Silicon Carbide Electronics for Advanced Power, Sensing and System Integration

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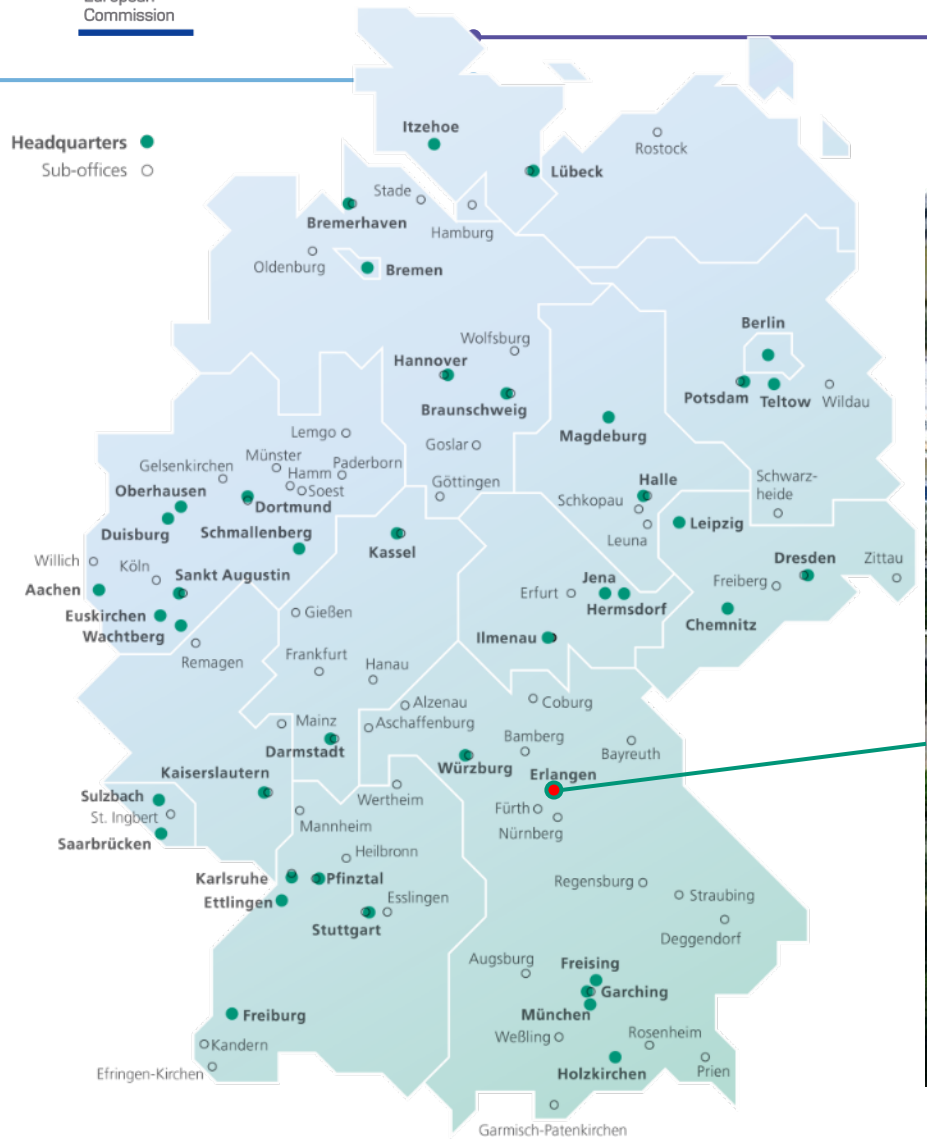
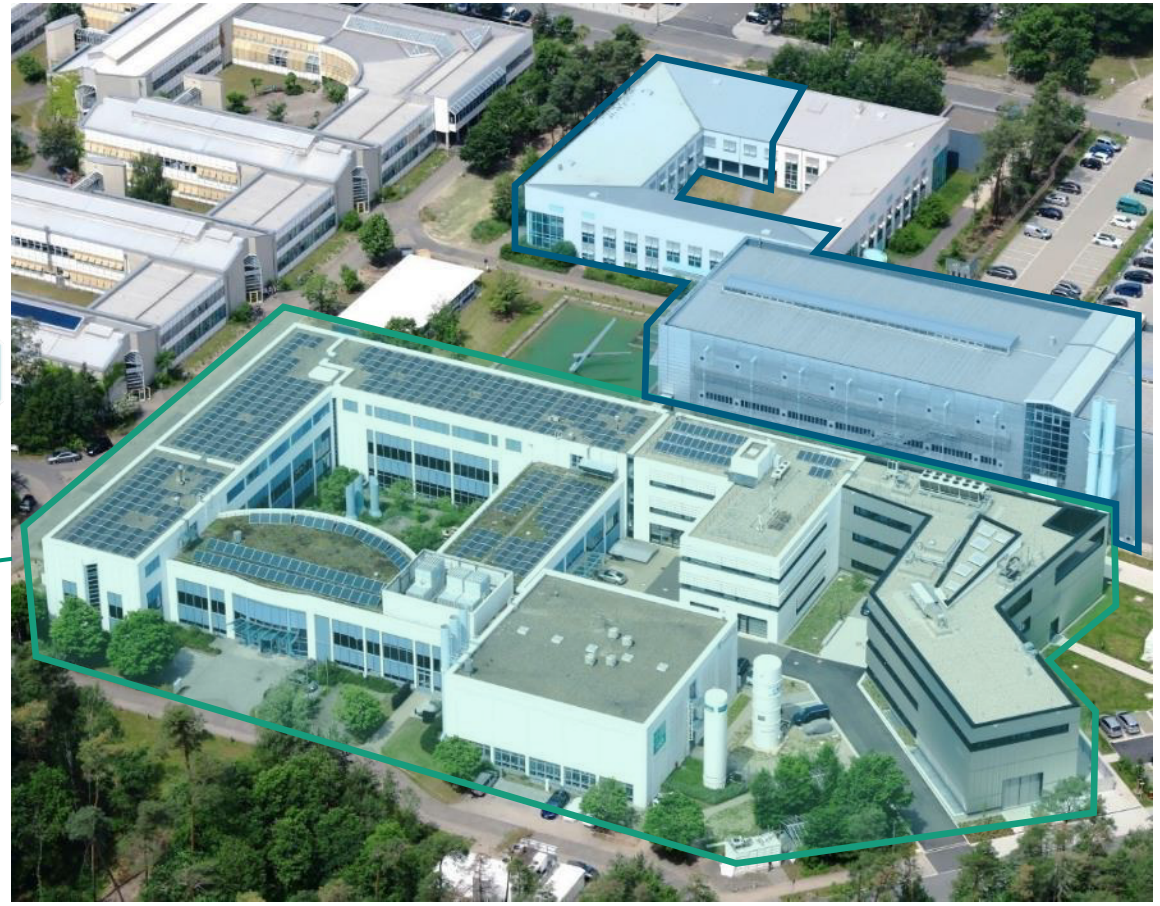
R&D Semiconductor Devices and Processing

Fraunhofer IISB, Erlangen, Germany

Introduction to IISB





Friedrich-Alexander-Universität Erlangen-Nürnberg

LEB

Electron Devices
Prof. Dr.-Ing. habil. Jörg Schulze
Director of IISB

LEE

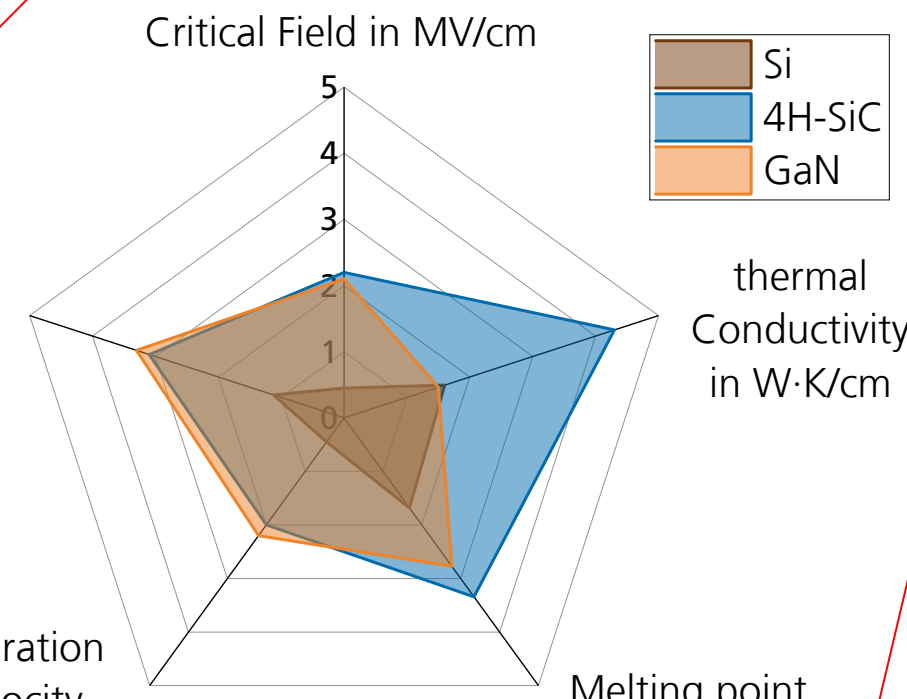
Power Electronics
Prof. Dr.-Ing. Martin März

