Opportunities of Wide Bandgap Devices for Energy Conservation and Emerging Applications

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OUTLINE

1. **Introduction & Scope**
2. **WBG Fundamentals**
3. **WBG Power Device Status**
4. **Application Demonstrations**
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6. **New Areas – High Temperature Applications**
7. **Summary & Conclusions**

The Societal Challenge

Global Warming/Pollution

Energy Conservation

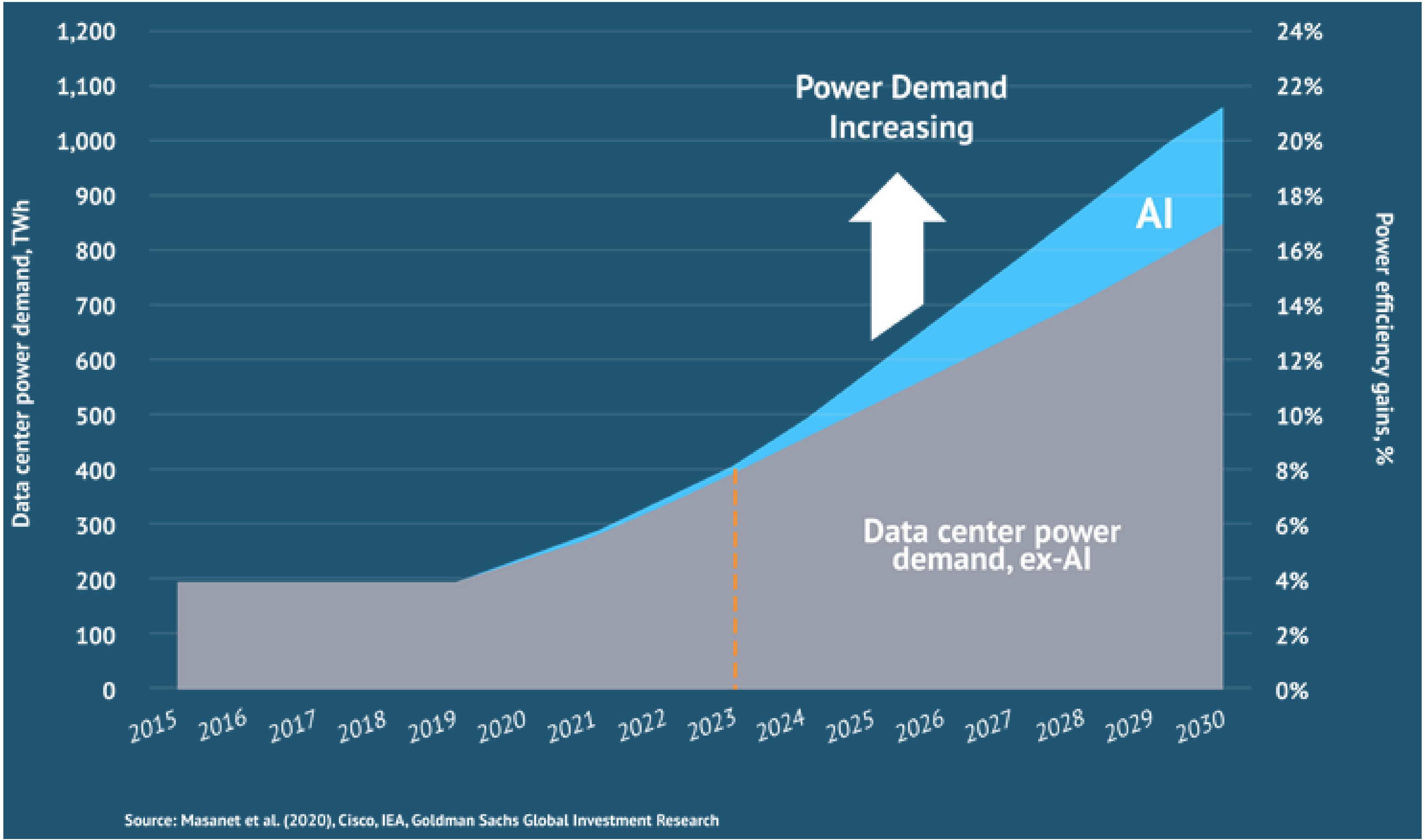
Renewable Energy

Improving the Efficiency

Electrical Conversion

Power Devices

Data Center Power Demand



Data center forecast

(source Goldman Sachs, Bloomberg)

7000

Data centers either built or in construction (as of 2024)

5X

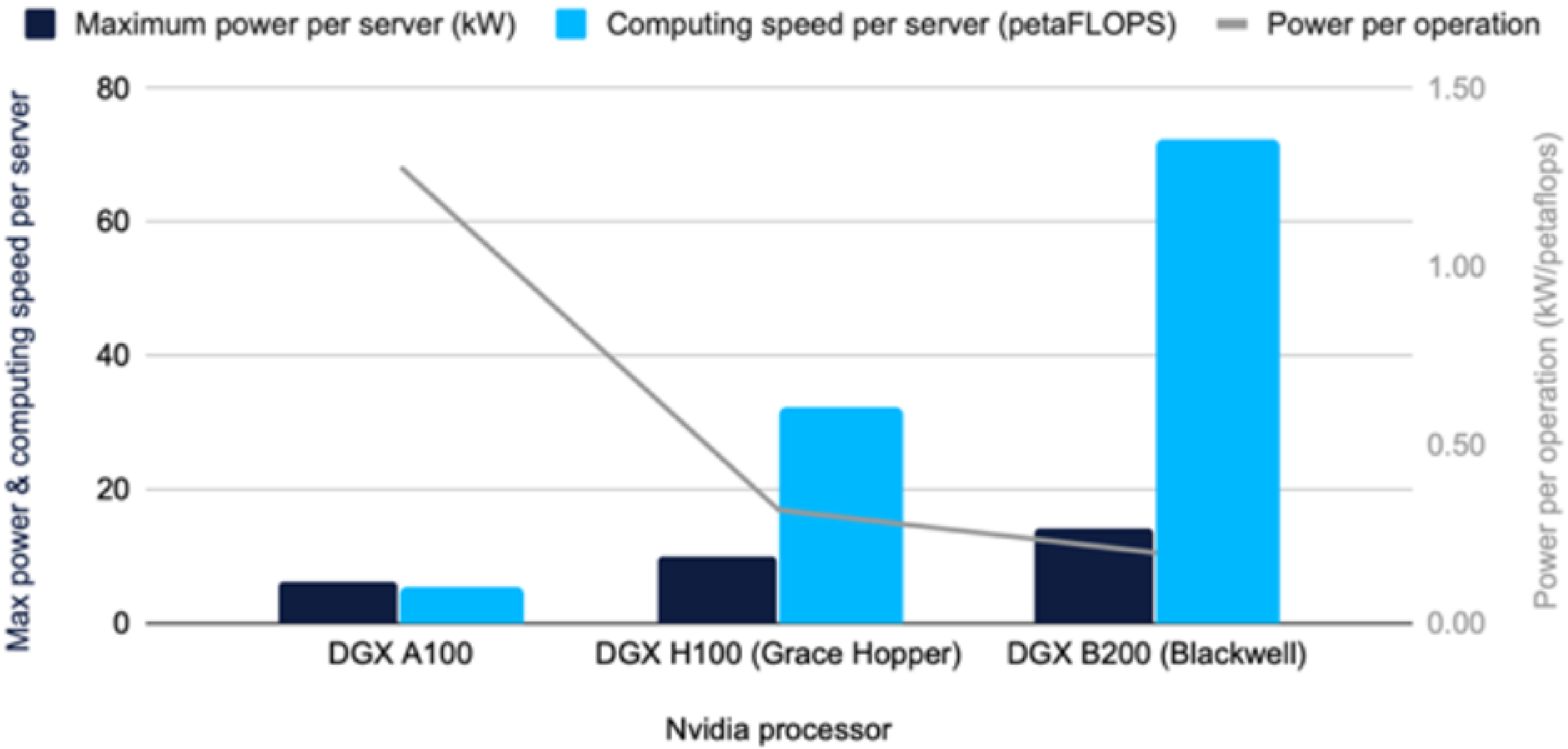
Energy use increase over the next 10 years

