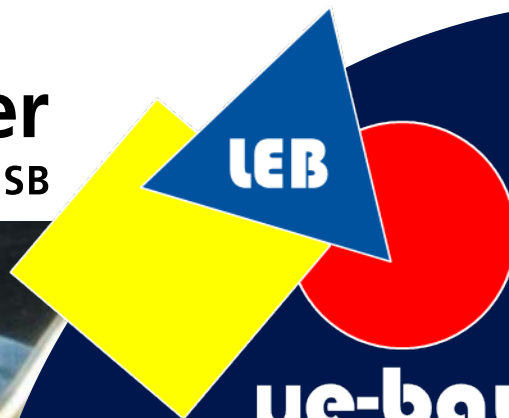




Friedrich-Alexander-Universität
Lehrstuhl für Elektronische
Bauelemente | LEB



Fraunhofer
IISB



µe-bauhaus
erlangen-nürnberg

SEMICON Europe 2022 (Ultra)Wide Bandgap Semicon- ductors for Sensor and Power Electronic Applications

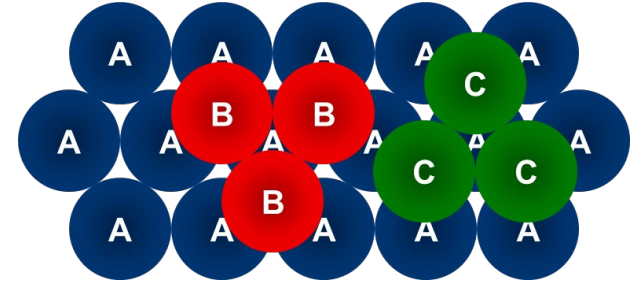
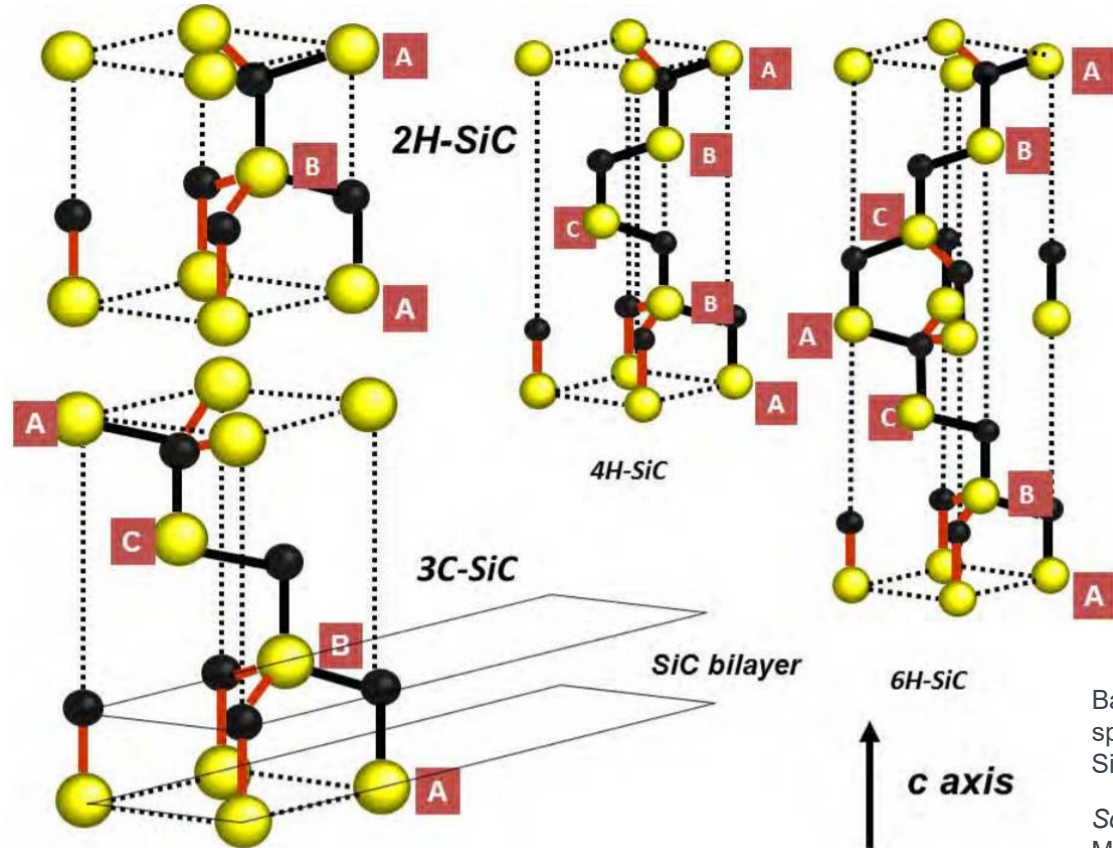
Prof. Dr. habil. Jörg Schulze | Friedrich-Alexander University (FAU) Erlangen-
Nuremberg | Chair on Electron Devices | Cauerstr. 6 | Fraunhofer Institute of
Integrated Systems and Devices Technology IISB | Schottkystr. 10 | 91058
Erlangen | <https://www.leb.tf.fau.de/> | <https://www.iisb.fraunhofer.de/>

Wide and ultrawide band-gap semiconductors

What are (U)WBG semiconductors? What are they good for?

Wide and ultrawide bandgap semiconductors

Silicon carbide (SiC) polytypes



Ball and stick representation in three dimensional perspective of the first polytypes 2H-SiC, 4H-SiC and 6H-SiC compared to 3C-SiC. The SiC bilayer is also shown.

Source: "SiC Cage Like Based Materials", Patrice Mélinon, University of Lyon and CNRS, France

Wide and ultrawide bandgap semiconductors

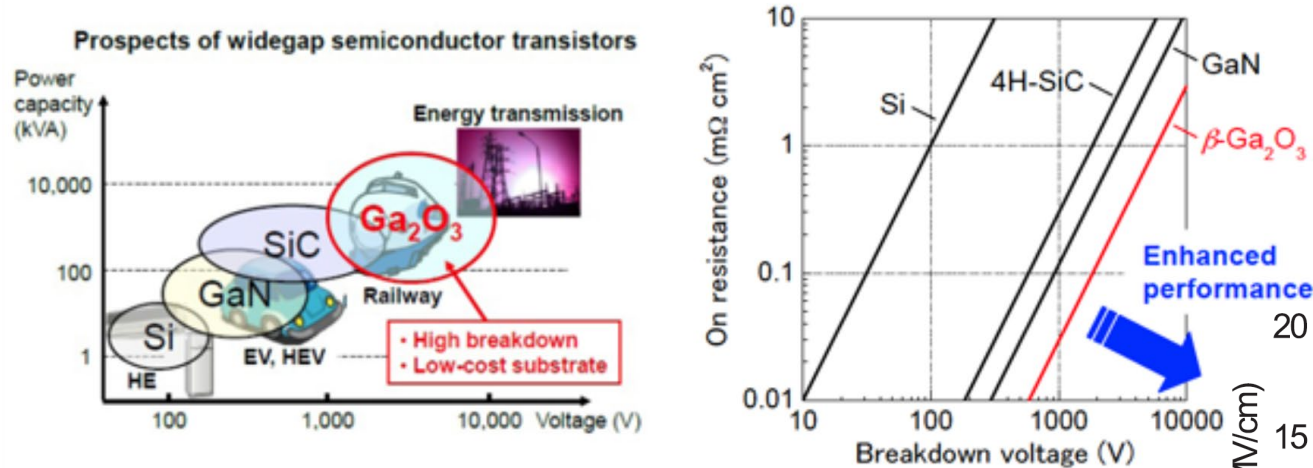
Harsh environments

Energy Industries	Geothermal	Oil & Gas Exploration	Industrial Gas Turbines	Aircraft Engines	Automotive Engines
Required Sensing Temperatures	 375°C	 275°C	 600°C	 600°C	 300°C
Desired Sensing Measurands	• Pressure • Temperature • H₂S • Strain	• Pressure • Temperature • Hydrocarbon • Strain	• Pressure • Temperature • Flame speed • Acceleration	• Pressure • Temperature • Flame speed • Acceleration	• Pressure • Temperature • Flame speed • O₂

Source: Harsh Environment Sensor Cluster, University of California, San Diego

Wide and ultrawide bandgap semiconductors

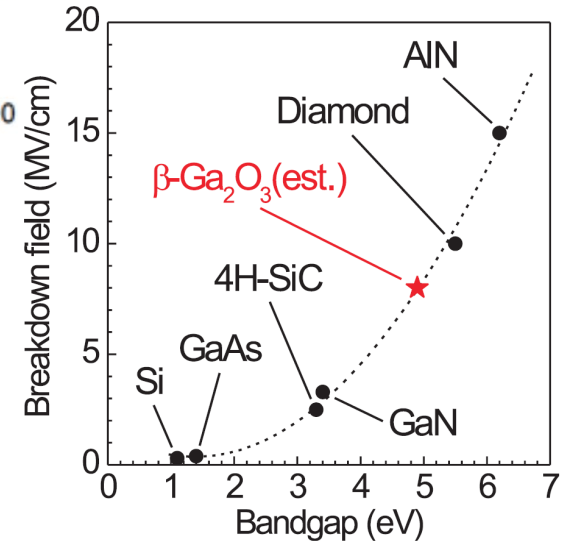
The family of (ultra)wide bandgap semiconductors



Sources:

[1] Higashiwaki et al. NICT Press Release (<https://www.nict.go.jp/en/press/2012/01/13-01-1.html>)

[2] M. Higashiwaki et al., APL 100, 013504 (2012).