Contents

- Silicon Carbide Technologies at Fraunhofer IISB
- MOS and Bipolar SiC Power Devices
- High-Temperature SiC CMOS Technology

Materials Properties of SiC

high voltage operation

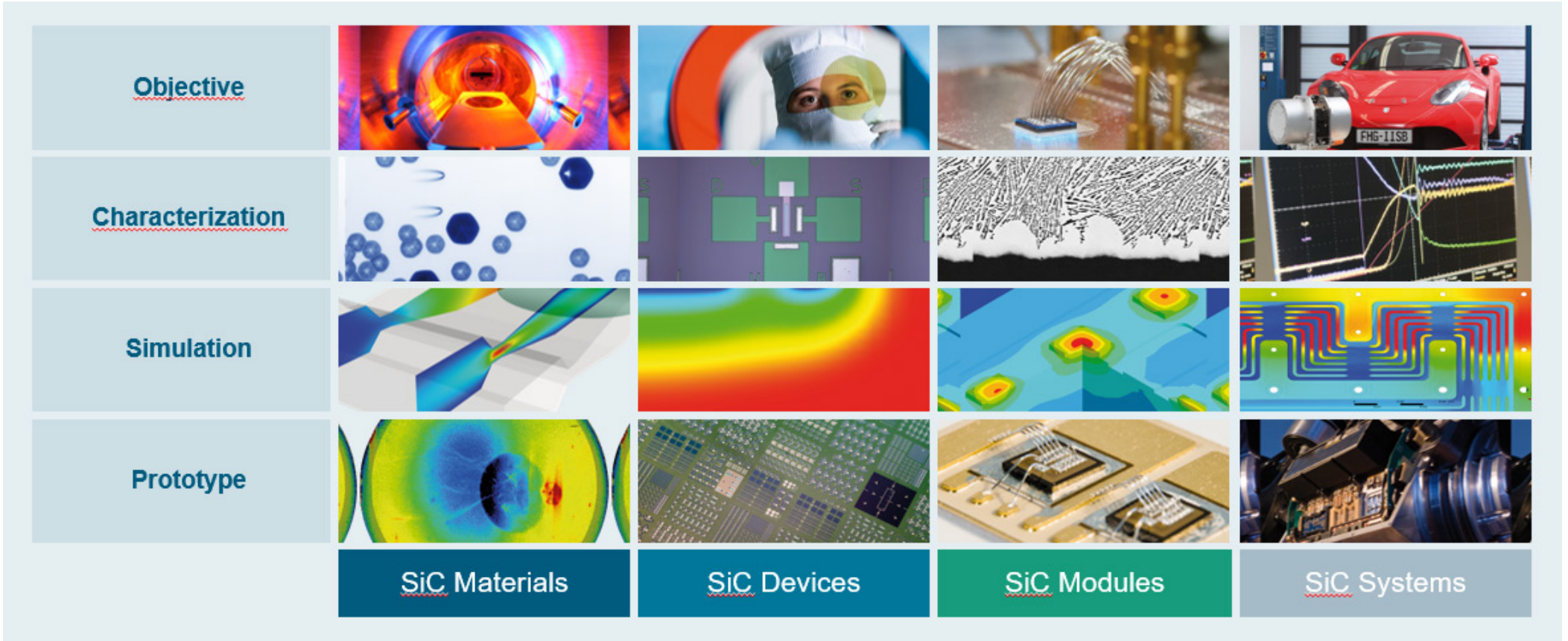


high power, temperatures

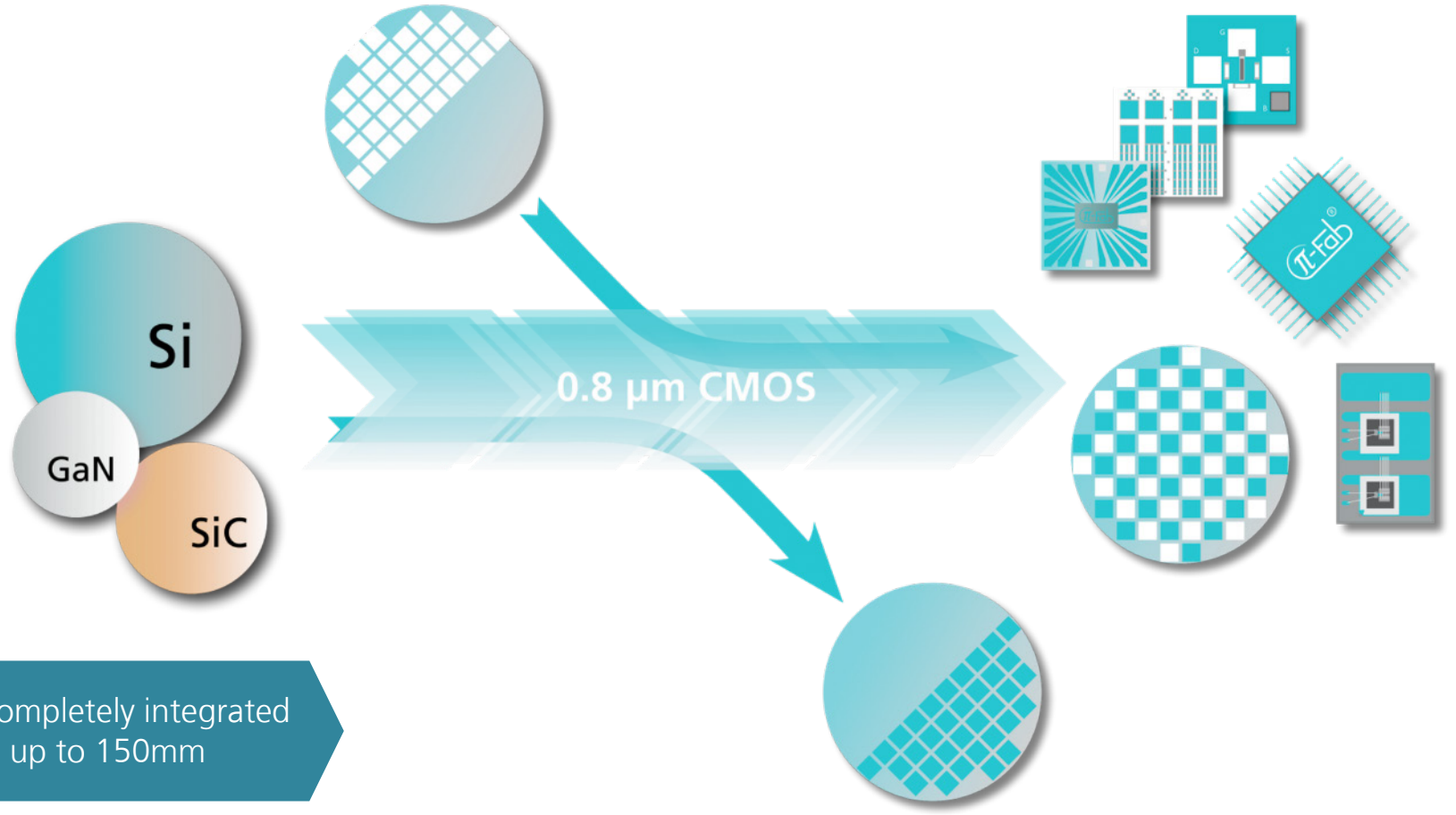
high frequency, current density

Power Devices on SiC

- IISB‘s Integrated Vertical Value Chain



SiC Process Environment



Full CMOS
Si-process chain

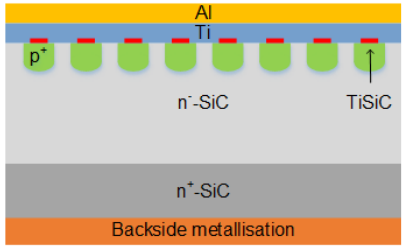
SiC completely integrated
up to 150mm

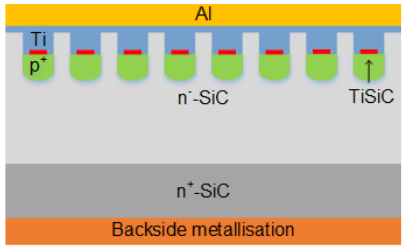
SiC Power Devices

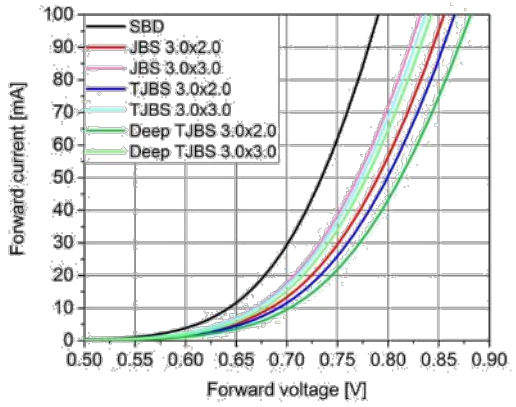
Power Devices on SiC