up to **10X**

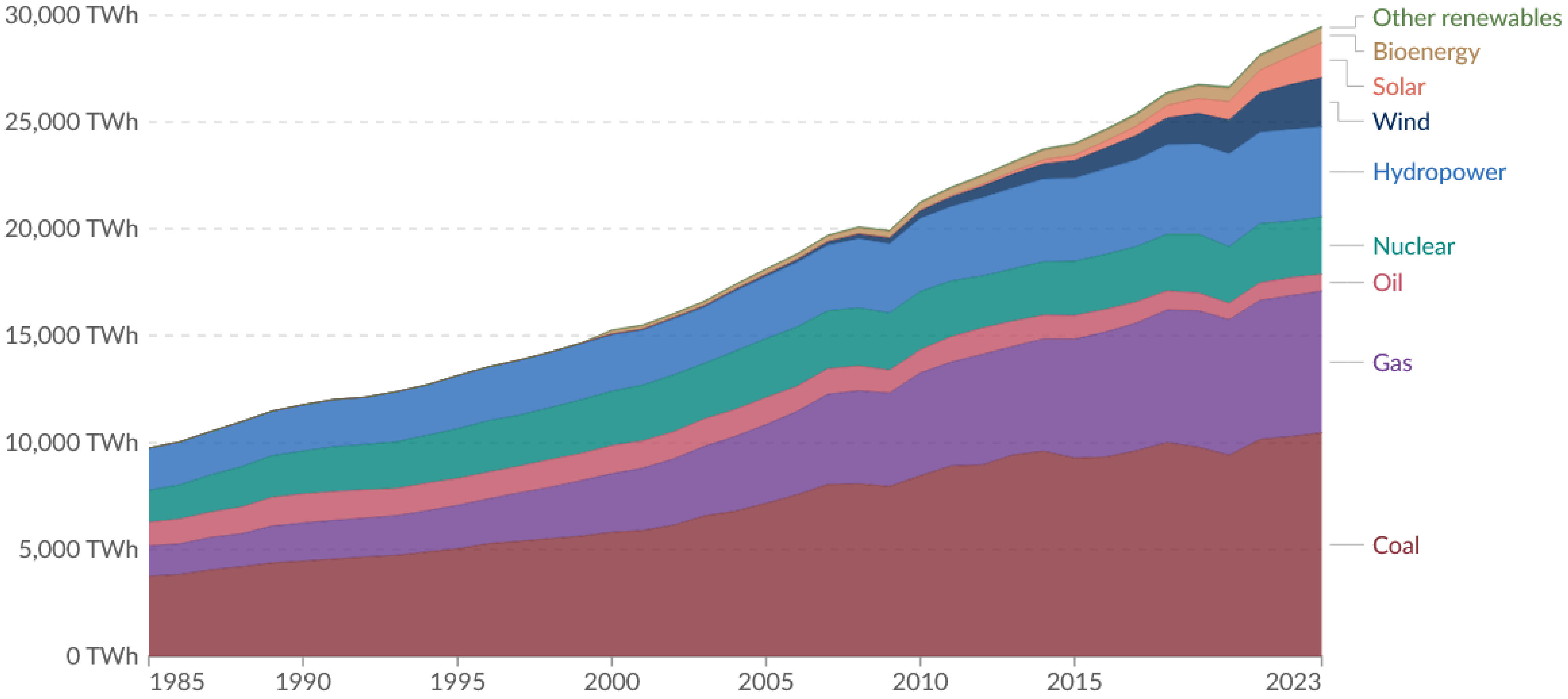
Power consumption of ChatGPT query versus Google

Processors are getting significantly more efficient, but AI's growth still requires ever greater power densities

Source: Goldman Sachs



Global Electricity Mix



https://ourworldindata.org/electricity-mix

How about efficiency – What can we expect?

- More than 60% of the generated electrical energy is produced by fossil based fuel
- Urgent to change the energy mix in a sustainable way
- At the same time we need to improve the efficiency in both the way we produce the electrical energy and how efficient we can distribute and consume the energy
- One important technology to improve power electronic efficiency is to introduce Wide Bandgap Semiconductors, such as SiC and GaN in our future technology

By improving today's power electronics efficiency by only 1% will reduce the consumption by 300 TWh – about 70 typical coal powered plants !

→

Fundamental WBG Characteristics

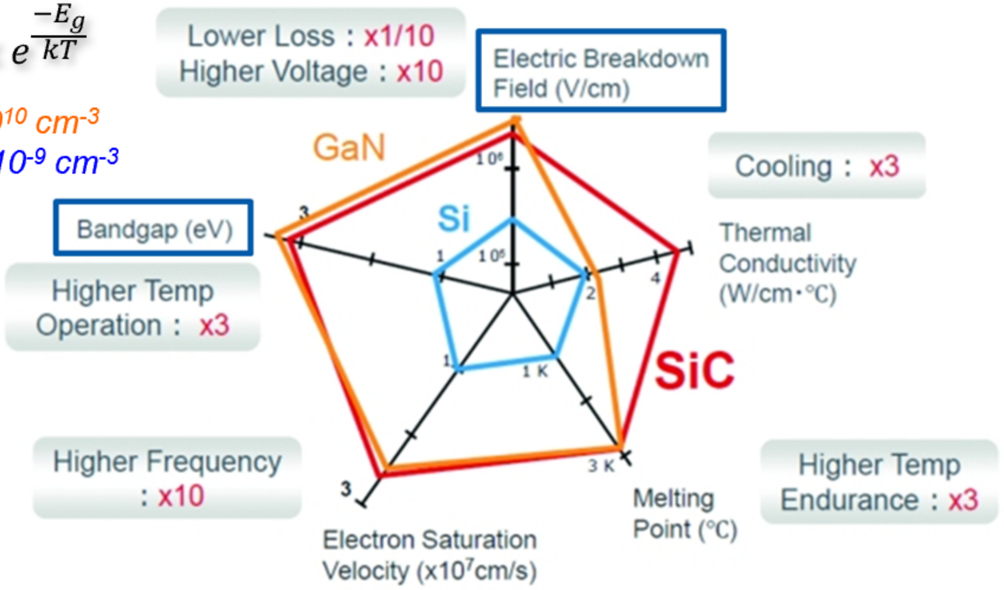
European Commission

ICOS International Cooperation On Semiconductors

$$n_i^2 \propto e^{\frac{-E_g}{kT}}$$

Si: ~10^{10} cm^{-3}

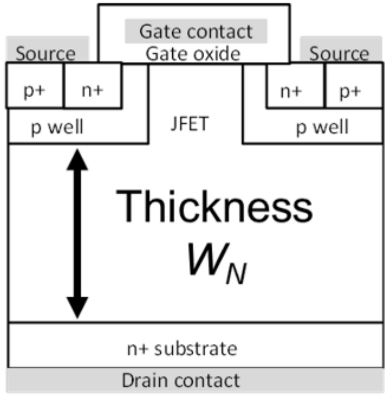
SiC: ~10^{-9} cm^{-3}



Courtesy: Rohm Semiconductor

Device Thickness

$$W_N = \left(\frac{3}{2}\right)\left(\frac{V_B}{E_C}\right)$$



Device Resistance

$$R_{ON,SP} = \left(\frac{3}{2}\right)^3 \frac{V_B^2}{\mu_N \varepsilon_S E_C^3}$$

Large Bandgap and Critical Electric Field allow for high voltage devices with thinner layers: lower resistance and associated conduction losses, low leakage, and robust high temperature operation

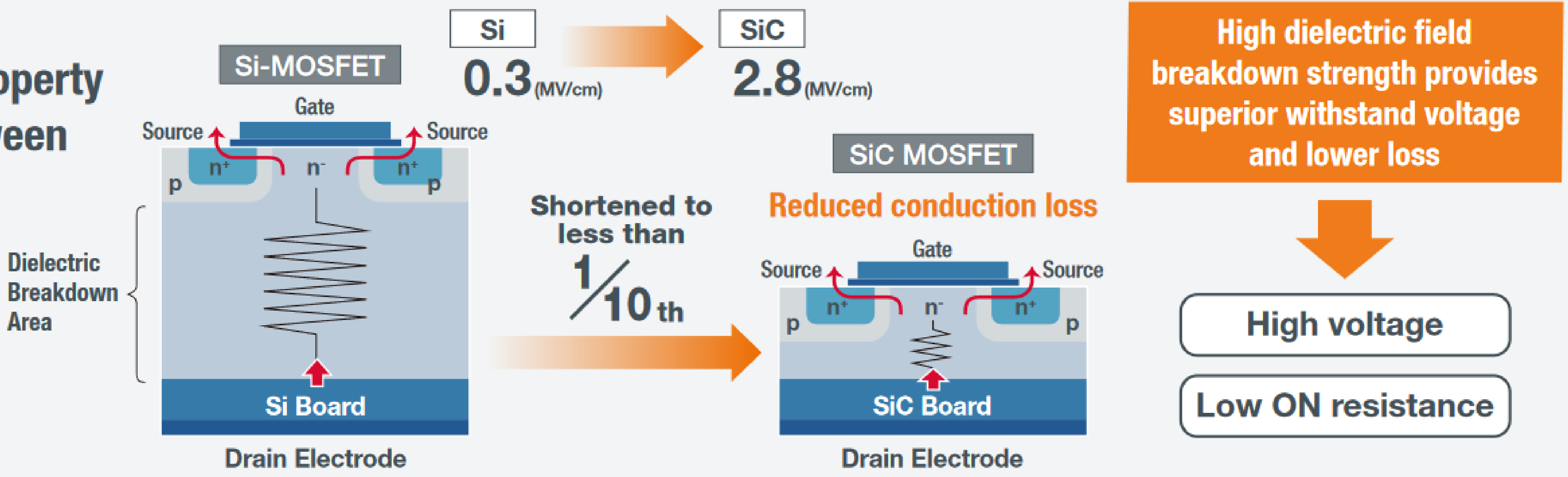
Thinner layers and lower specific on-resistances allow for smaller form factors that reduce capacitance: higher frequency operation, reduced size passives

Large Thermal Conductivity: high power operation with simplified thermal management