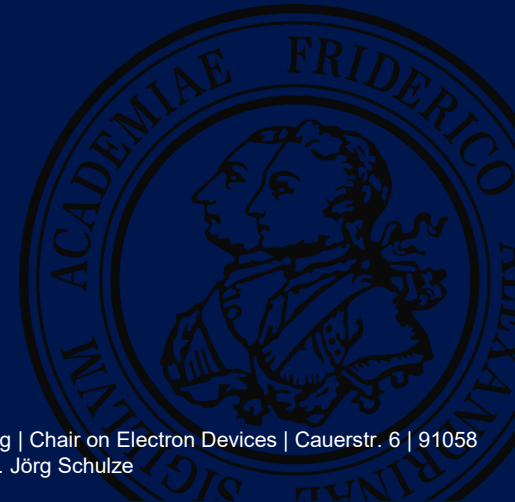




Friedrich-Alexander-Universität
Technische Fakultät

The art of SiC wafer manufacturing

How to manufacture large SiC wafers?

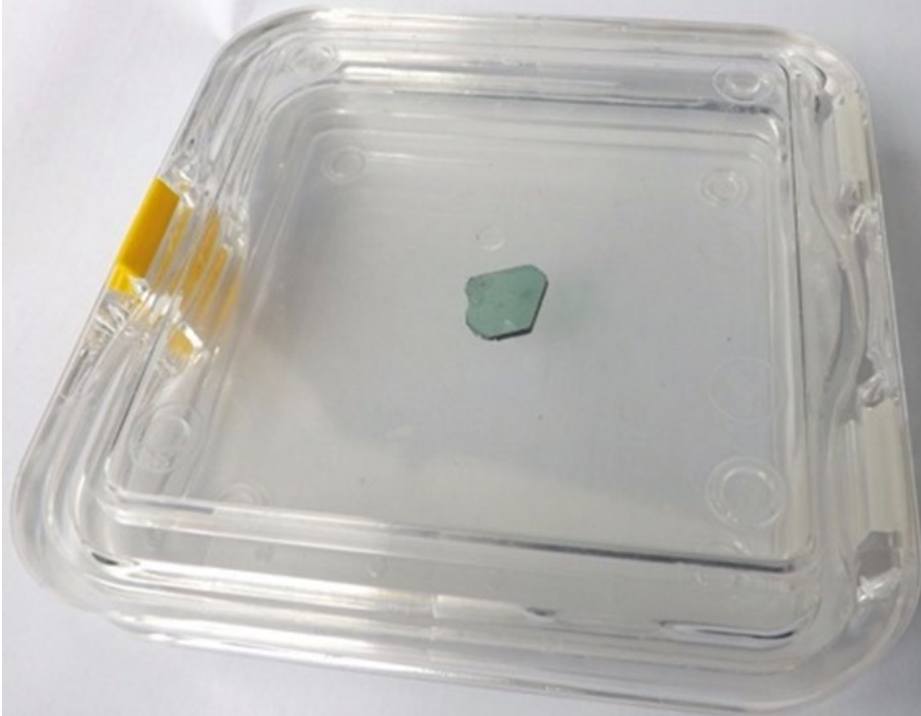


SEMICON Europe 2022

FAU Erlangen-Nuremberg | Chair on Electron Devices | Cauerstr. 6 | 91058
Erlangen | Prof. Dr. habil. Jörg Schulze

The art of SiC wafer manufacturing

Lely process for SiC crystal growth

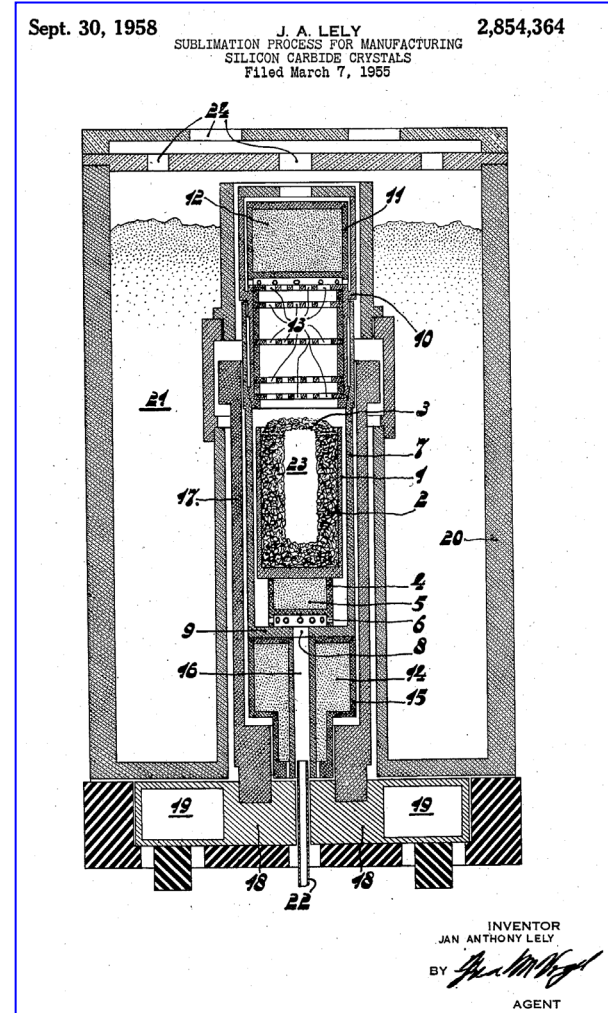


SiC crystal grown by using the Lely process

Source: <https://www.elektroniknet.de/halbleiter/leistungshalbleiter/so-entsteht-ein-sic-wafer.135010.html>

SEMICON Europe 2022

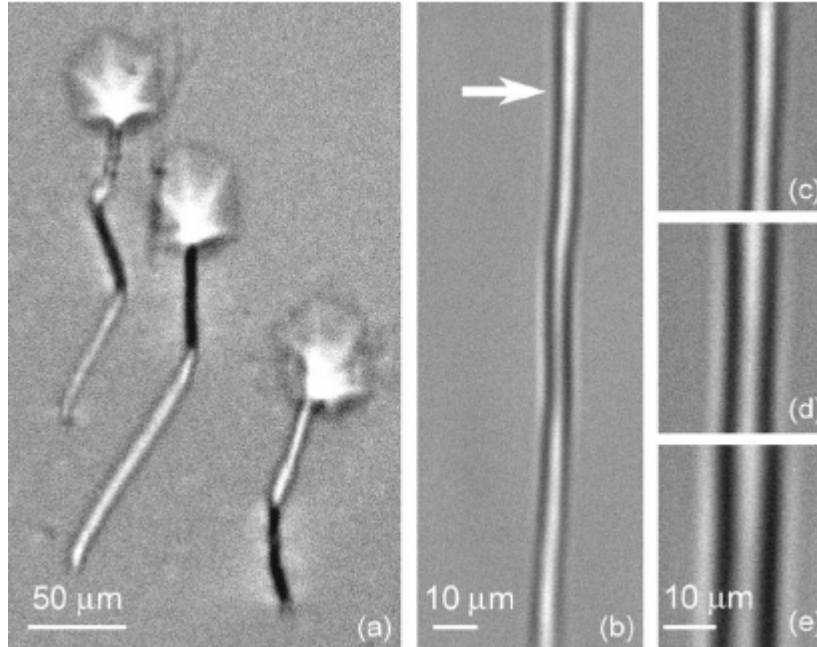
FAU Erlangen-Nuremberg | Chair on Electron Devices | Cauerstr. 6 |
91058 Erlangen | Prof. Dr. habil. Jörg Schulze



Schematic drawing of a process chamber for the Lely process, taken from the patent on: "Sublimation process for manufacturing Silicon carbide crystals" by J. A. Lely (filed: March 7, 1955; issued: September 30, 1958, US patent number 2854364)

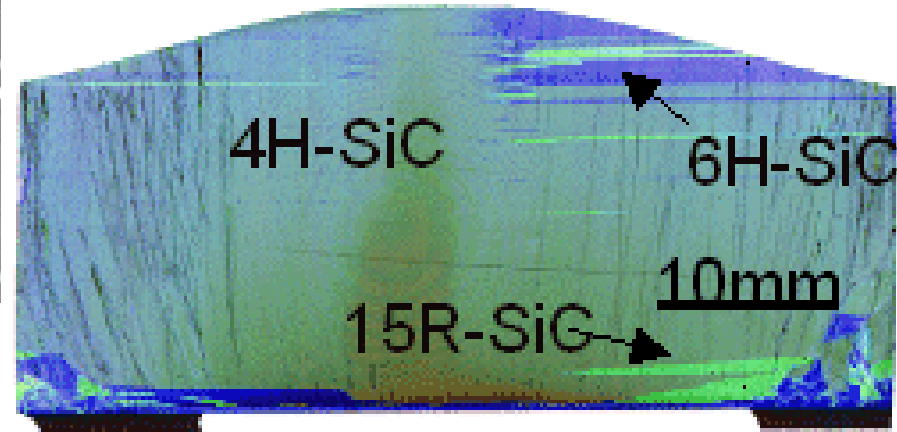
The art of SiC wafer manufacturing

Crystal defects and polytypes of grown SiC crystals



Typical images of micropipes in SiC wafers cut perpendicular to the 0001 growth direction (a) and along the growth direction (b). The arrow in (b) indicates the fragment shown in (c) – (e) at various sample-to-detector distances: 10, 30, and 50 cm, respectively. Halos in (a) correspond to etch pits on the wafer surface.