- Bipolar and MOS Power Devices

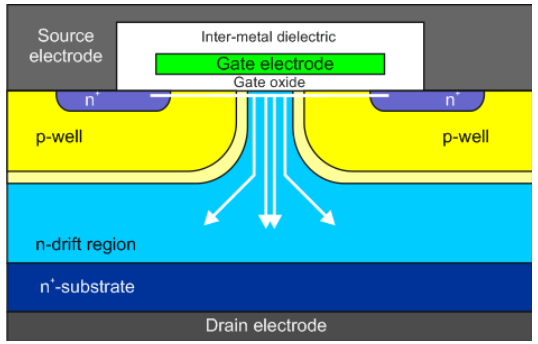
Merged Schottky/pn Diodes

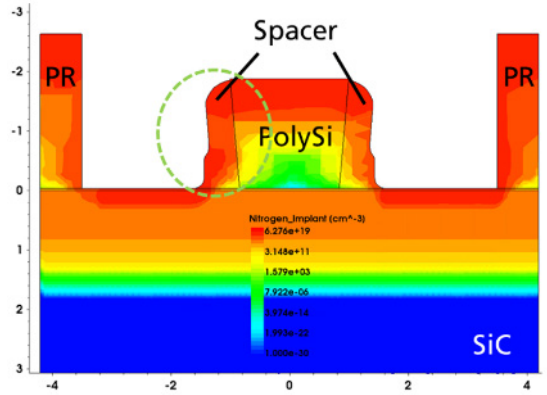


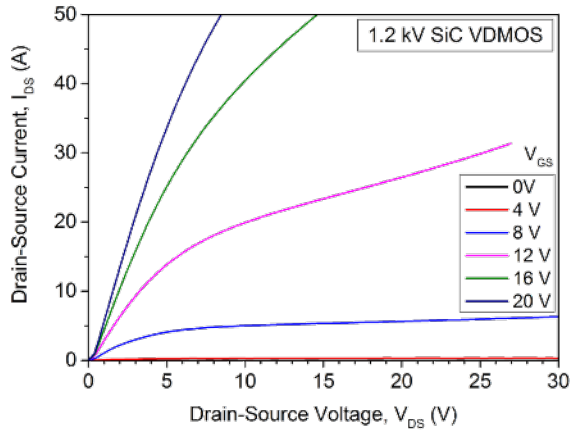


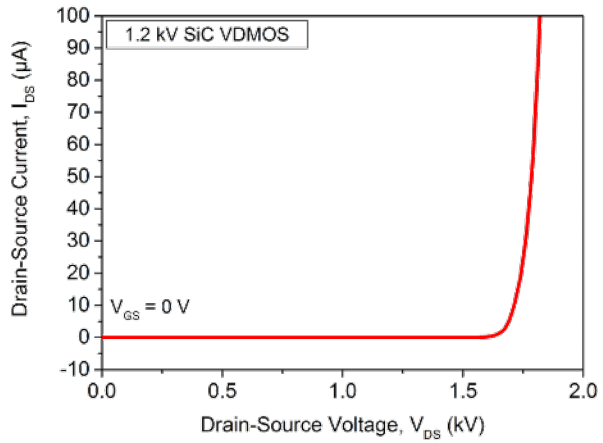


1.2 kV VDMOS (planar)





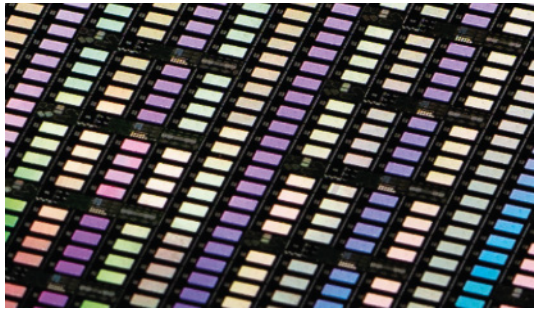




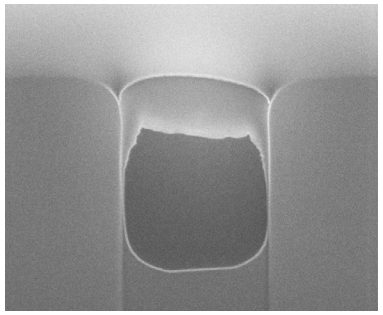
Power Devices on SiC

- Advanced Trench Technologies

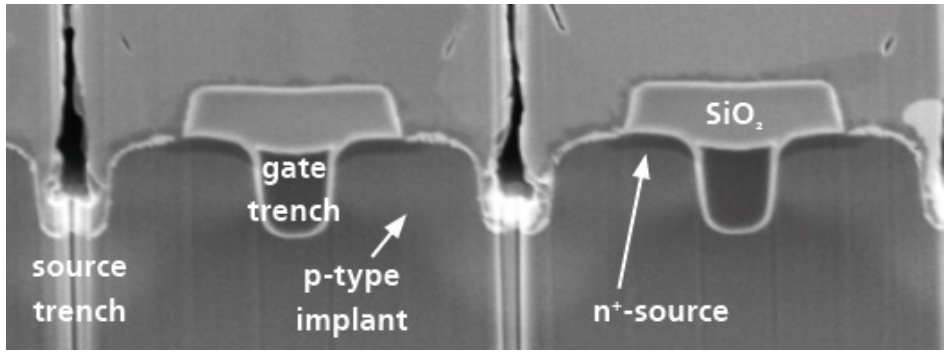
1.2 kV TrenchMOS



Devices on wafer



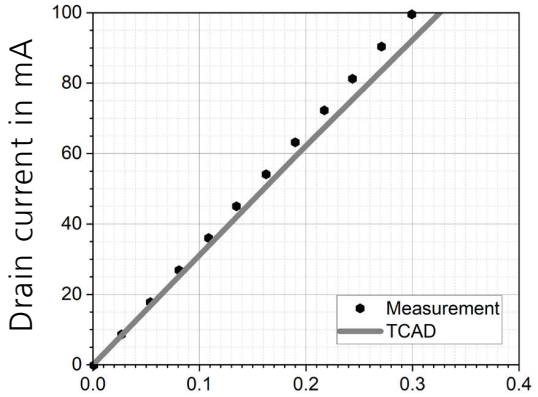
Poly-Si-plug with oxidation



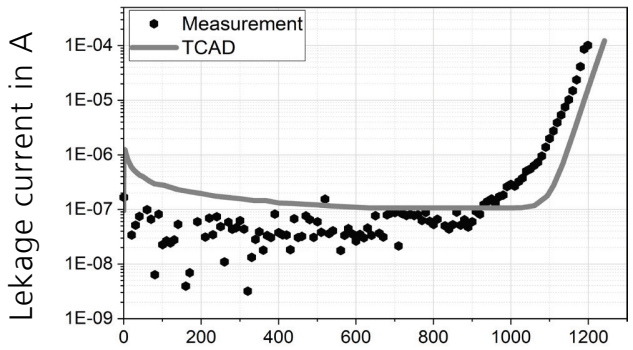
FIB cross-section of active area

Electrical Performance

Transfer characteristics (lin.)