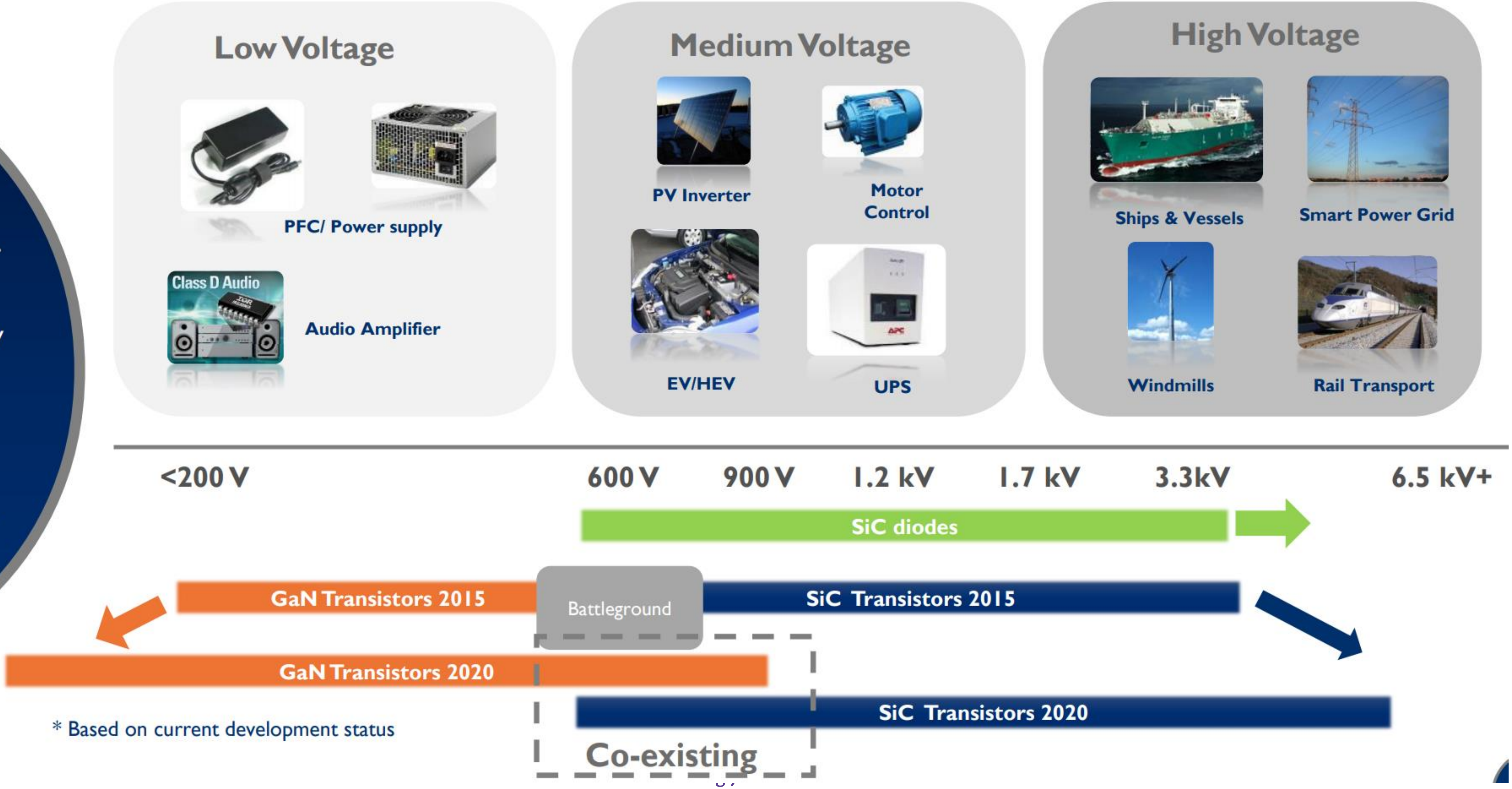
Modified slide from Victor Veliadis, Power America

Comparison of the Physical Property Constants Between Si and SiC

(Dielectric Breakdown Electric Field Strength)



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



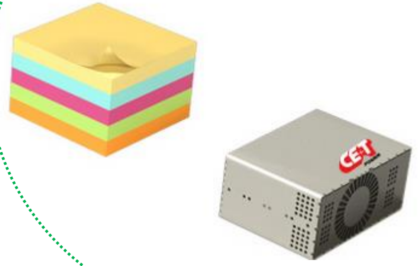
Google little box challenge

Task: minimize the volume of a 2kW inverter

Si reference
~200 $inch^3$

Requirement
40 $inch^3$

CE+T winner
13.8 $inch^3$



Won by CE+T POWER

Powered by GaN!

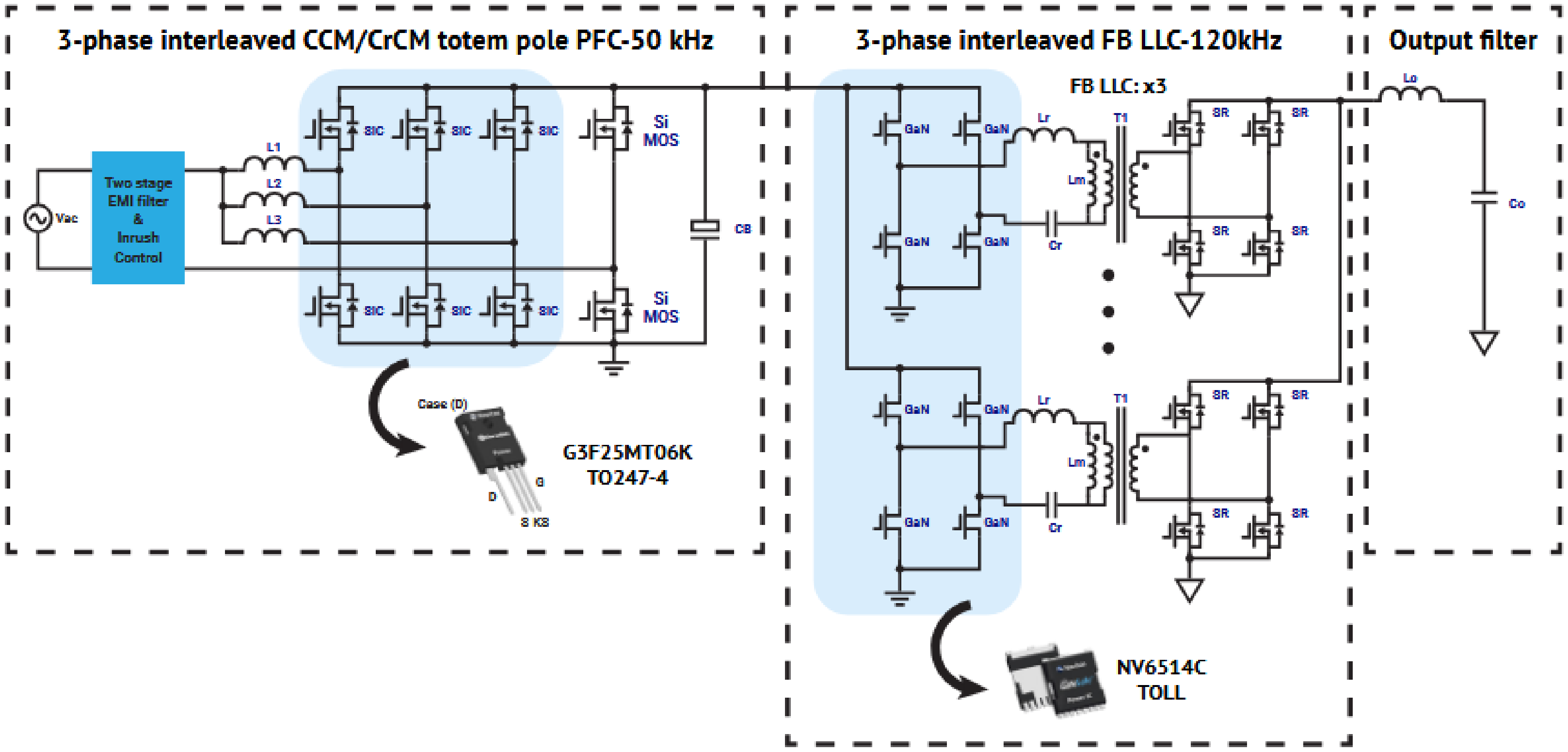
	Google's request	CE+T Power
Maximum Power Tested	2000VA	2062 VA
Volume of the rectangular enclosure	0.655 liter / 40 in^3	0.226 lier / 13.77 in^3
Resulting power density at 2 kW load	3050 W per liter 50W/in^3	8850 W per liter 145.24 W/in^3
DC voltage range	399.5Vdc	300 to 450 Vdc
AC voltage (RMS) output	230or 240 Vac	240 Vac split phase
DC to AC efficiency (CEC Method)	min 95%	95.4%
Voltage total harmonic distortion + noise	1.1%	1.1%
Current total harmonic distortion + noise	1.1%	1.1%

World's First 12 kW PSU for Hyper-Scale AI Data Centers using GaN and SiC

Navitas
Electrify Our World™

12 x NV6514
TOLL

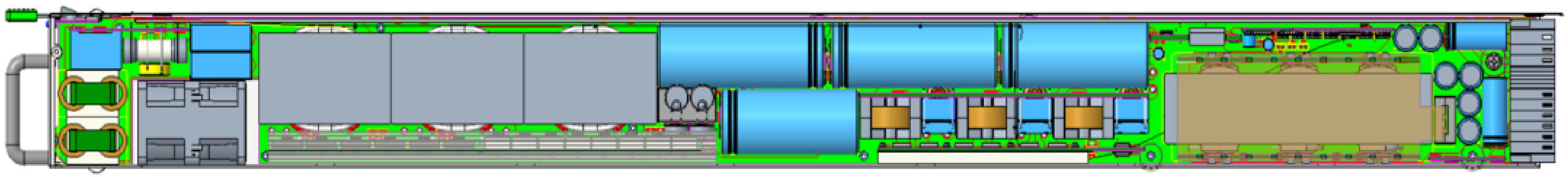
6 x G3F25MT06K
TO247-4



EMI filter, surge protection circuit, etc. to meet safety/regulation requirements

Supports RS485 & CAN communication protocols

Input/Output connector



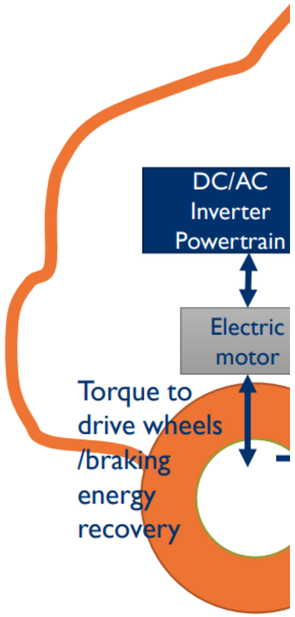
WBG in Automotive

CONVERTERS & INVERTERS IN EV/H

Where are SiC and GaN?