Source: Kohn et al., Applied Physics Letters, 2007, DOI: 10.1063/1.2801355



Grown SiC crystal with domains of different polytypes

Source: https://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_a/backbone/ra_1_1.html

The art of SiC wafer manufacturing

Efforts to increase the SiC wafer diameter

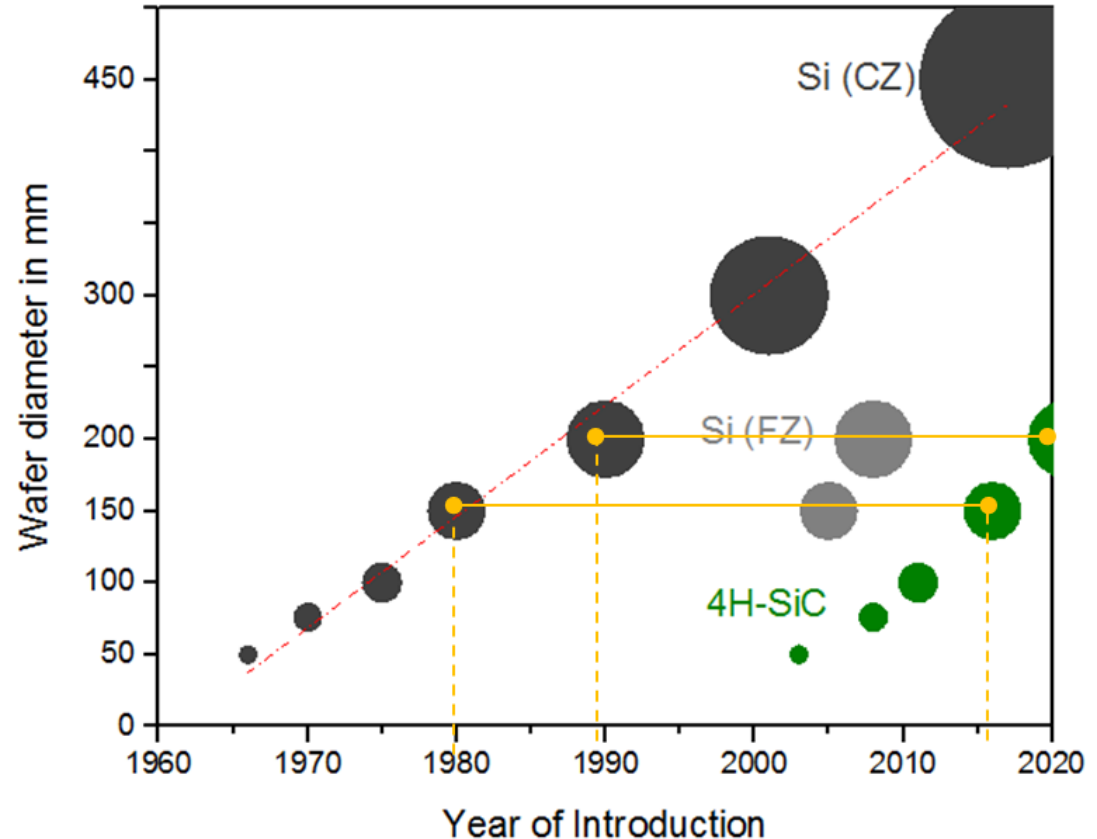
4H-SiC technology

150 mm: 1980th Silicon era

200 mm: 1990th Silicon era

Silicon concepts in SiC

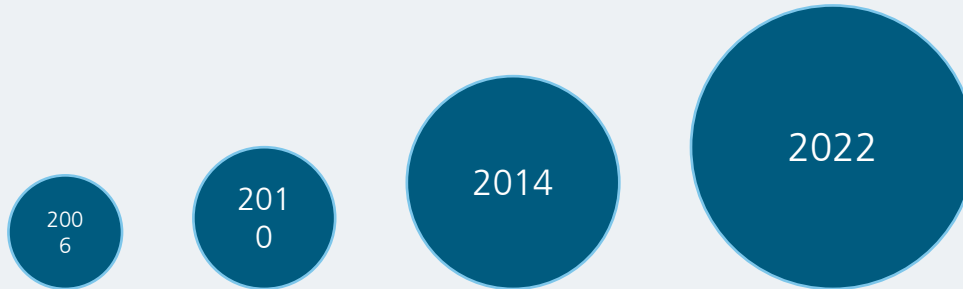
- Shorter development cycles
- Process equipment largely available