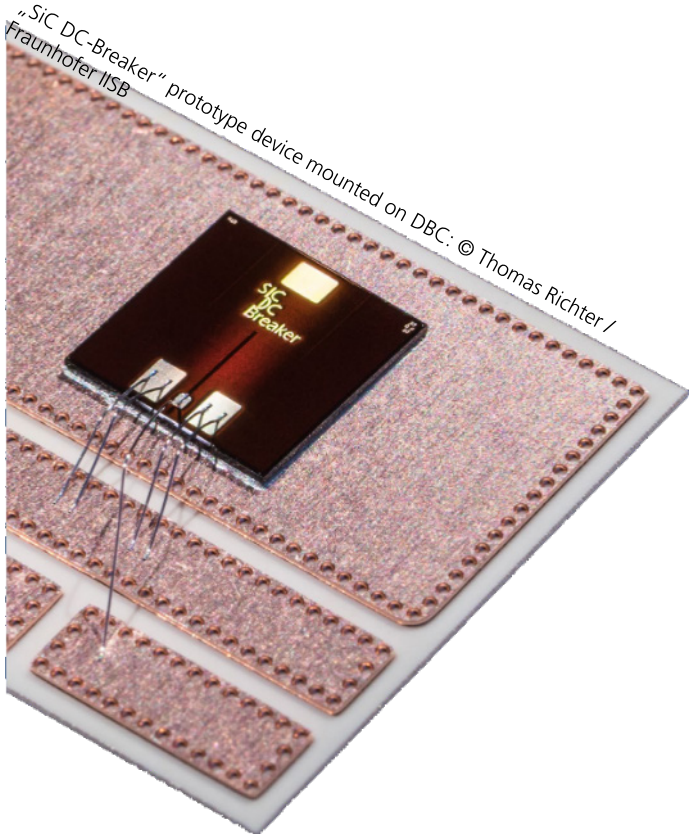


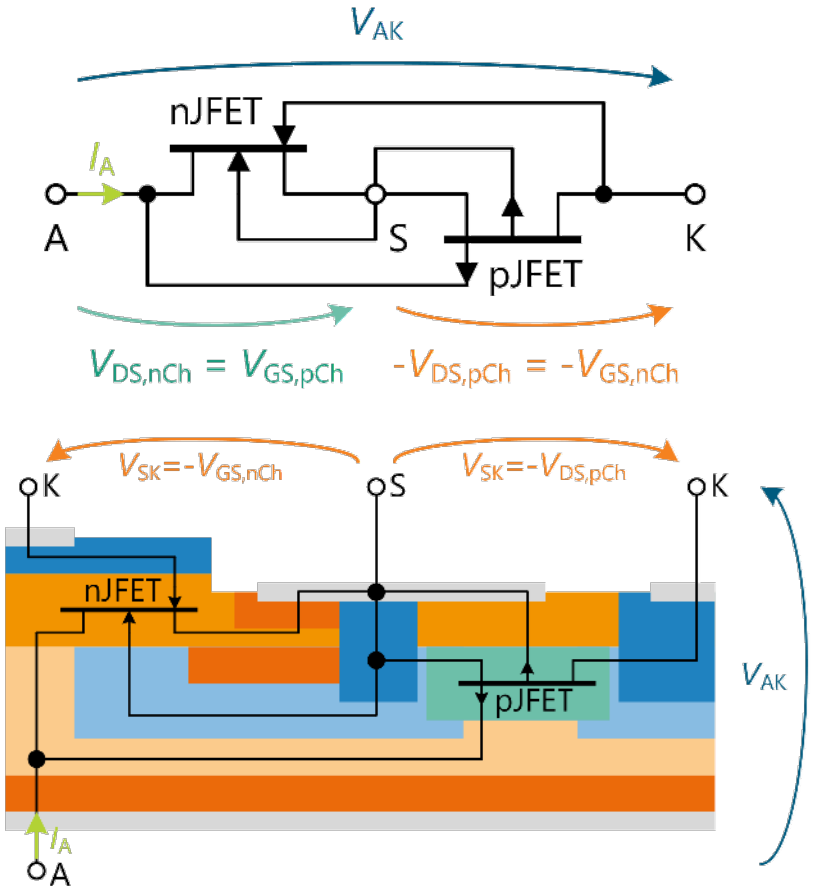
Reverse operation



Power Devices on SiC

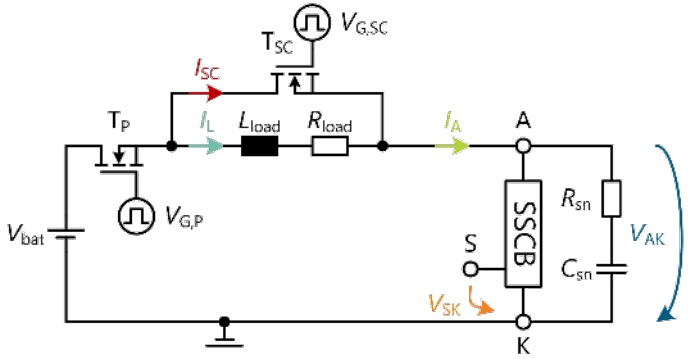
- Solid-State Circuit Breaker
  - Self-Supplied
  - Self-Sensed
  - Self-Sustained