EV/HEV is a segment where the competition between SiC, GaN, and Si (the incumbent) will be intense

- Technologically speaking, SiC is more suitable for high-power DC/AC inverters and GaN is better adapted to low-power DC/DC and AC/DC converters
- However, the choice of SiC or GaN is more complex and depends on numerous criteria, such as technology maturity and device availability
- According to our knowledge, SiC-based diodes have already been implemented in low-power converters for the on-board charger



YOLE Développement

Electric traction motor: Uses power from the traction battery pack to drive the vehicle's wheels

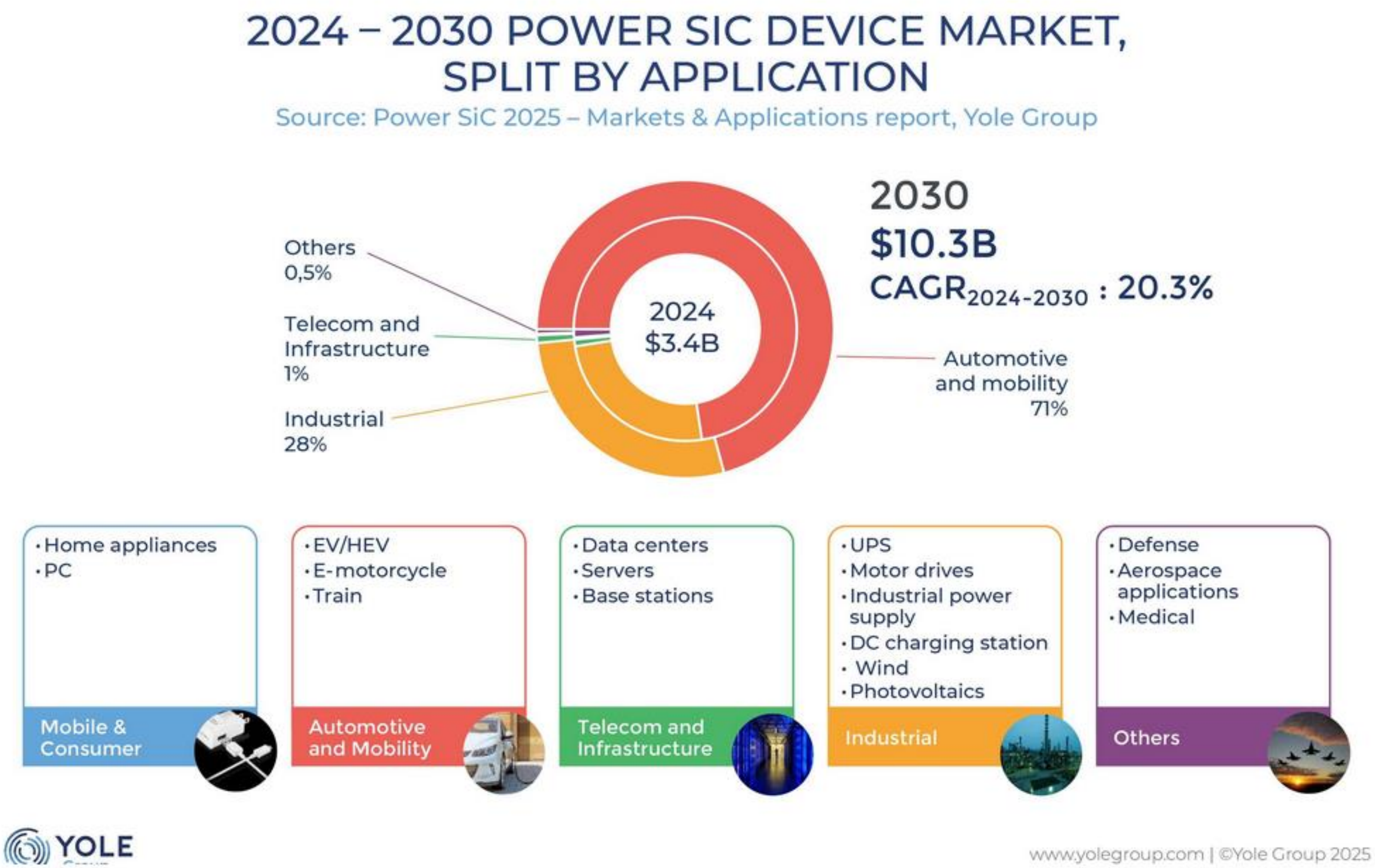
DC/DC converter: This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

Onboard charger: Takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery.

Traction battery pack: Stores electricity for use by the electric traction motor.

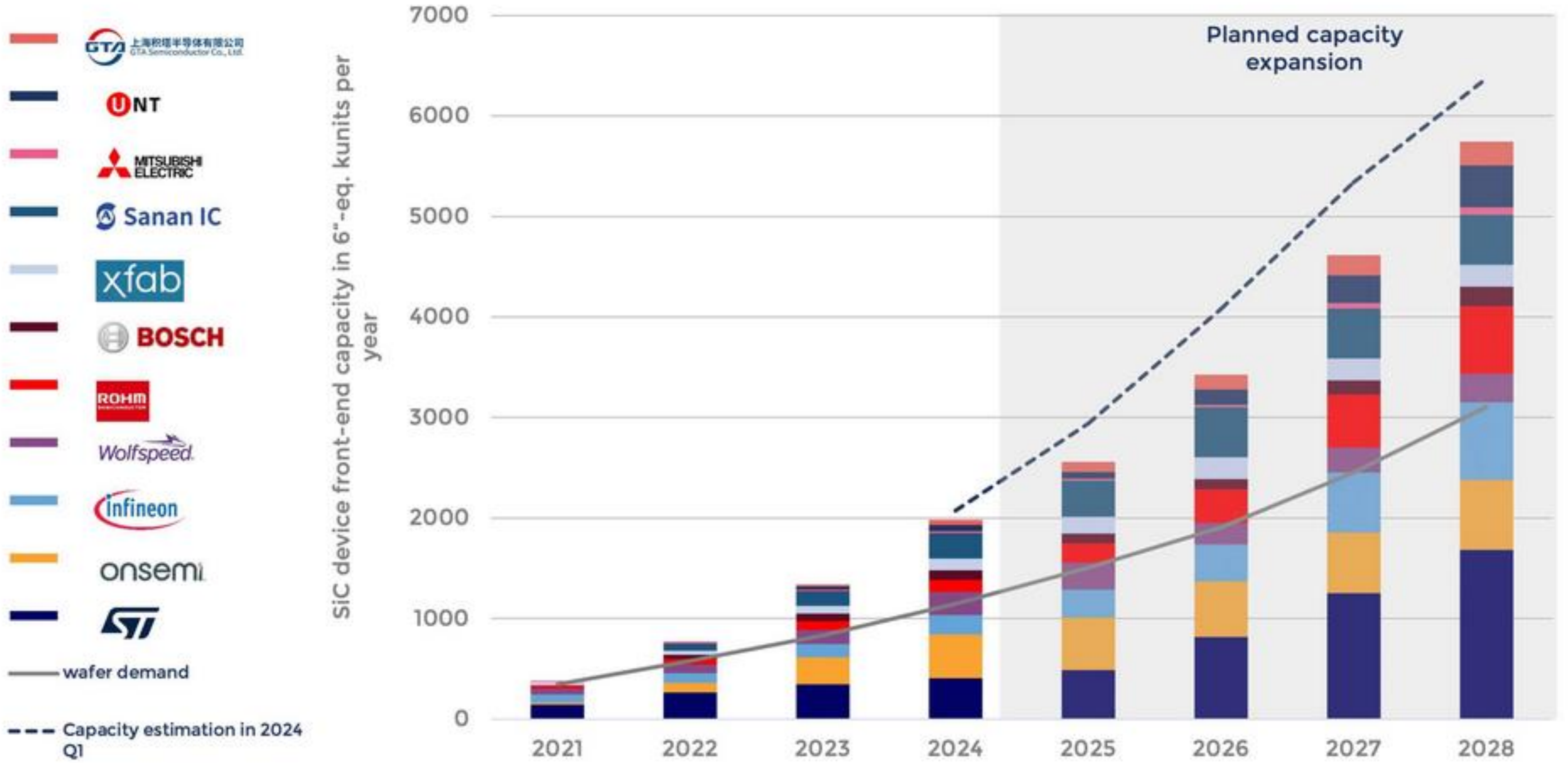
Battery (all-electric auxiliary): In an electric drive vehicle, the auxiliary battery provides electricity to power vehicle accessories.