The art of SiC wafer manufacturing

EU ECSEL TRANSFORM project of IISB

TRANSFORM

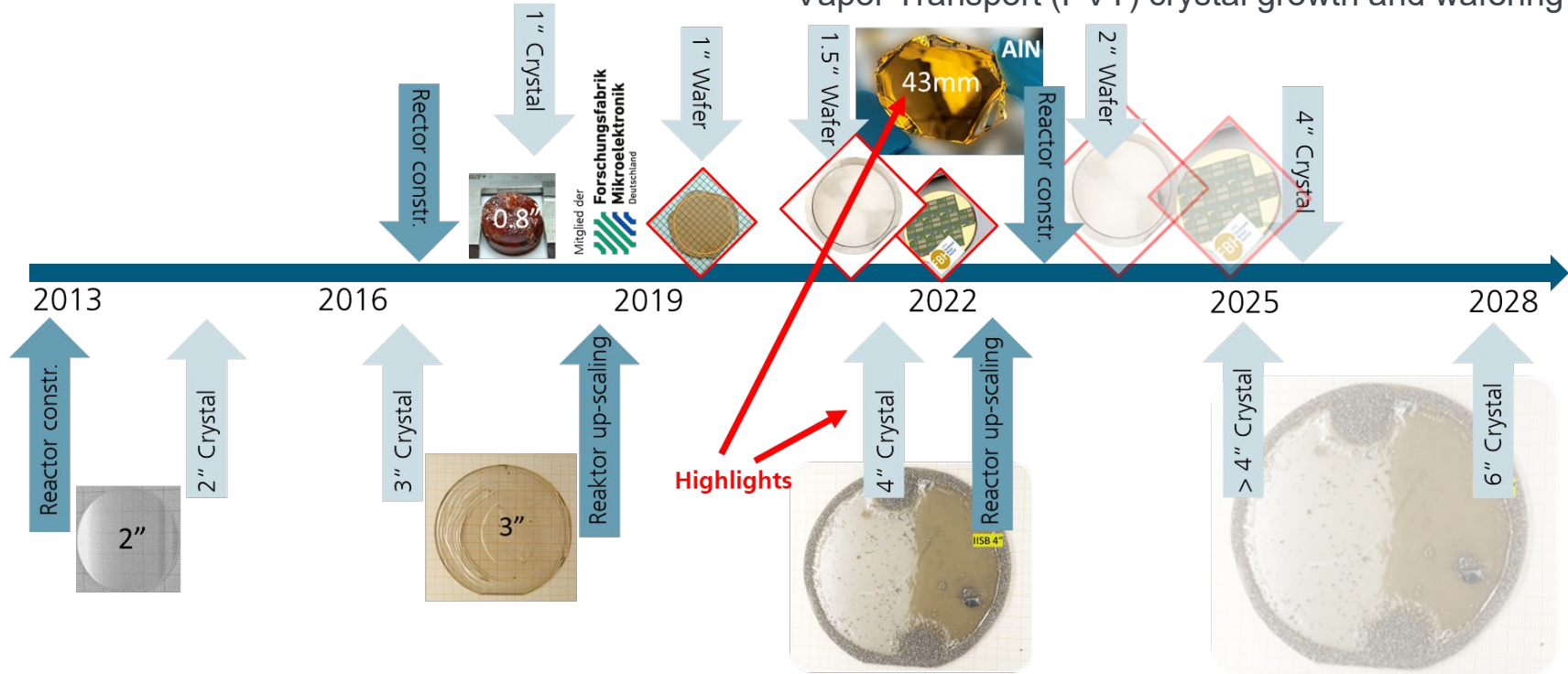


Pioneering 200 mm SiC

The art of SiC wafer manufacturing

GaN and AlN crystal growth roadmap of IISB

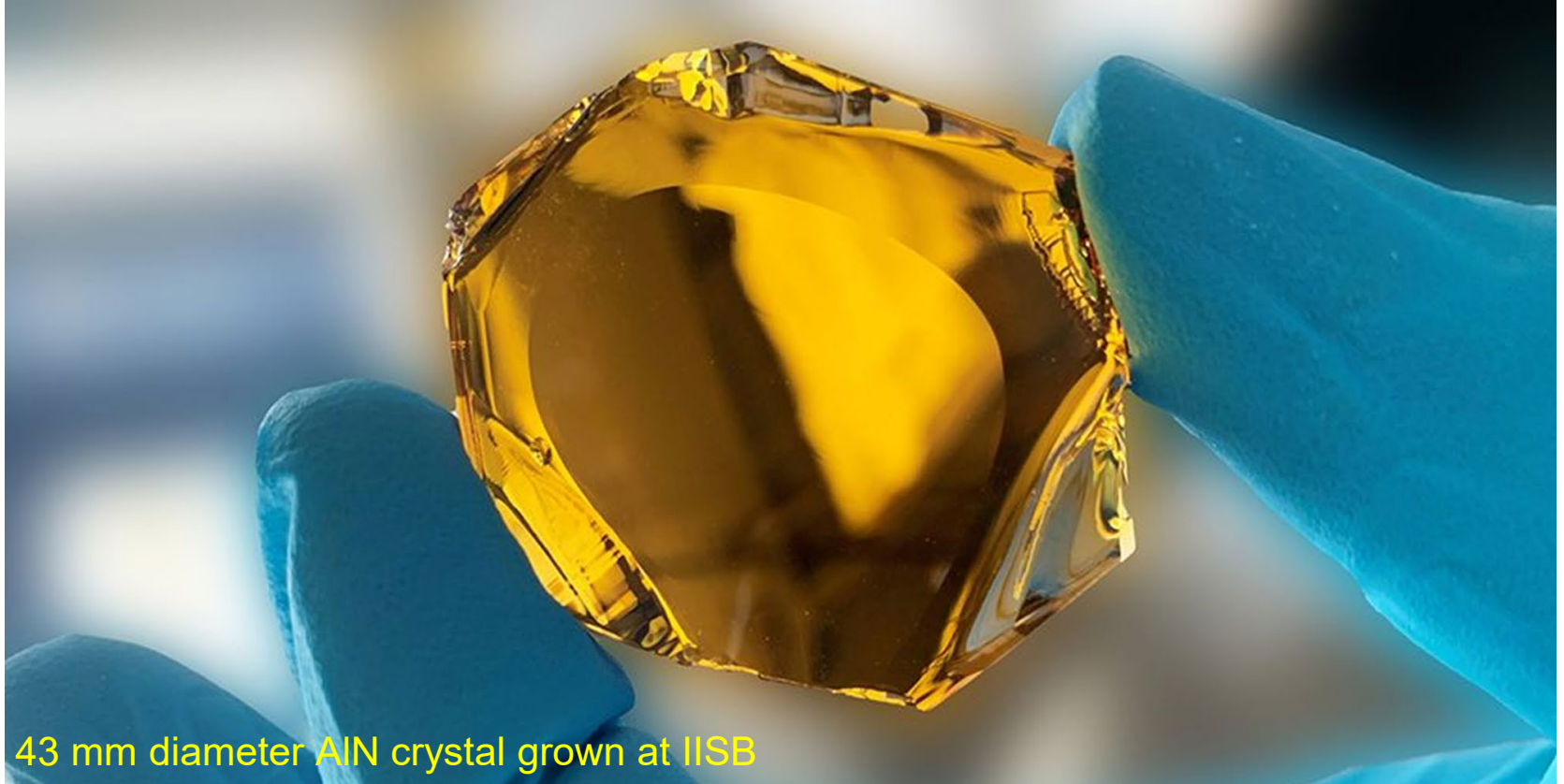
Developing AlN technology for power electronics: AlN Physical Vapor Transport (PVT) crystal growth and wafering



Enabling commercial GaN-on-GaN power electronics: Availability of Hydride Vapor Phase Epitaxy (HVPE) GaN wafers $\geq 4"$

The art of SiC wafer manufacturing

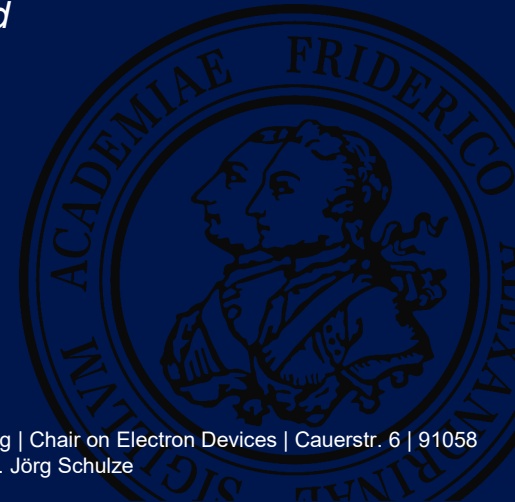
GaN and AlN crystal growth roadmap of IISB



43 mm diameter AlN crystal grown at IISB

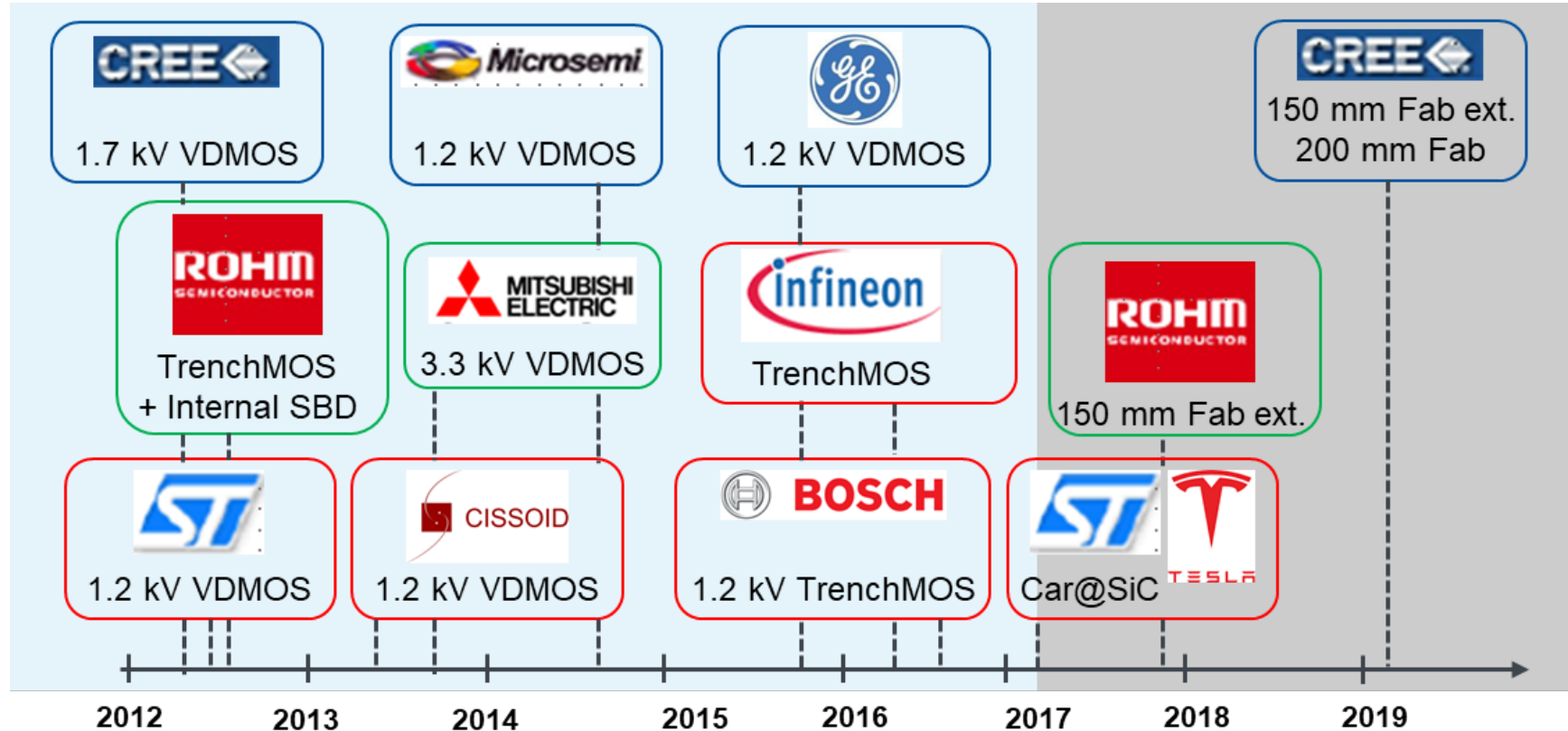
Exploiting benefits of SiC power device technology

What is the status of the transition from R&D to ramp-up around the globe?