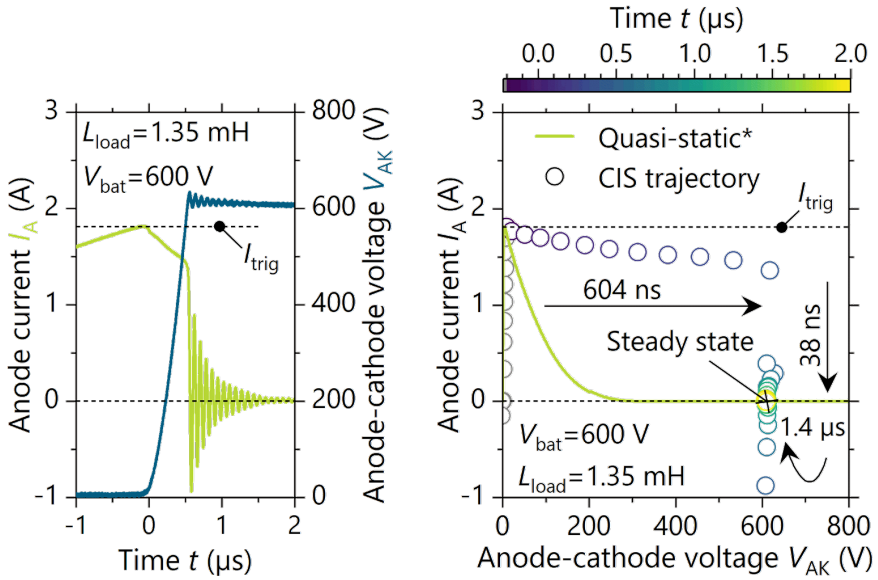


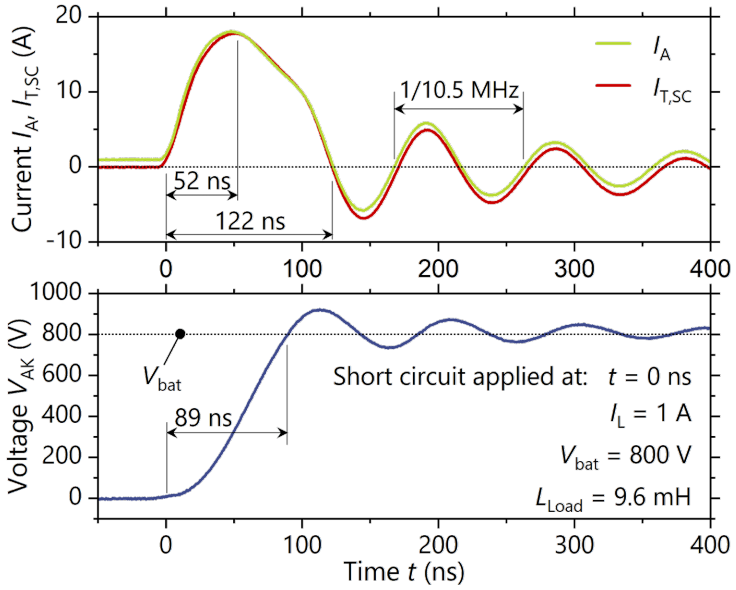


Power Devices on SiC

- Solid-State Circuit Breaker
  - Self-sensed sub-µs switching







SiC CMOS Technology for harsh environments

High-Temperature SiC Circuits

- Operation > 500°C

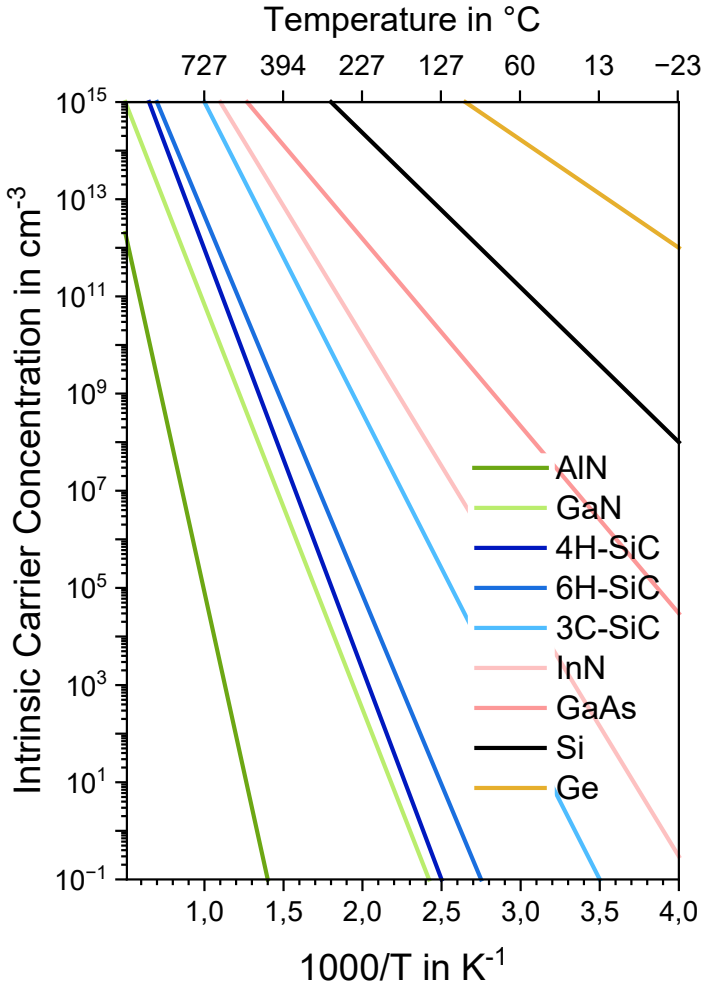
Energy Industries	Geothermal	Oil & Gas Exploration	Industrial Gas Turbines	Aircraft Engines	Automotive Engines
Required Sensing Temperatures	375°C	275°C	600°C	600°C	300°C
Desired Sensing Measurands	•Pressure •Temperature •H_2S •Strain	•Pressure •Temperature •Hydrocarbon •Strain	•Pressure •Temperature •Flame speed •Acceleration	•Pressure •Temperature •Flame speed •Acceleration	•Pressure •Temperature •Flame speed •O_2

Harsh Environment Sensor Cluster, University of California, San Diego

Power Electronics

Integrated Gatedriver:
- Current
- Temperature

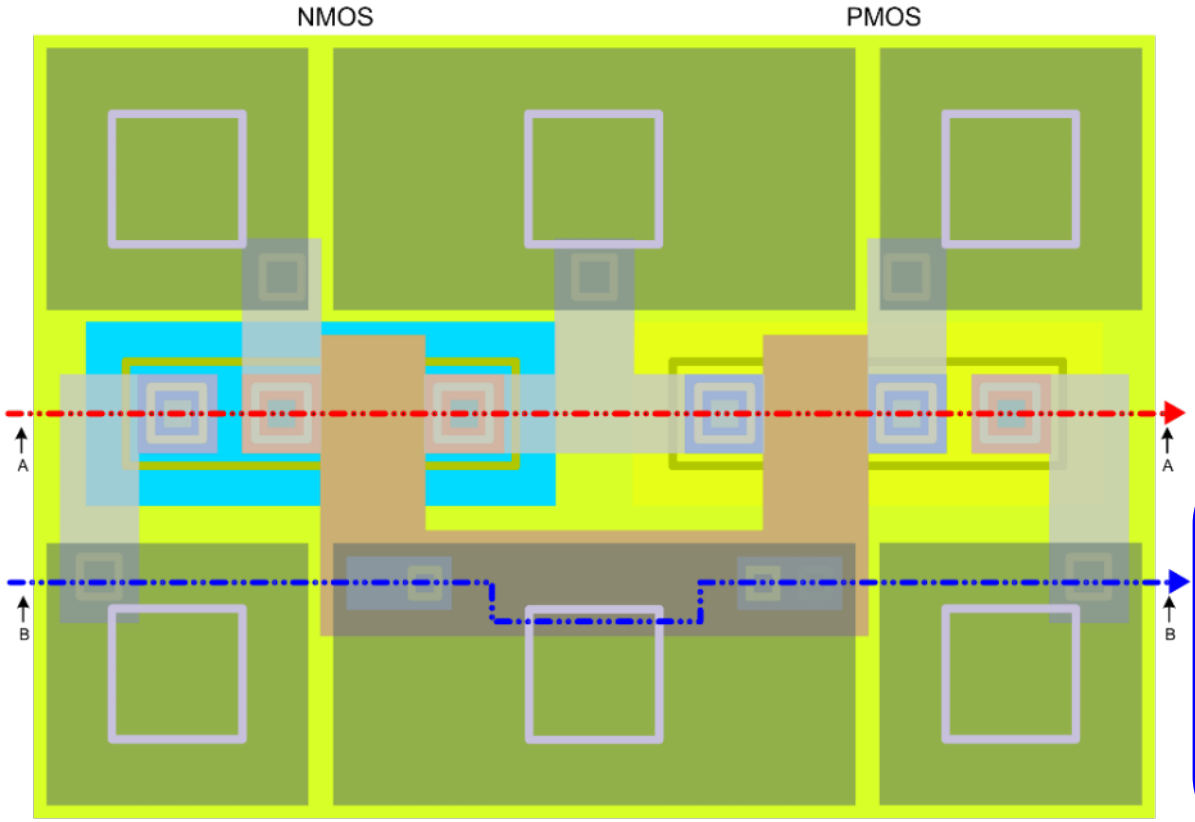
- High switching frequencies
- reliabilty