Market Outlook



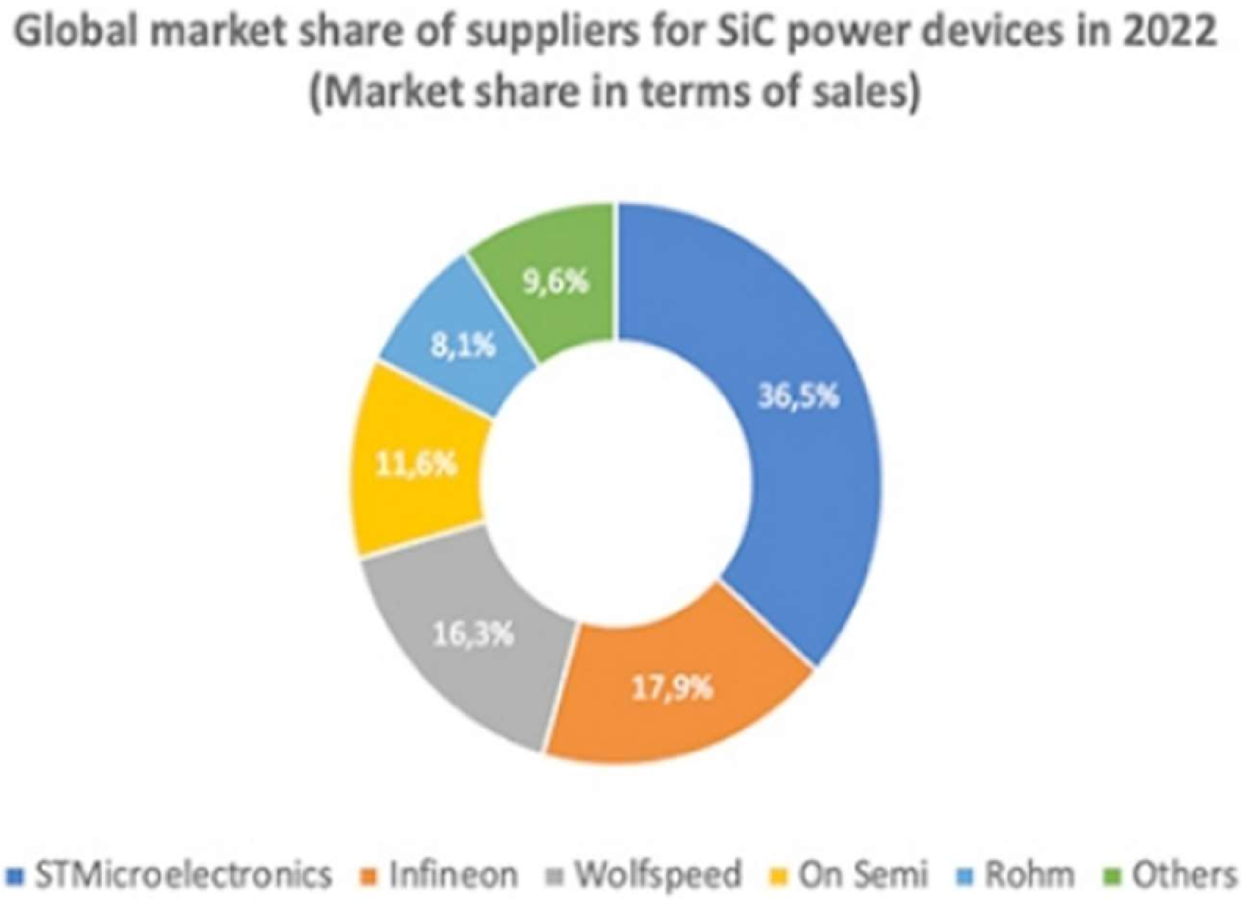
THE LATEST SIC DEVICE CAPACITY FORECAST OF KEY PLAYERS

Source: Power SiC 2025 – Markets & Applications report, Yole Group



YOLE

Europe is the market leader



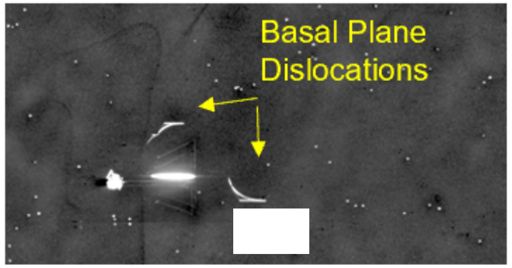
If we add the market share of STMicroelectronics and INFINEON, Europe has more than 50% of the total global market share of SiC power devices.

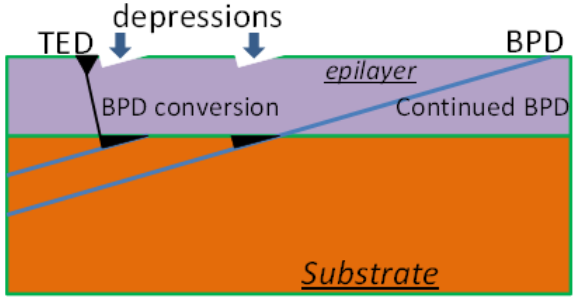
SiC Wafer Situation

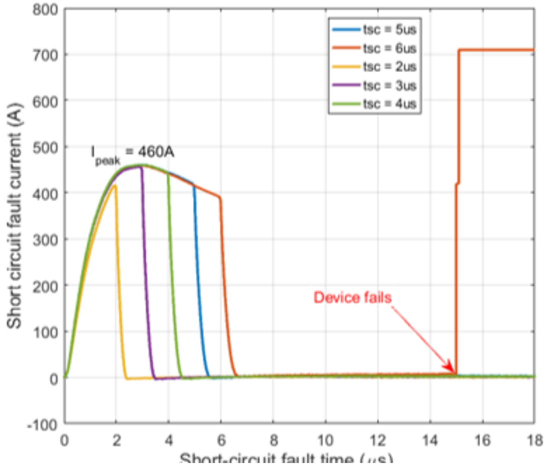
A 200 mm SiC Wafer by STMicrelectronics

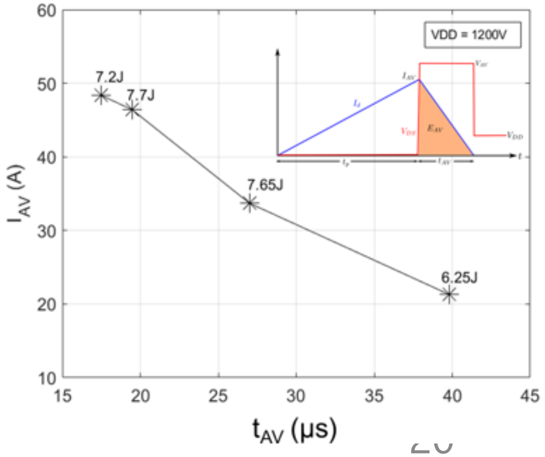
Initial problems with materials quality

- Material and Fabrication optimizations improve device yields and reliability
  - Minimize killer material defects (BPDs, micro-pipes, etc.)
  - Improve wafer planarity
  - Eliminate defect generation during processing (implantation)
  - Reduce Threshold-Voltage-Instability (high quality gate oxide)
- Design rugged SiC devices and fast gate drives for safe operating areas similar to Si
  - Short circuit withstand time similar to that of Si or use fast/intelligent gate drives
  - High Avalanche Energy tolerance





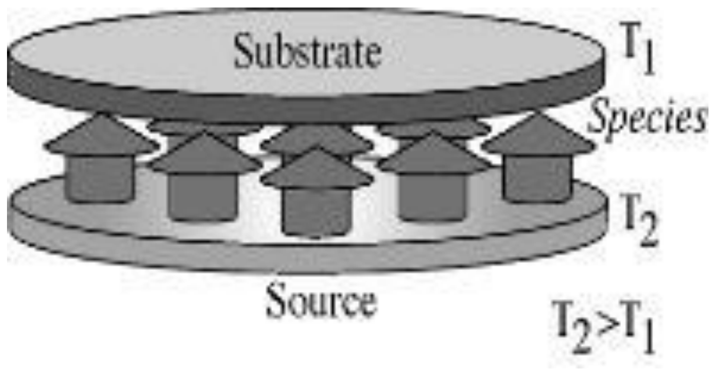




FSGP-M - a flat growth front - the key feature

The Fast Sublimation Growth Process – Monocrystalline (FSGP-M), provides perfectly uniform seed and source substrate temperatures and a uniform supply of growth species which ensures that a uniform growth rate is obtained over the whole substrate surface during the entire growth process.

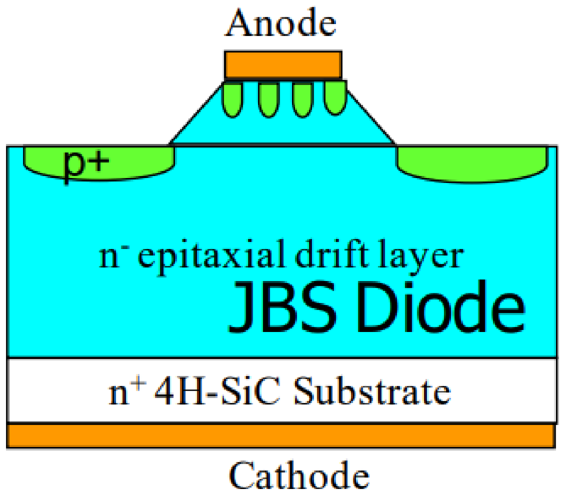
FSGP-M Principle configuration

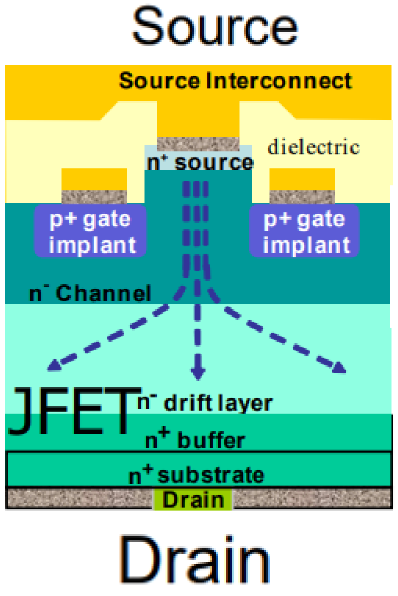


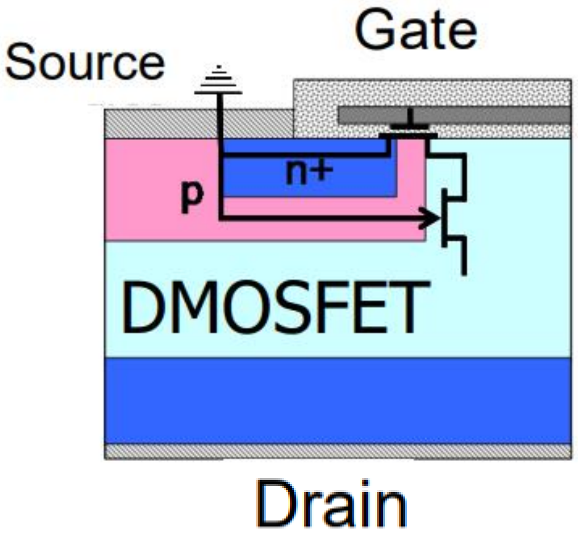
As a consequence, no BPDs are formed either during or post growth. The novel technology enables ultra high crystalline quality over large areas also in thick layers. There is practically no stress inside the crystal and in 6-inch size substrates bow is typically <5µm and warp <15µm. Doping concentration and resistivity are practically constant over the entire substrate surface. We have developed and taken into operation a production system for growth of 6-inch 4H-SiC substrates. Presently a system is being prepared for growth of 8-inch size substrates.