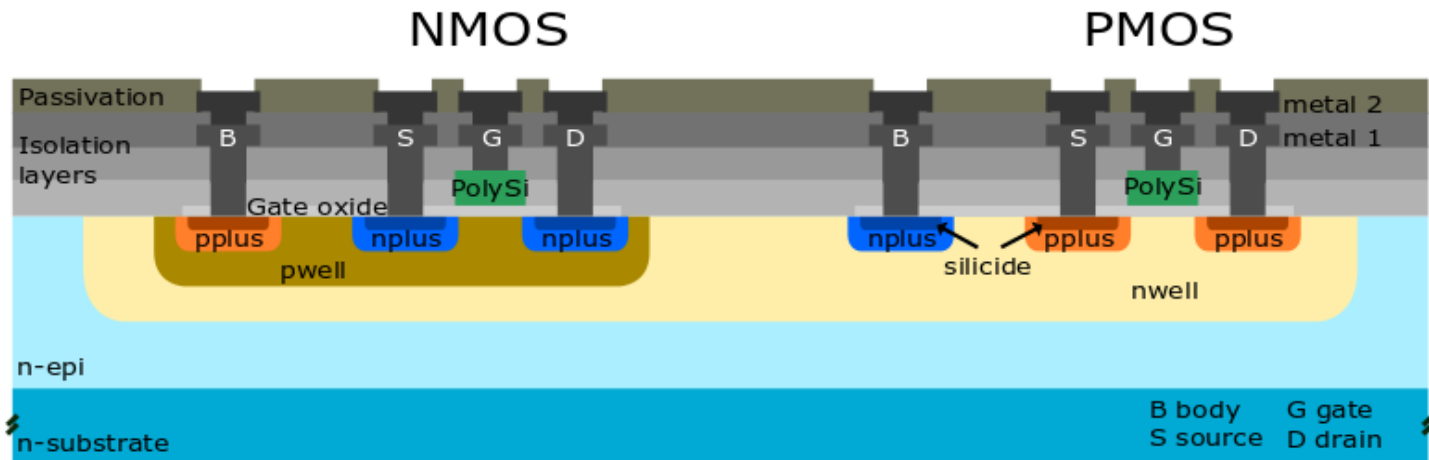
Exploiting benefits of SiC power device technology

Recent SiC MOSFET device activities and innovations



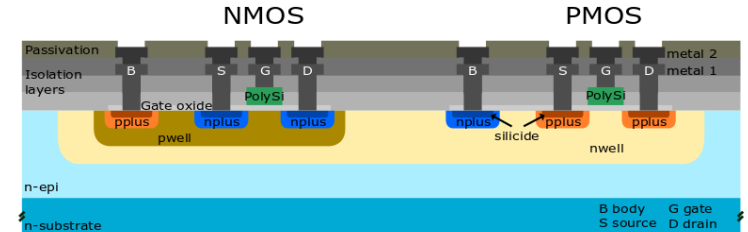
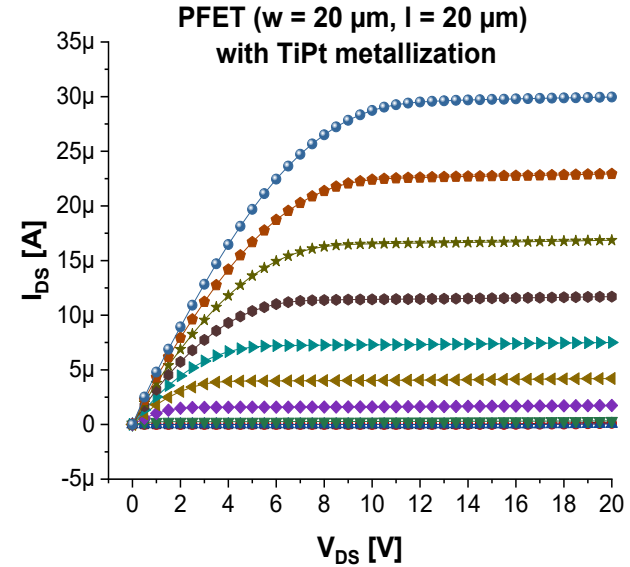
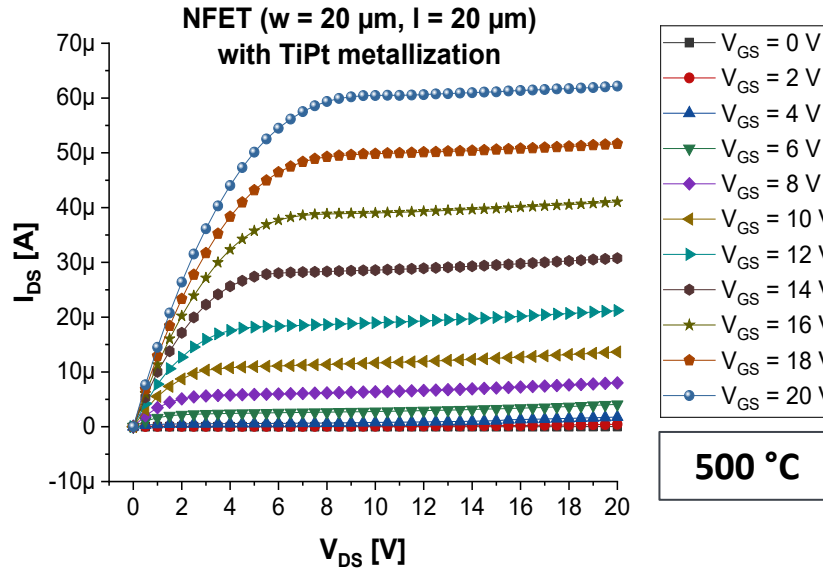
Exploiting benefits of SiC power device technology

SiC BiCMOS technology development @ IISB



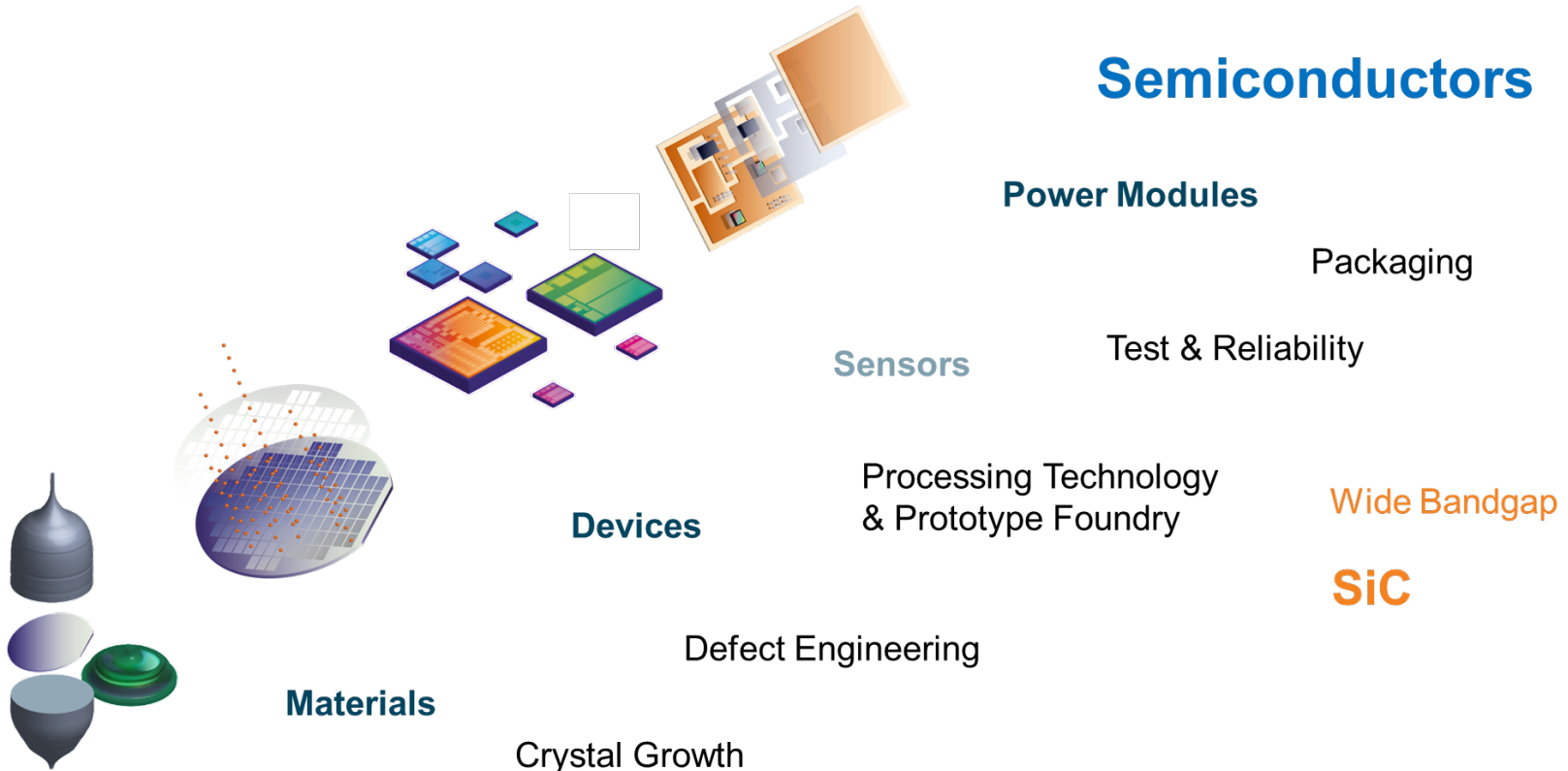
Exploiting benefits of SiC power device technology