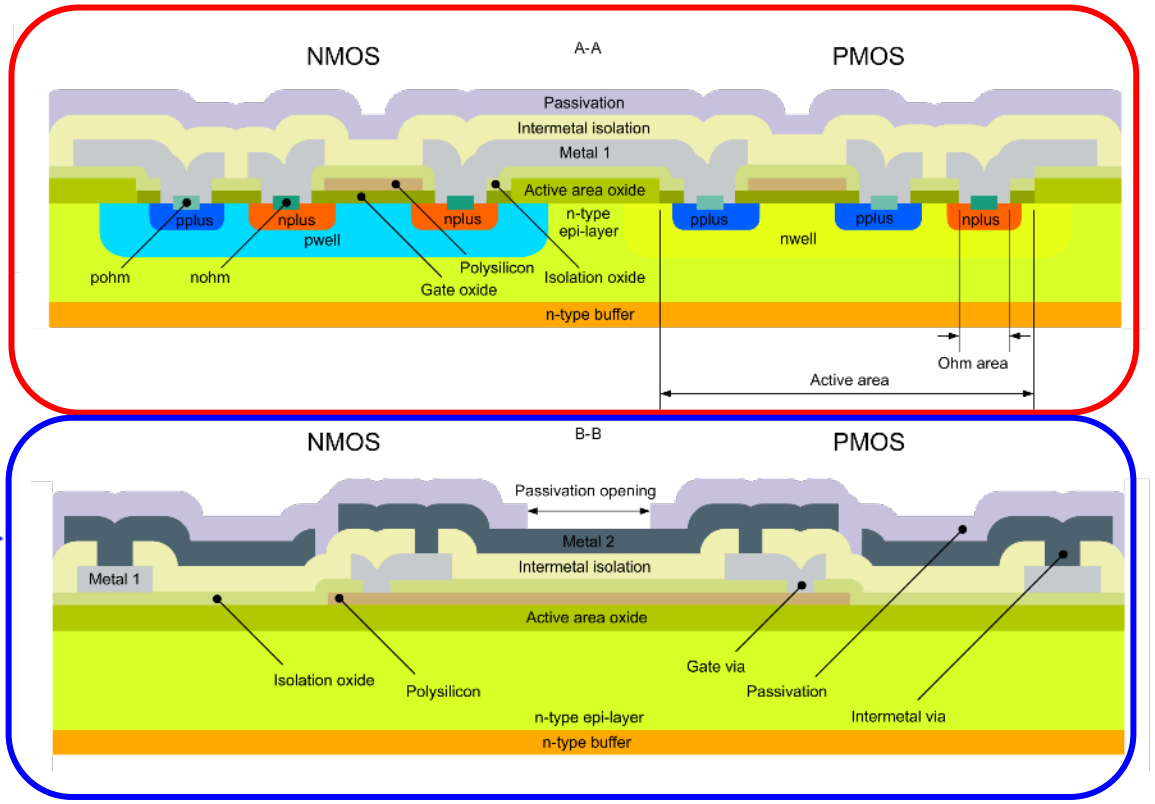
High-Temperature SiC Circuits

- Technology overview

Top View of Circuit Blocks



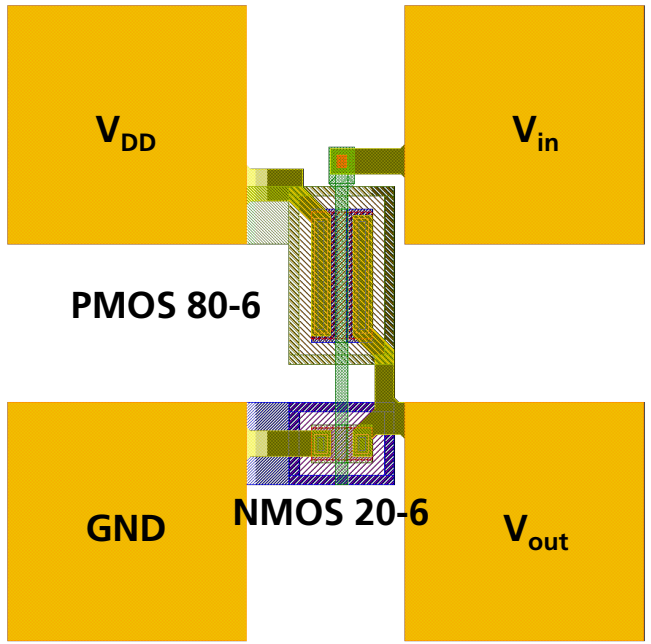
Circuit Cross-Cuts



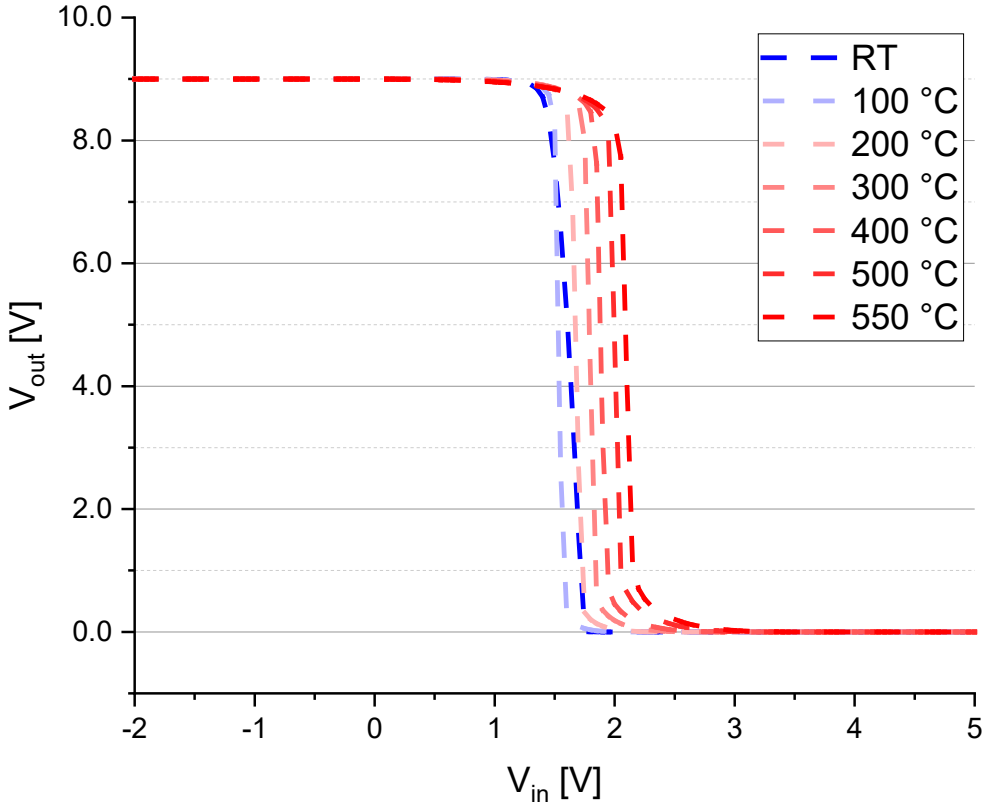
High-Temperature SiC Circuits

- CMOS inverters up to 550 °C

Inverter Layout



Temperature Dependence of Transfer Characteristics

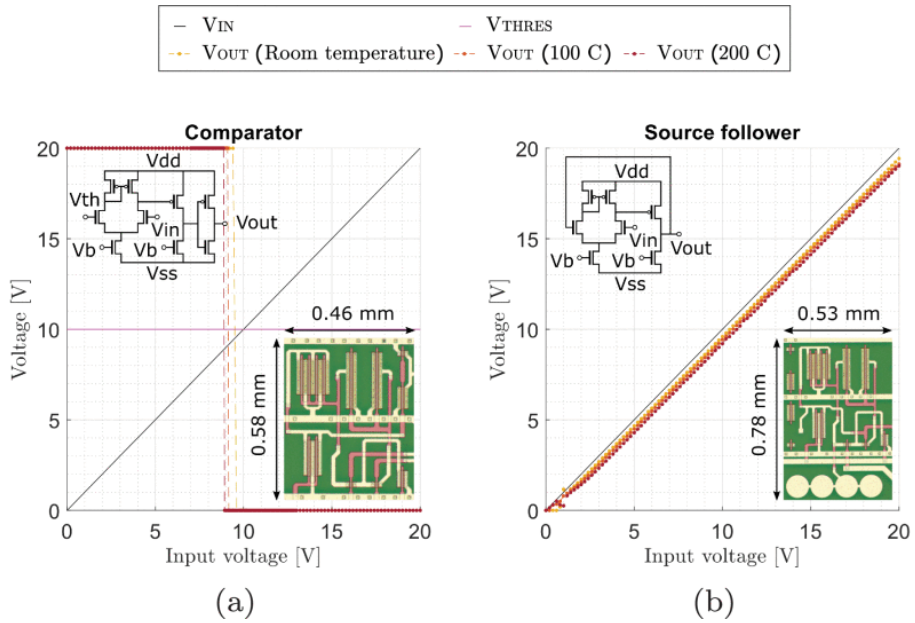


High-Temperature SiC Circuits

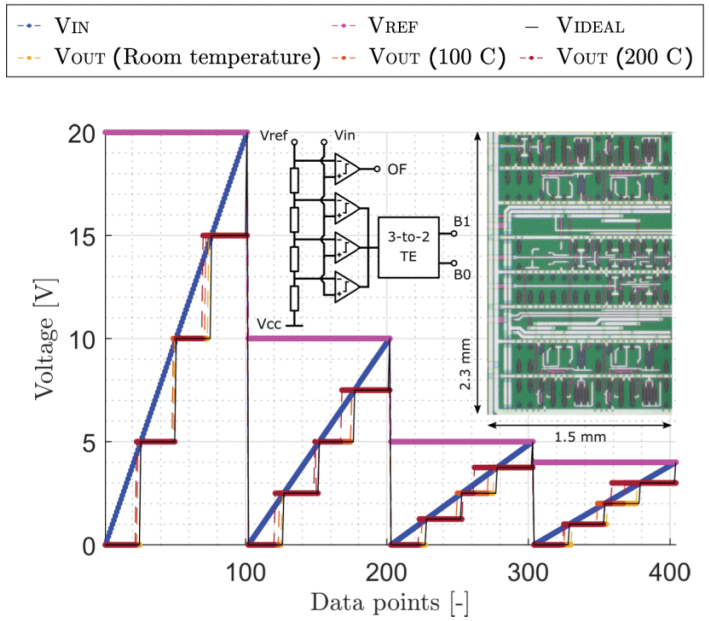
in cooperation with TU Delft Delft University of Technology

