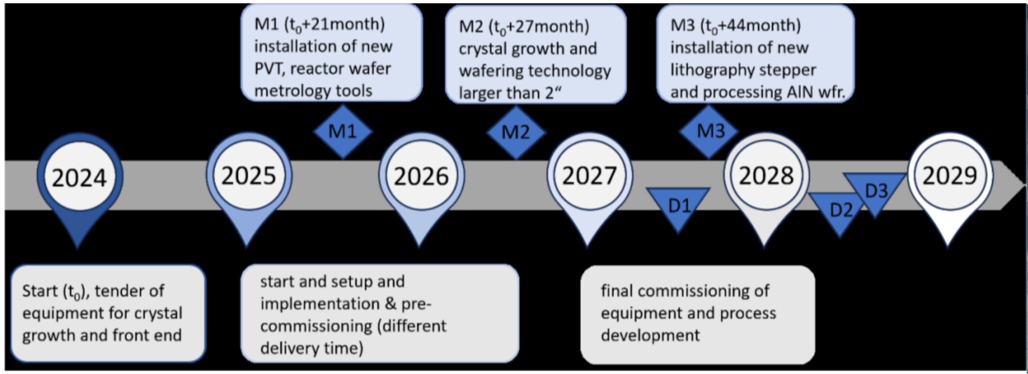


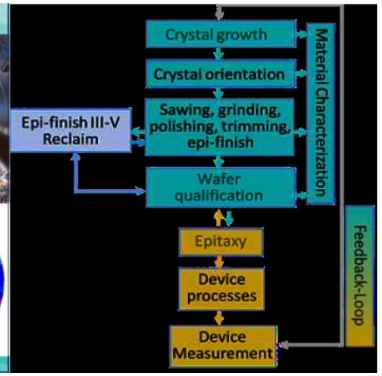
General idea, vision and topical coverage of the WBG Pilot Line



Income prospect of WBG PL business model

Planned timeline and outcome for AlN





AlN will be very far-reaching and AlN will be able to function as a next-generation semiconductor with a wide range of applications in automotive and industry such as:

- Electronics for extreme environmental conditions such as radiation-resistant and cold electronics for satellites, aerospace, and quantum electronics
- Energy-efficient power electronics for automotive and data centers
- Power Transistors for radio frequency (RF) and communication applications
- Energy-efficient UVC LEDs for disinfection purposes

Summary

- 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