SiC BiCMOS technology development @ IISB



Exploiting benefits of SiC power device technology

SiC value chain @ IISB

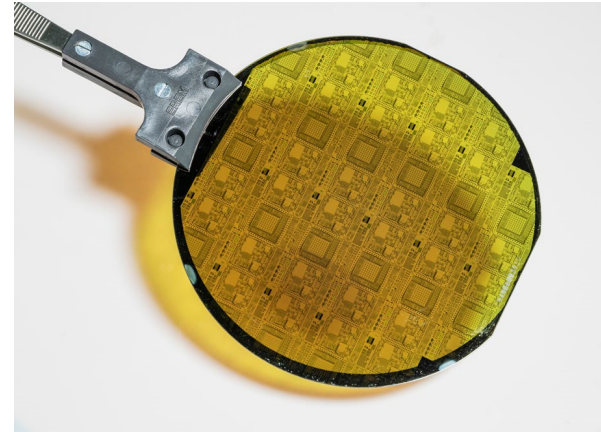
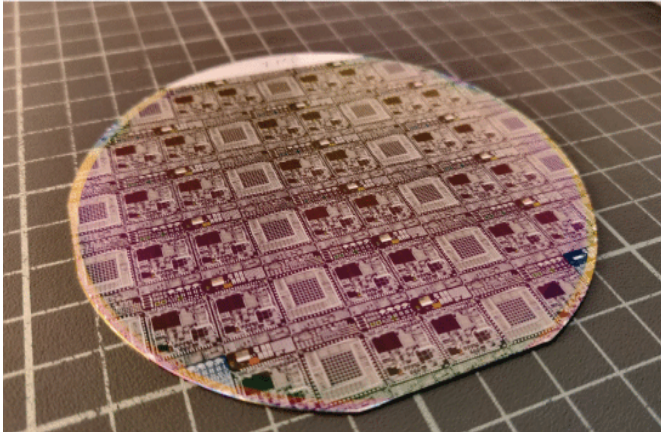


Exploiting benefits of SiC power device technology

Early-access 1 μm SiC CMOS technology @ IISB



EUROPRACTICE
IC SERVICE



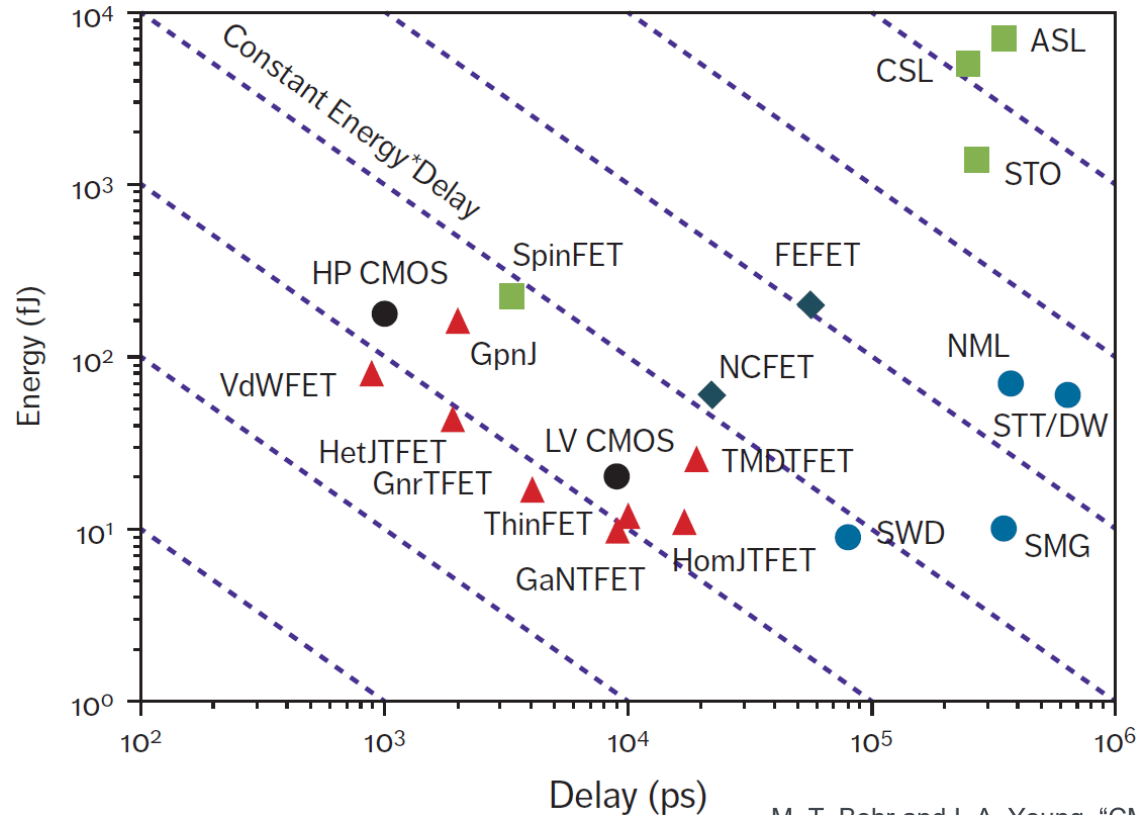
LZE Leistungszentrum
Elektroniksysteme

SiC-based sensing & quantum electronics

What is quantum electronics? Is it always the hunt for the “quantum computer”? What quantum sensing?

SiC-based sensing & quantum electronics

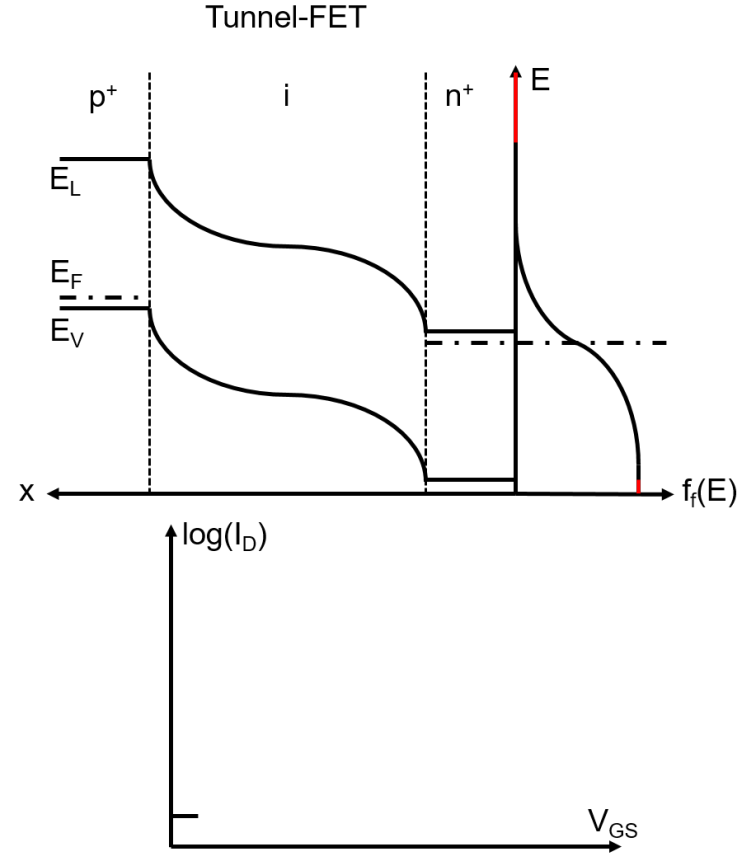
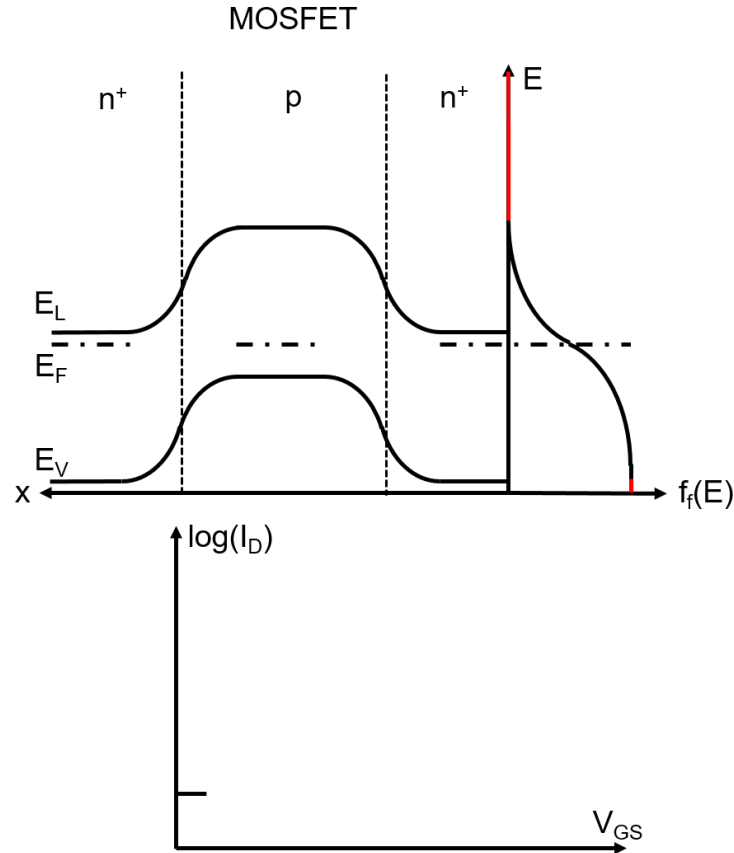
Switching energy and speed of scaled field-effect transistors (FETs)