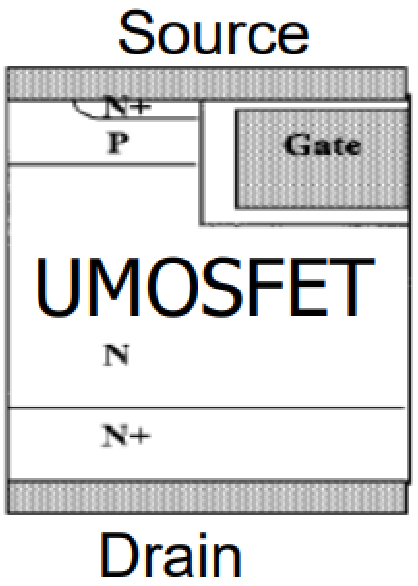
KISAB AB based in Kista

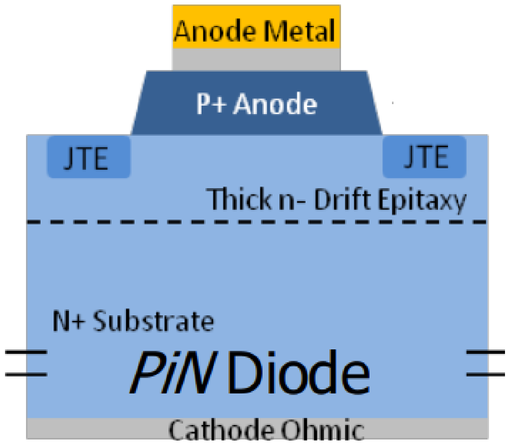
SiC Device Structures

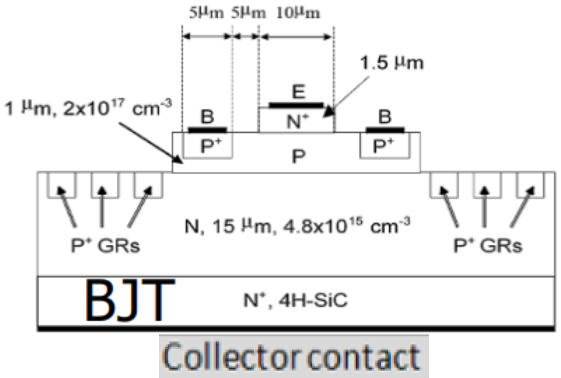


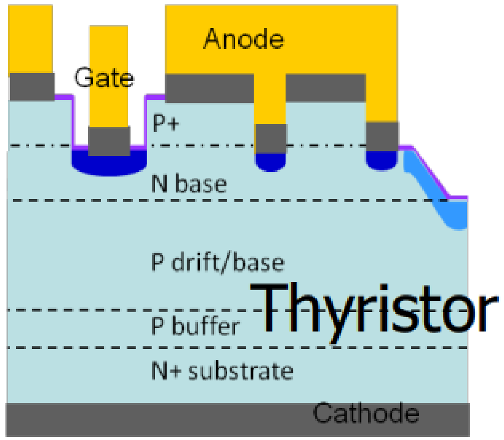


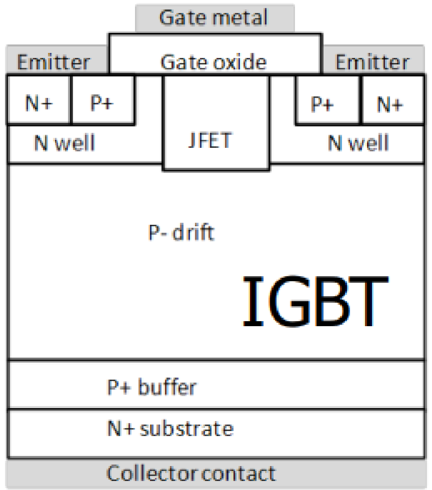






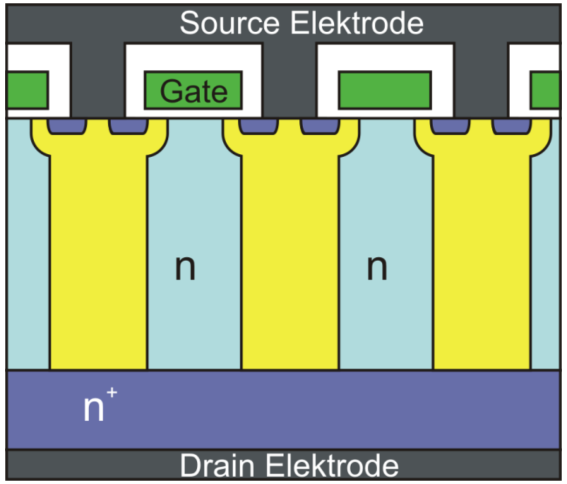


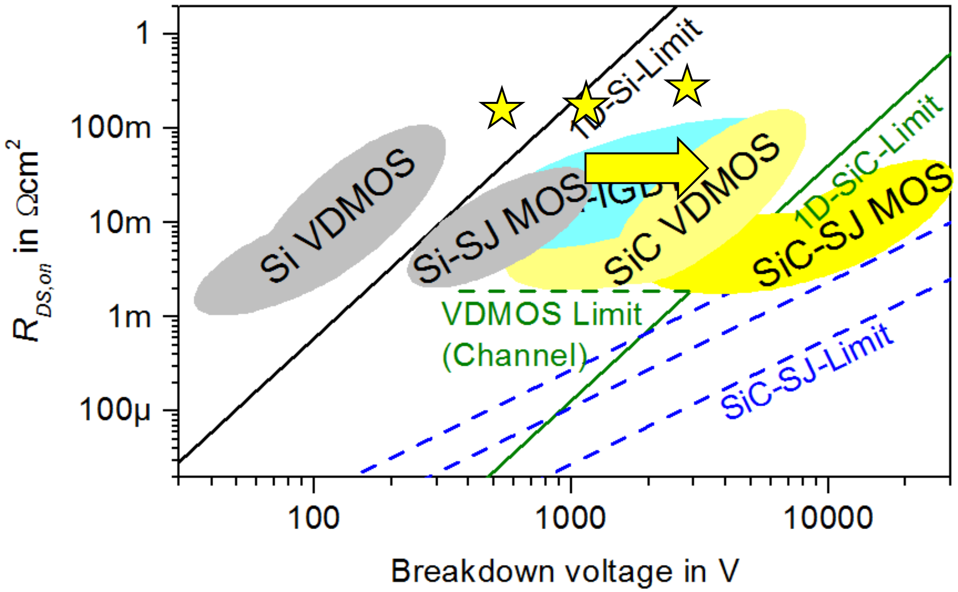




Evolution of Power SiC MOS Technology

- 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





Recent News SiC Trench Superjunction

Infineon presents 1200 V ID-PAK for automotive traction inverters and combine the advantages of trench technology and superjunction design

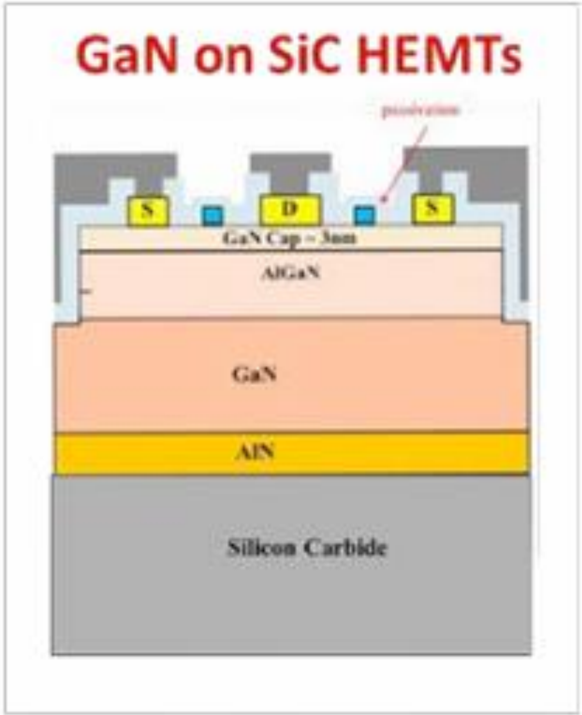
40 percent improvement in R DS(on)*A, allowing for more compact designs within a given power class.