- Development of System Building Blocks

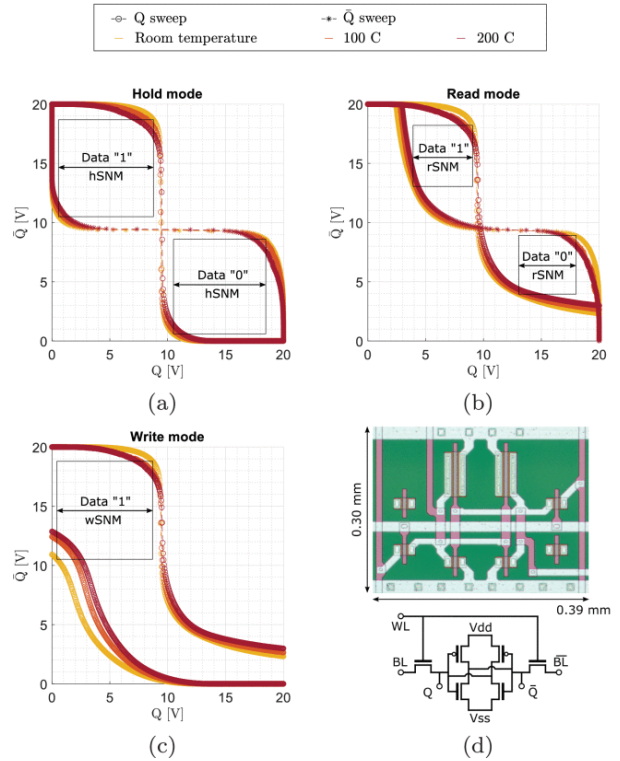
Comparator & source follower



2-bit ADC



SRAM cells



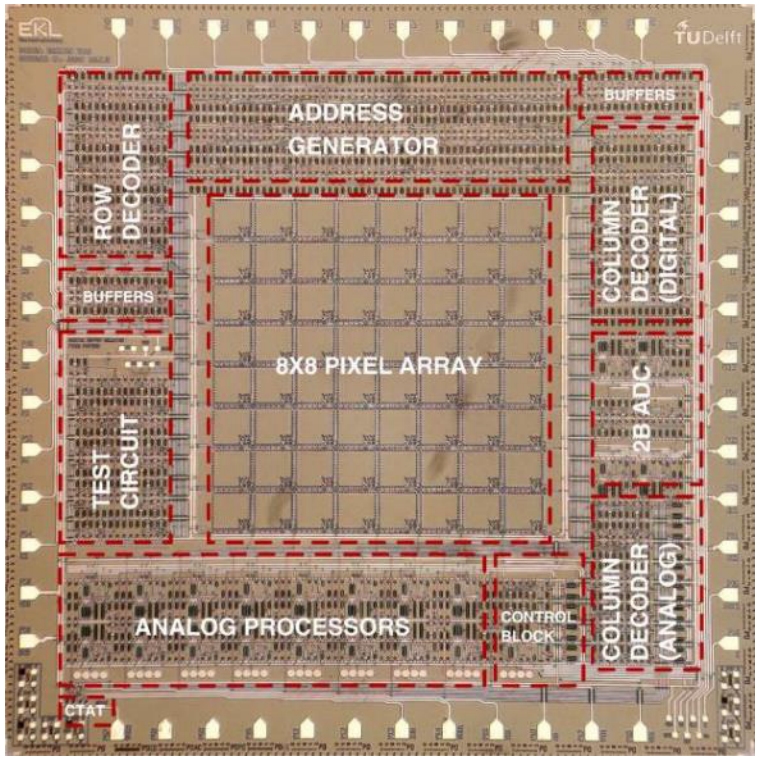
Integrated Digital and Analog Circuit Blocks in a Scalable Silicon Carbide CMOS Technology
Romijn et al. *IEEE Transactions on Electron Devices*, 2022

High-Temperature SiC Circuits

in cooperation with TU Delft Delft University of Technology

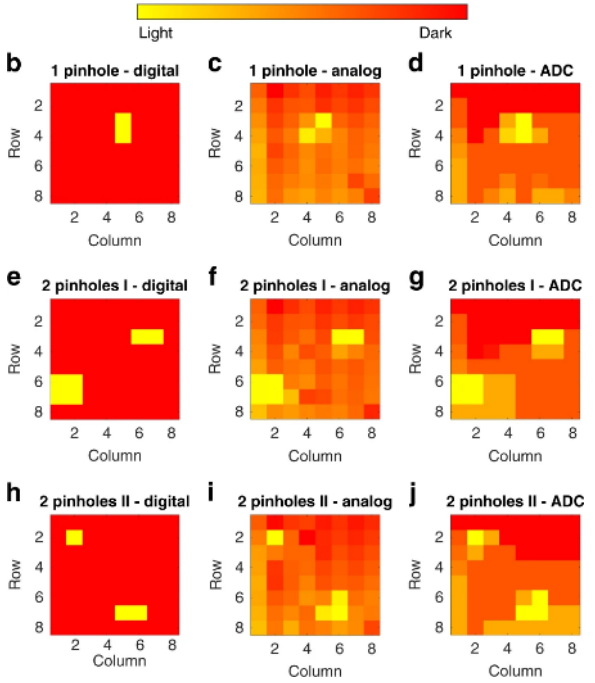
- Smart System Integration on SiC

8x8 UV pixel array with integrated read-out electronics



Integrated 64 pixel UV image sensor and readout in a silicon carbide CMOS technology
Romijn et al. *Microsystems & Nanoengineering*, 2022