M. T. Bohr and I. A. Young, "CMOS Scaling Trends and Beyond," *IEEE Micro*, vol. 37, no. 6, pp. 20–29, 2017

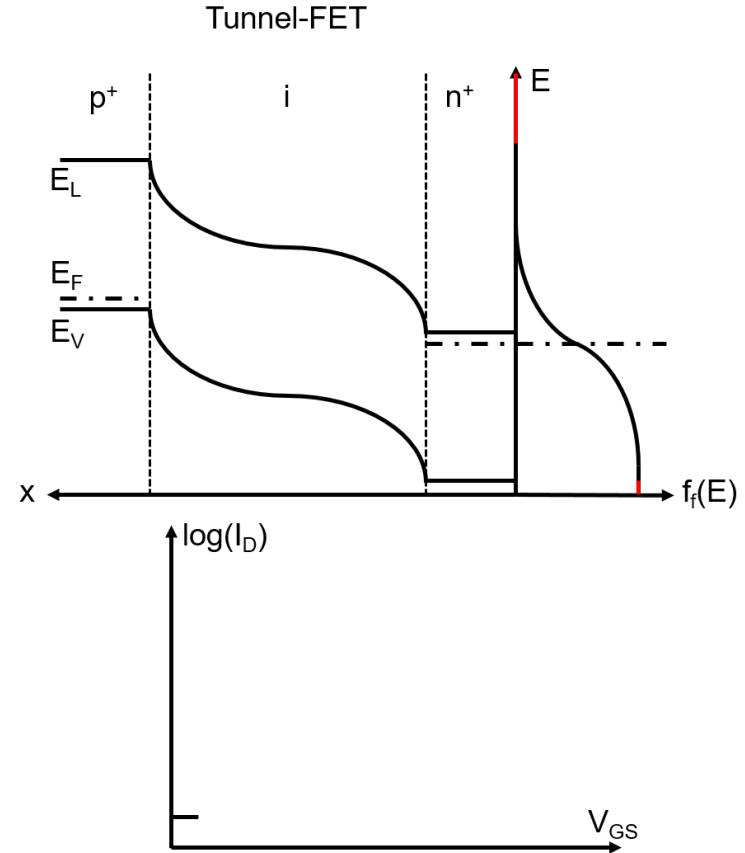
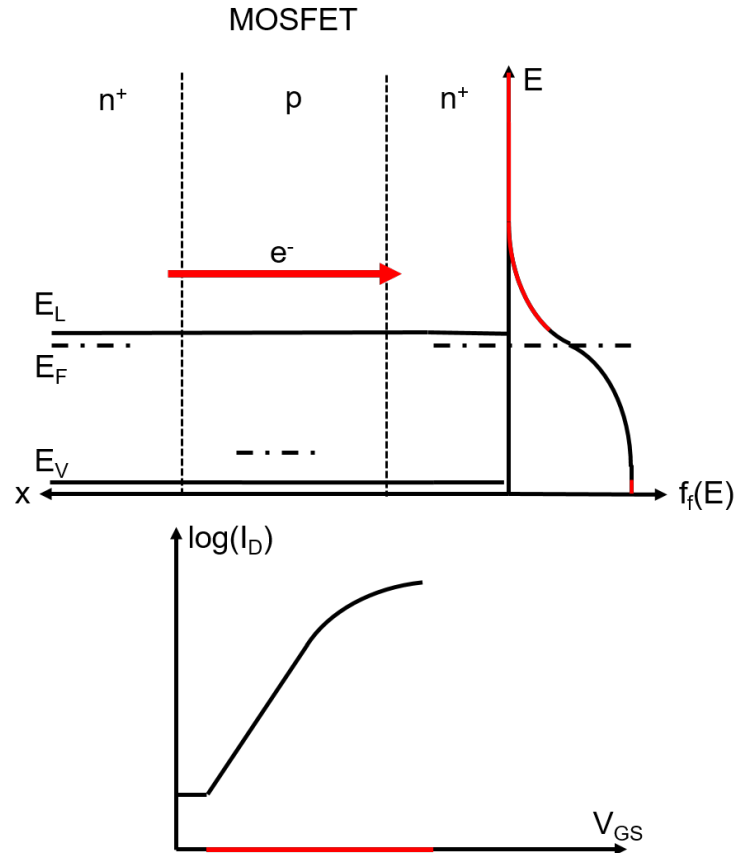
SiC-based sensing & quantum electronics

Working principles of Tunnel FET (TFET) vs. MOSFET



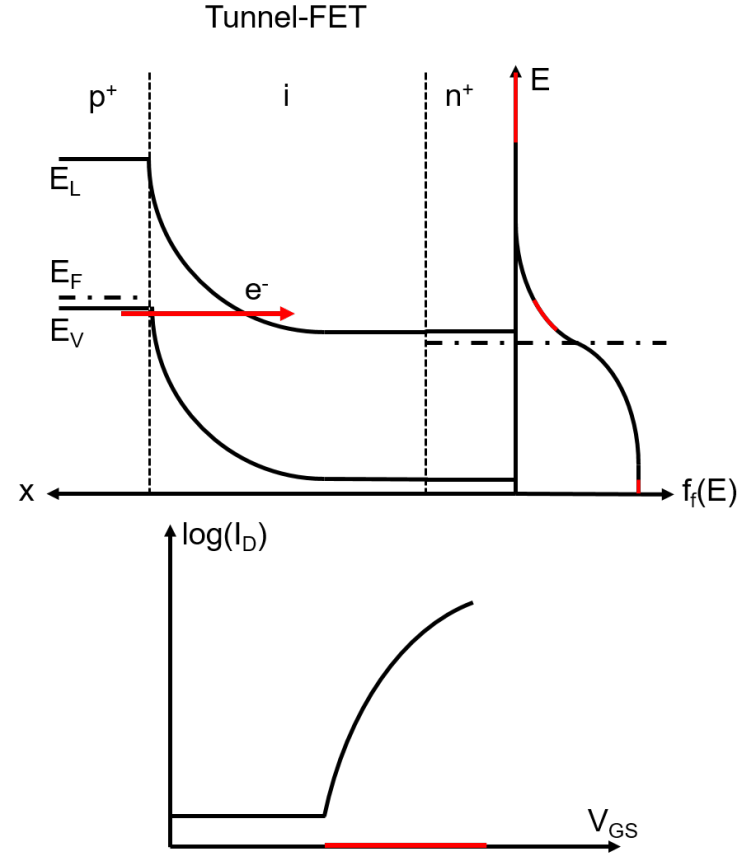
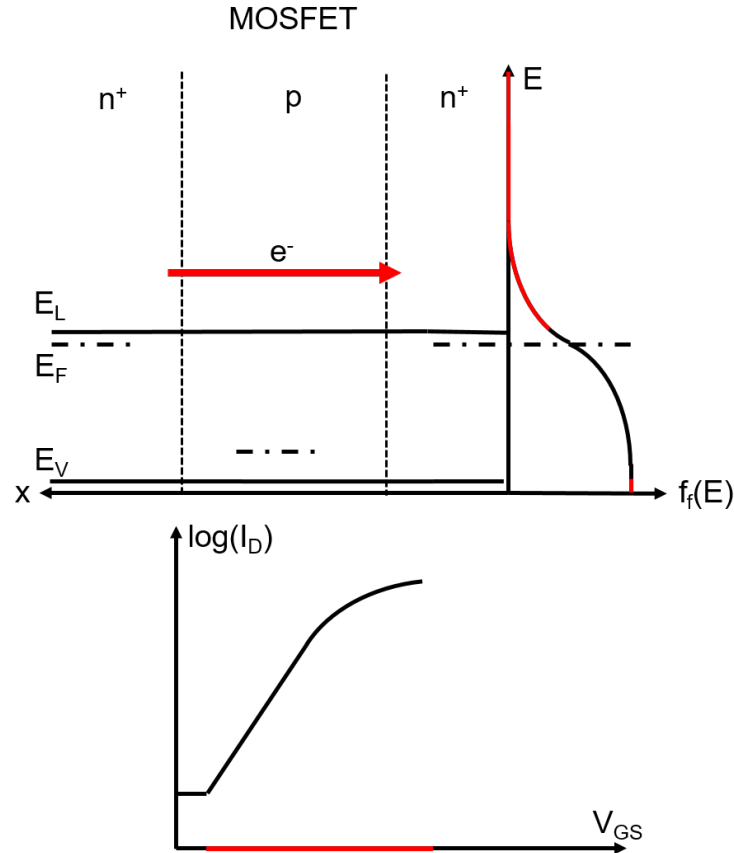
SiC-based sensing & quantum electronics