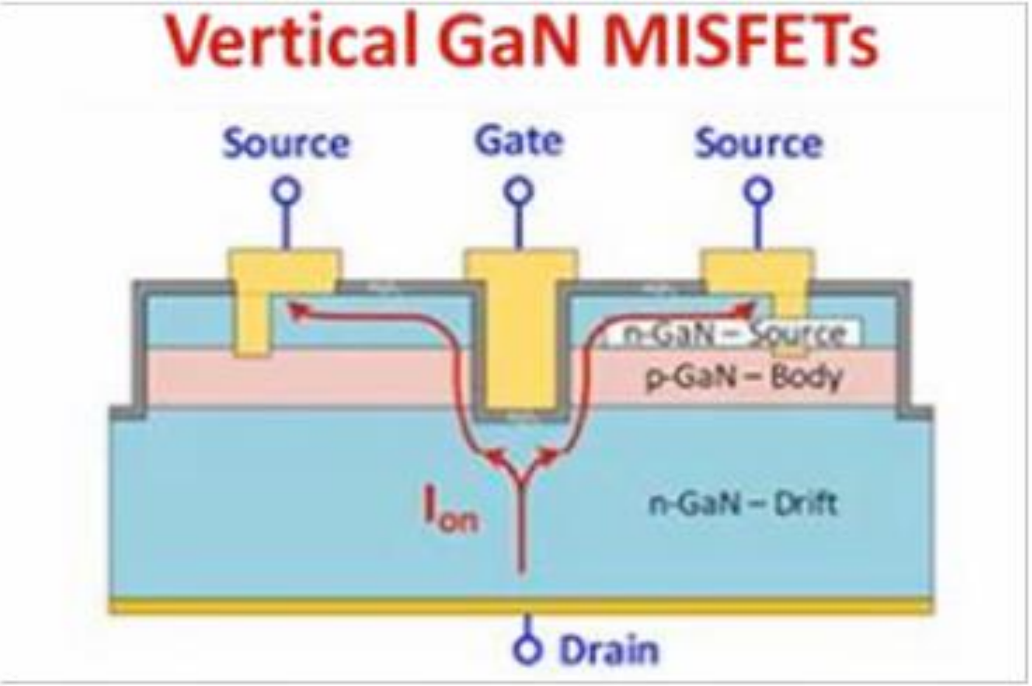
Hyundai Motor Company development teams will engage with Infineon’s trench-superjunction technology, leveraging its benefits to enhance their EV offerings

POWER SEMICONDUCTORS WEEKLY

May 6, 2025

GaN Devices





- Today, all GaN devices are produced on Si or SiC substrates, resulting in horizontal structures with limited scalability and low current capacity.
- Hetero-epitaxy introduces defects that reduce performance and reliability.

The WBG Pilot Line will develop processes for bulk GaN wafers, enabling vertical devices

Lower defect densities; Higher current-carrying capacity; Enhanced scalability and performance

WBG Wide Band Gap

future power electronics

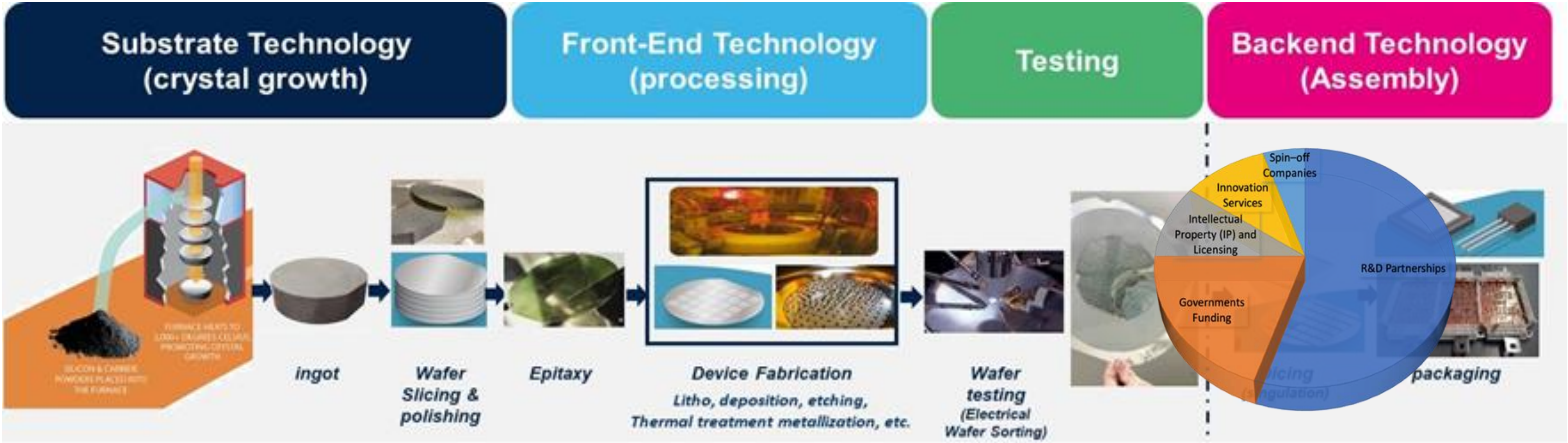
WBG Pilot Line: a major boost for Europe’s innovation and competitiveness

Total budget from EU €181,2M

	Euros
Total cost (EU)	362,609,738
EU funding	181,304,870
National funding	181,196,617

WBG Pilot Line

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).



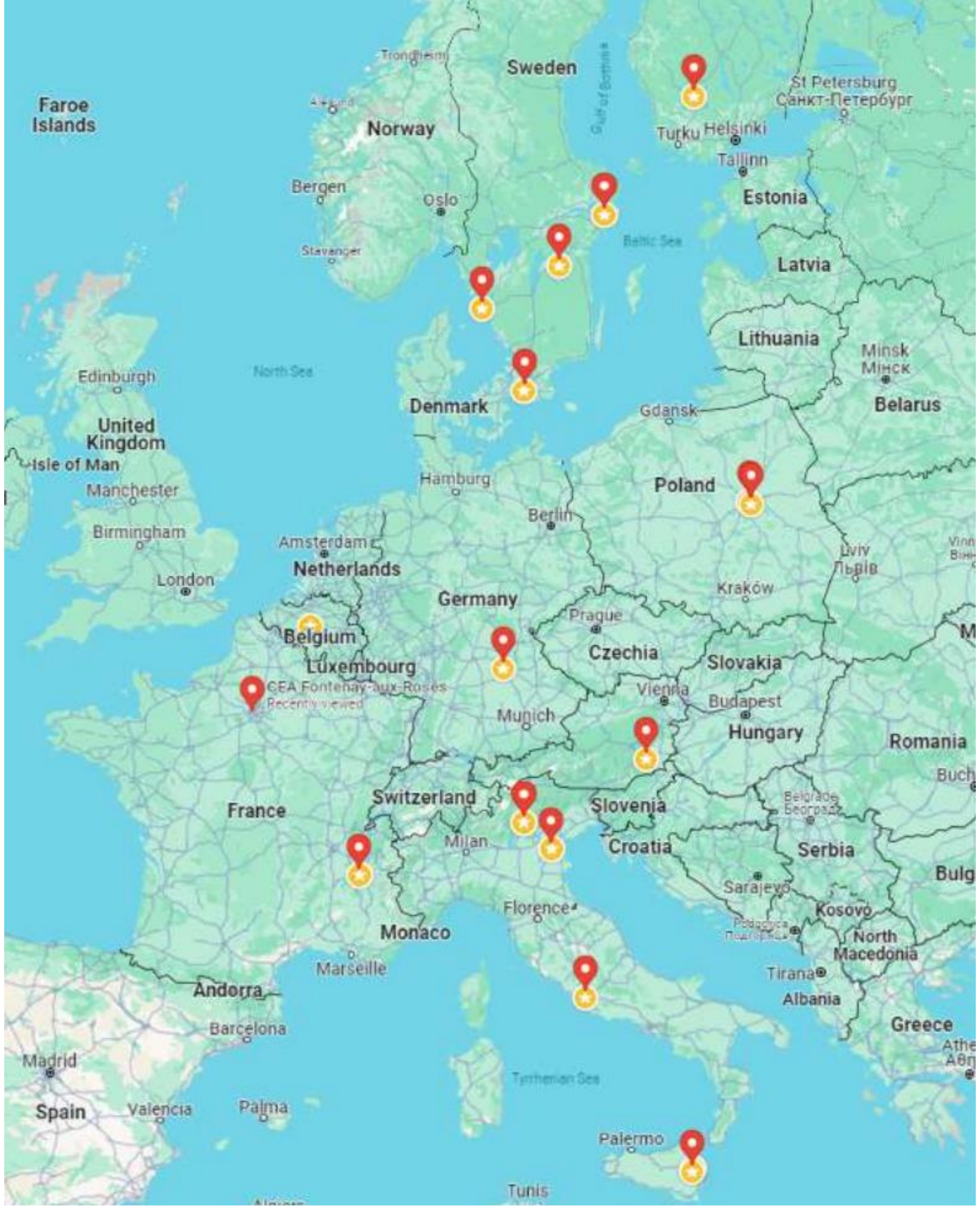
General idea, vision and topical coverage of the WBG Pilot Line

Participating organizations

14 Partners

7 Countries

CNR
FBK
IU.NET
CHIPS.IT
KTH
LIU
ULUND
Chalmers
Łukasiewicz - IMiF
IHPP PAS
TAU
SAL Austria
CEA LETI
Fraunhofer-IISB

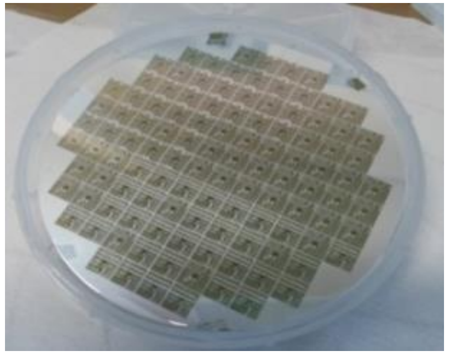


KTH Cleanroom for IC and Device Fabrication

- **Electrum Laboratory 1300 m²**
- ISO 9001 certified / controlled processes and calibrated characterization tools
- 100 – 200 mm wafers

- **Silicon Technology**
- Silicon - IC
- Silicon - Microsystems

- **Compound Semiconductors**
- SiC – Electronics, 100 mm
- InP - Opto / electronics
- GaAs - Opto / electronics