System response

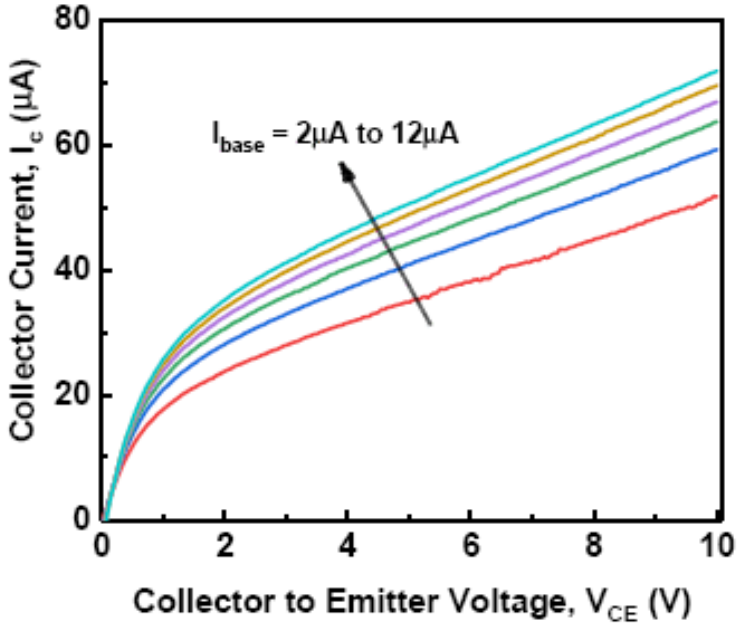


High-Temperature SiC Circuits

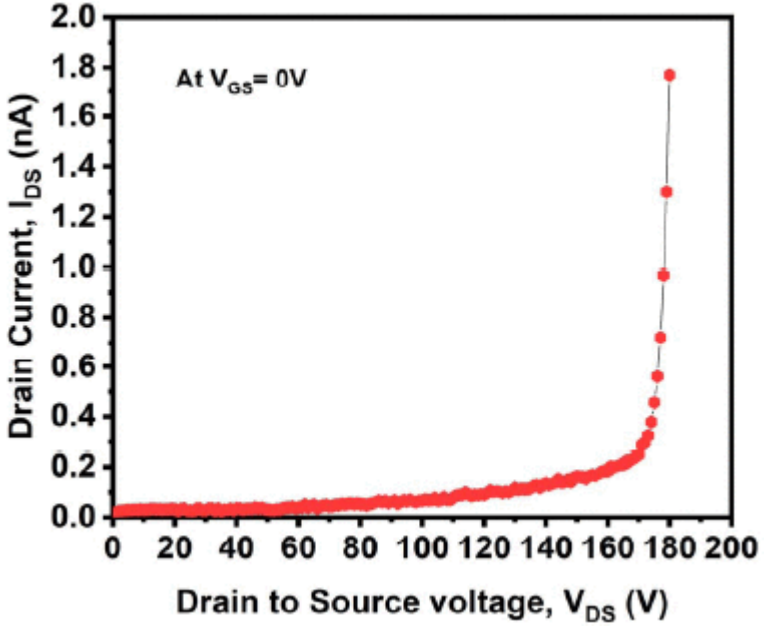
in cooperation with UNIVERSITY OF ARKANSAS

- SiC Smart Power Integration

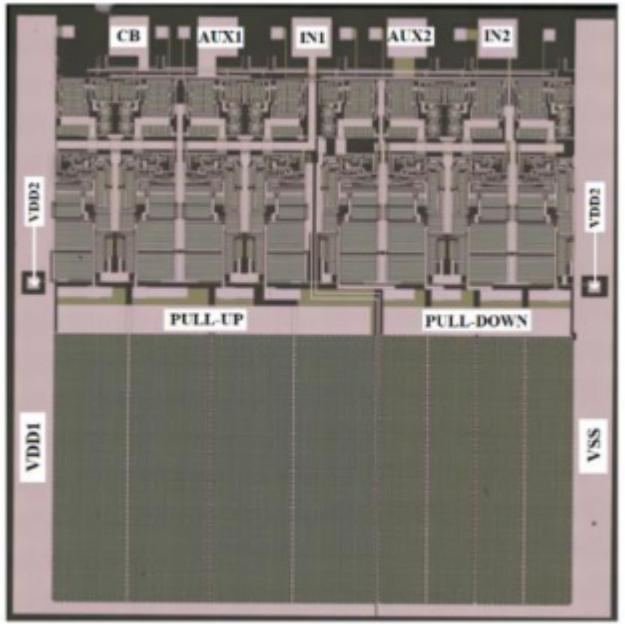
Bipolar Junction Transistor
Output Characteristics



LDMOS (W = 30 µm, L = 5 µm)
Breakdown at RT

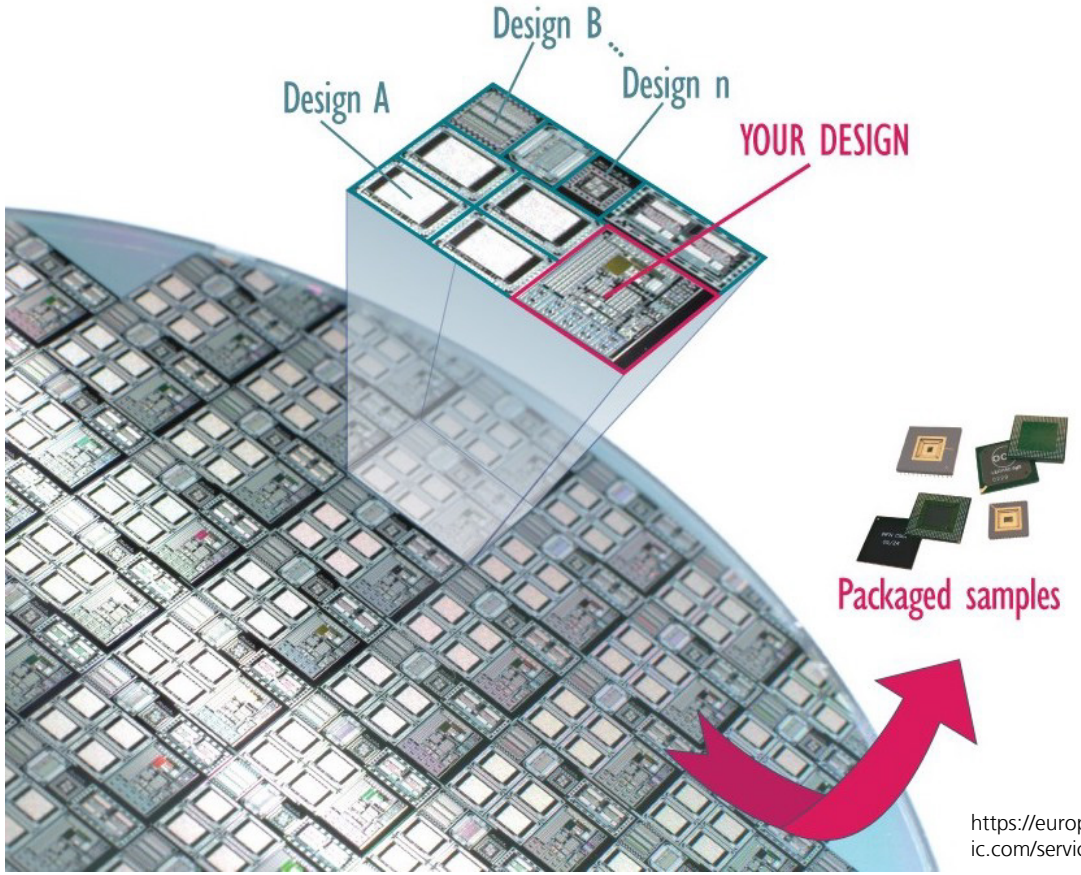


Multi-Level 5 x 5 mm²
Gate Driver



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

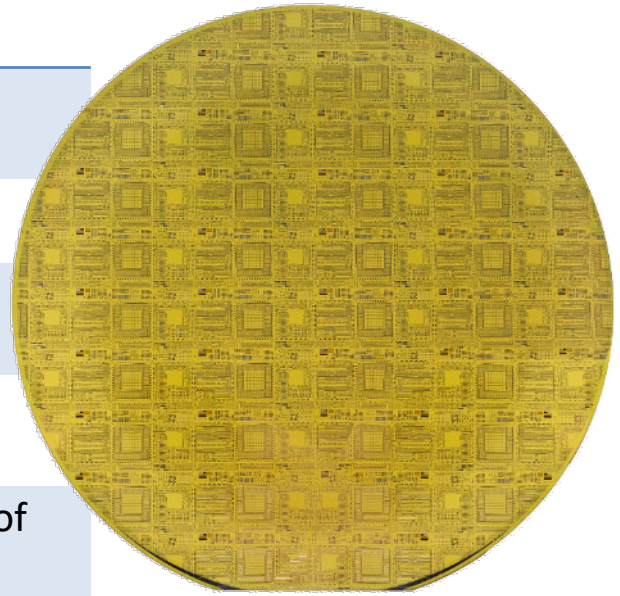


https://europractice-ic.com/services/fabrication/

High-Temperature SiC Circuits

- Process Options

Module	Description
RESURF I^2	Implantation Layer for Integration of CMOS with High-Voltage Power Switches towards Smart Power Systems
UV I^2	Implantation Module for monolithically integrated UV-Diodes
CUSTOM I^2	Customized Implantations for Application-Specific Devices
AL METAL	Low-Temperature Metallisation with Low Electrical Resistivity
GRIND	Wafer Backthinning for Advanced Applications and Optional Integration of Vertical Devices
SINTER	Backside Metallization for Silver Sintered High-Temperature Die Attach



Summary

- Unique SiC processing line for power, mixed-signal CMOS and sensors
- Research and development into advanced power devices
- Electronics for harsh environment
  - Available via EUROPRACTICE
- Quantum sensing and computing based on Si vacancies in SiC

THANK YOU

ICOS International Cooperation On Semiconductors

European Commission

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EU – SOUTH KOREA – Joint Researchers Forum on Semiconductors

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