Working principles of Tunnel FET (TFET) vs. MOSFET



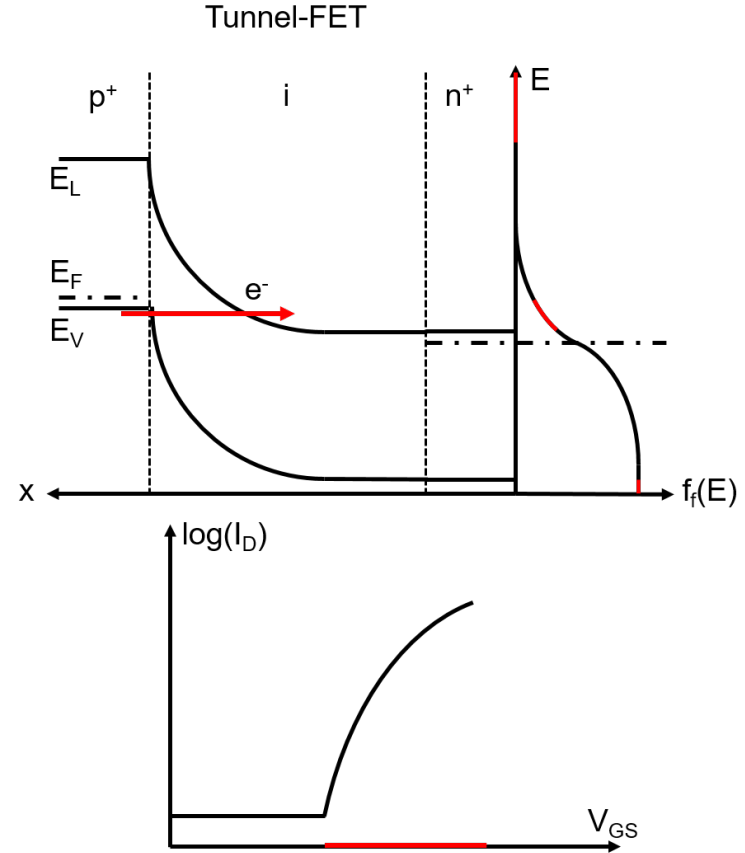
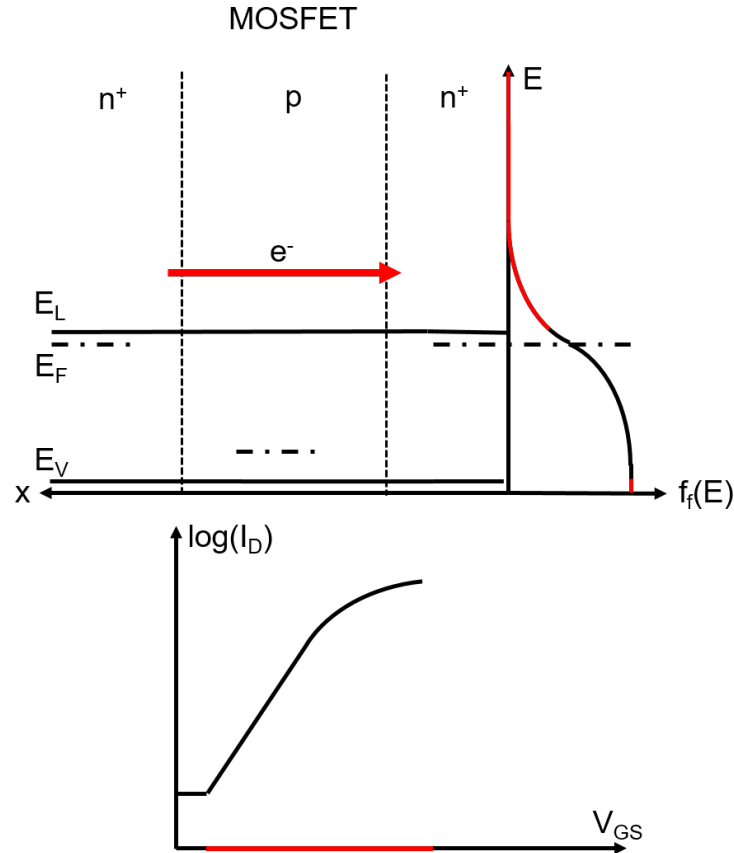
SiC-based sensing & quantum electronics

Working principles of Tunnel FET (TFET) vs. MOSFET



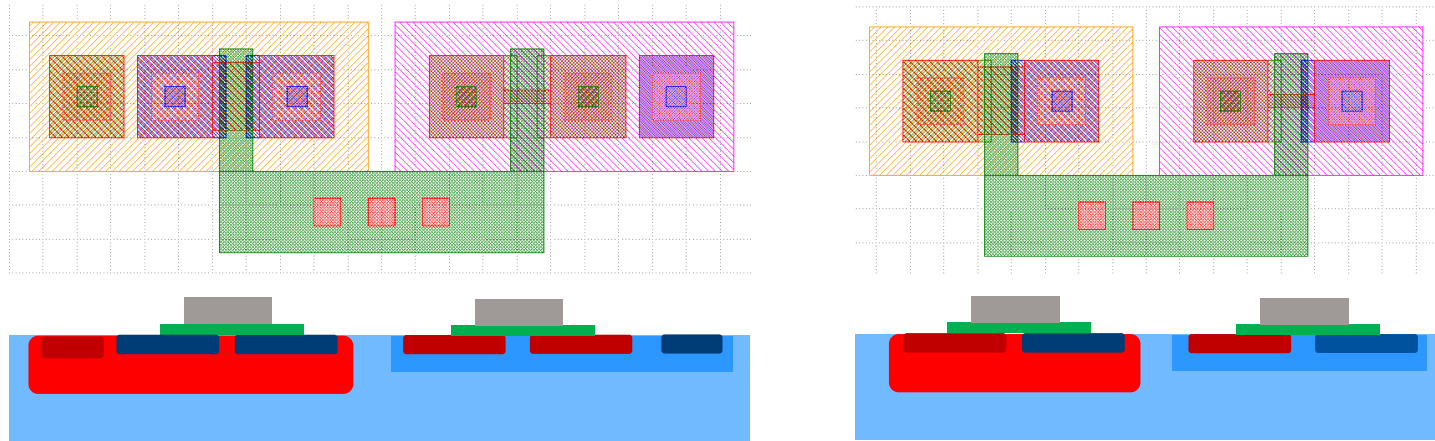
SiC-based sensing & quantum electronics

Working principles of Tunnel FET (TFET) vs. MOSFET



SiC-based sensing & quantum electronics

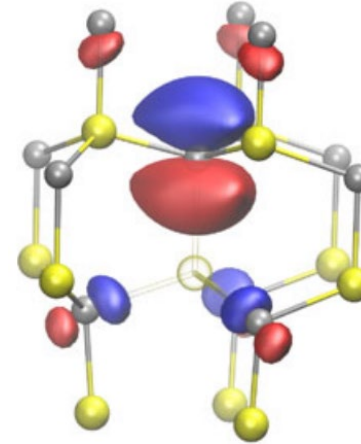
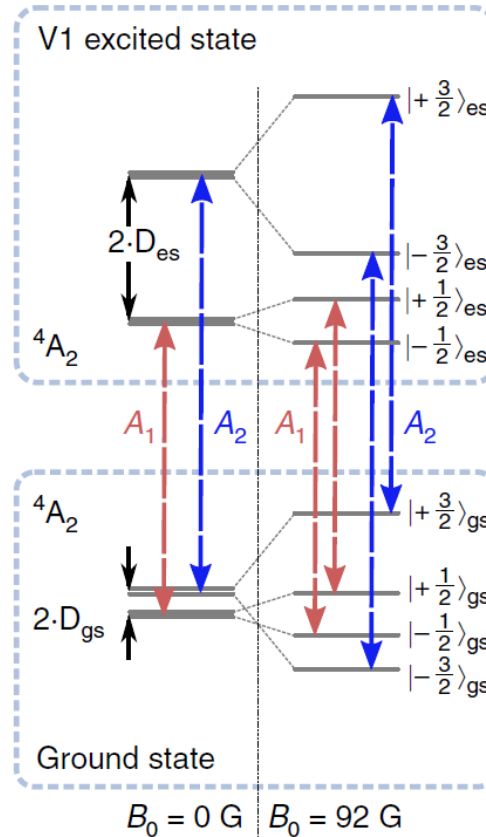
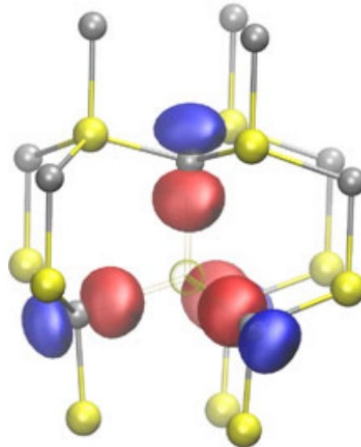
SiC circuits made from TFETs vs. MOSFETs



- The lateral TFET is about 1/3 smaller than the equivalent lateral MOSFET (same gate width and length).
- The MOSFET suffers from short channel effects such as channel length modulation and drain induced barrier lowering (DIBL). The TFET does not show this since it is a gated pin diode structure. → The TFET blocks higher voltages with the same channel length.

SiC-based sensing & quantum electronics

But it is the hunt for the quantum computer, too!



R. Nagy, M. Niethammer, et al.: Nature communications, Vol. 10, pp. 1954ff. 2019.

C. Kasper, D. Klenkert, et al.: Phys. Rev. Applied, Vol. 13. 2020.

J. Wang, X. Zhang, et al.: ACS Photonics, Vol. 4, pp. 1054ff. 2017.