KTH Contribution to the WBG Pilot Line: High Voltage SiC BJTs and IGBTs (>3.3 kV)

Mikael Östling, Per-Erik Hellström and Mattias Ekström

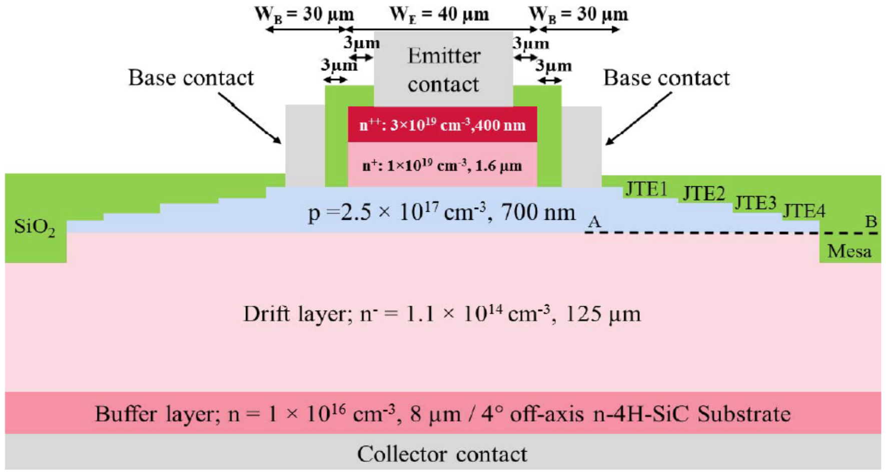
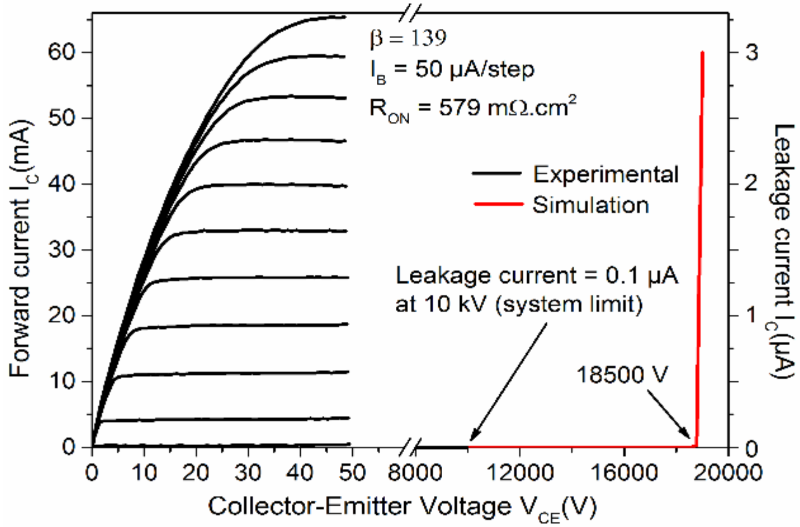


Fig. 1. Schematic cross-sectional view of the fabricated 4H-SiC BJT.

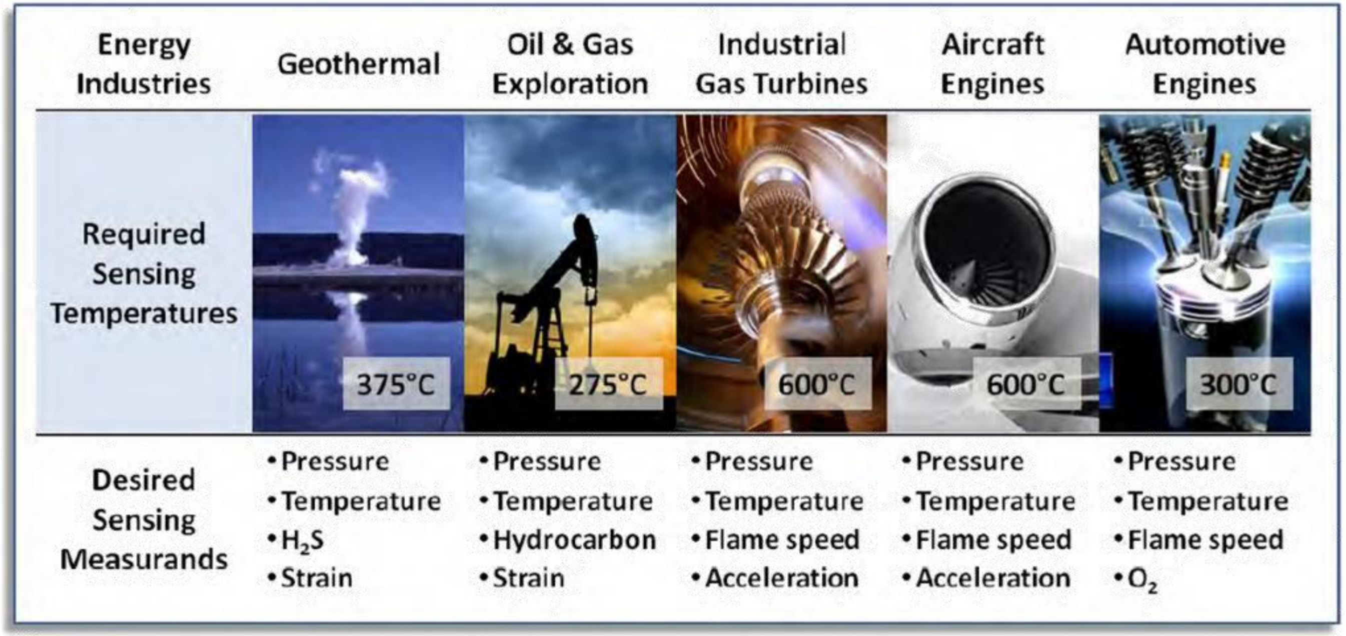


A. Salemi, H. Elahipanah, K. Jacobs, C. -M. Zetterling and M. Östling, "15 kV-Class Implantation-Free 4H-SiC BJTs With Record High Current Gain," in IEEE Electron Device Letters, vol. 39, no. 1, pp. 63-66, Jan. 2018, doi: 10.1109/LED.2017.2774139.

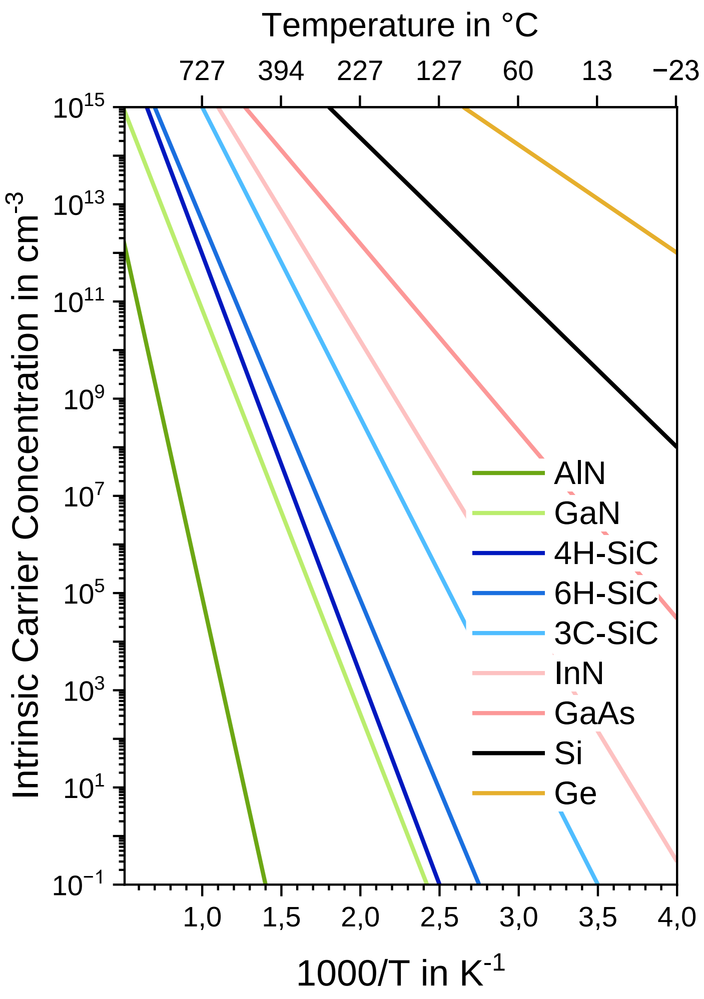
- The pilot line will initially deliver devices based on the the available high current gain (β>130) SiC BJT technology that has been demonstrated to sustain up to 15 kV of collector-emitter voltage .
- The pilot line will initially offer BJT devices for 3-5 kV (TRL level 5) on 150 mm SiC wafers.
- Technology development will bring 15 kV devices, currently at TRL 4 to TRL 5-6.
- In house available innovative, basal plane dislocation-free, 150 mm SiC substrates from KISAB (https://kisabsemi.com)
- The pilot line will also develop IGBT devices on KISABs p-type SiC substrates to be available to the pilot line after the qualification of the BJT devices.

High-Temperature SiC Circuits

- Operation > 500°C



Harsh Environment Sensor Cluster, University of California, San Diego



Summary

- WBG technology will be essential for the sustainable future when it comes to energy efficiency
- A long-term fabrication capacity increase is needed in Europe and globally and new facilities have been established successfully
- SiC market is currently down – Dependent on automotive sales but forecast is still very strong
- Power efficiency for data centers increasingly important
- WBG technology still needs materials development in the substrate/epi module

THANK YOU

mostling@kth.se

ICOS International Cooperation On Semiconductors

European Commission

This project has received funding from the European Union's Horizon Europe research and innovation programme under GA Nº 101092562

www.icos-semiconductors.eu