Fraunhofer
IISB

Fraunhofer Institute for Integrated
Systems and Device Technology IISB

Semiconductor Material Development

Crystals & Substrates, Epitaxial Layers, Coatings, Metrology and Device Processing

We support material, device and tool manufacturers and their suppliers by delivering solutions in the field of production and characterization of crystals, epitaxial layers, and devices.

We contribute to improving the material quality and to reducing the production costs.

We identify defects harmful for device performance and reliability and find solutions to avoid them.

We develop technologies for new materials, and we tailor the material properties for new applications.

Our focus is on semiconductors for power electronics, sensors and detectors, and quantum and photonic technologies.

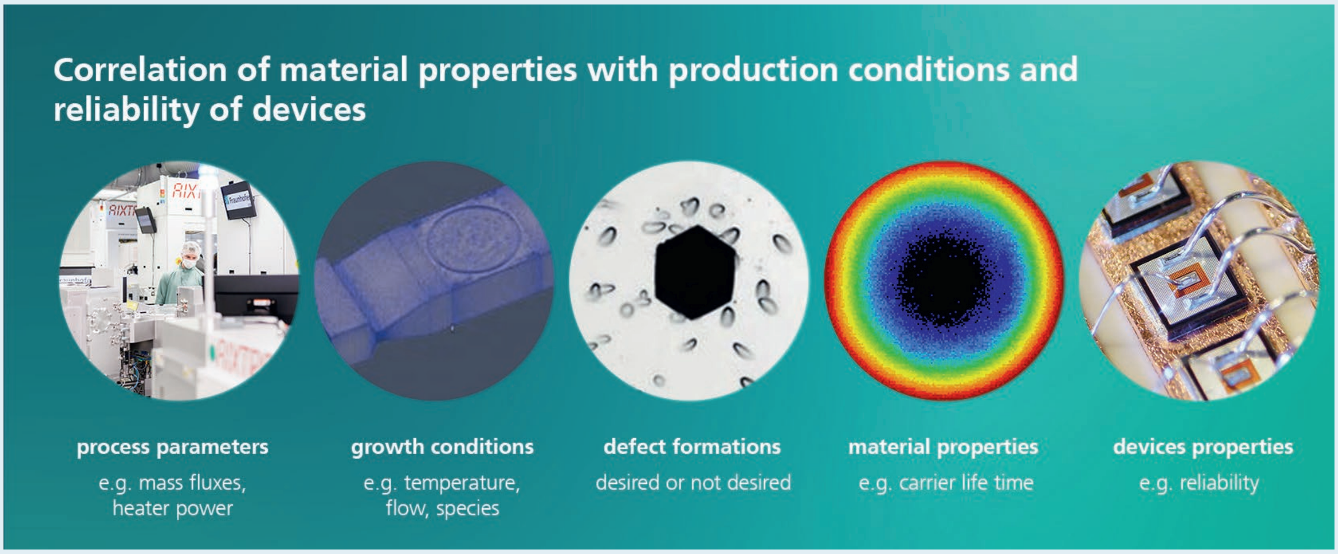
Competences

We have profound experience in the areas of semiconductor crystal growth, epitaxy, and device processing, including characterization and modeling. In the past, we have significantly contributed to the development of the VGF (Vertical Gradient Freeze) technique for the industrial production of a variety of crystal materials as well as to the epitaxial growth of high-quality SiC (Silicon Carbide) layers. Several national and international research awards underline the achievements of Fraunhofer IISB over the last years for its outstanding scientific-technological results as well as for its excellent contributions to the education of students and engineers.

Strategy & Approach

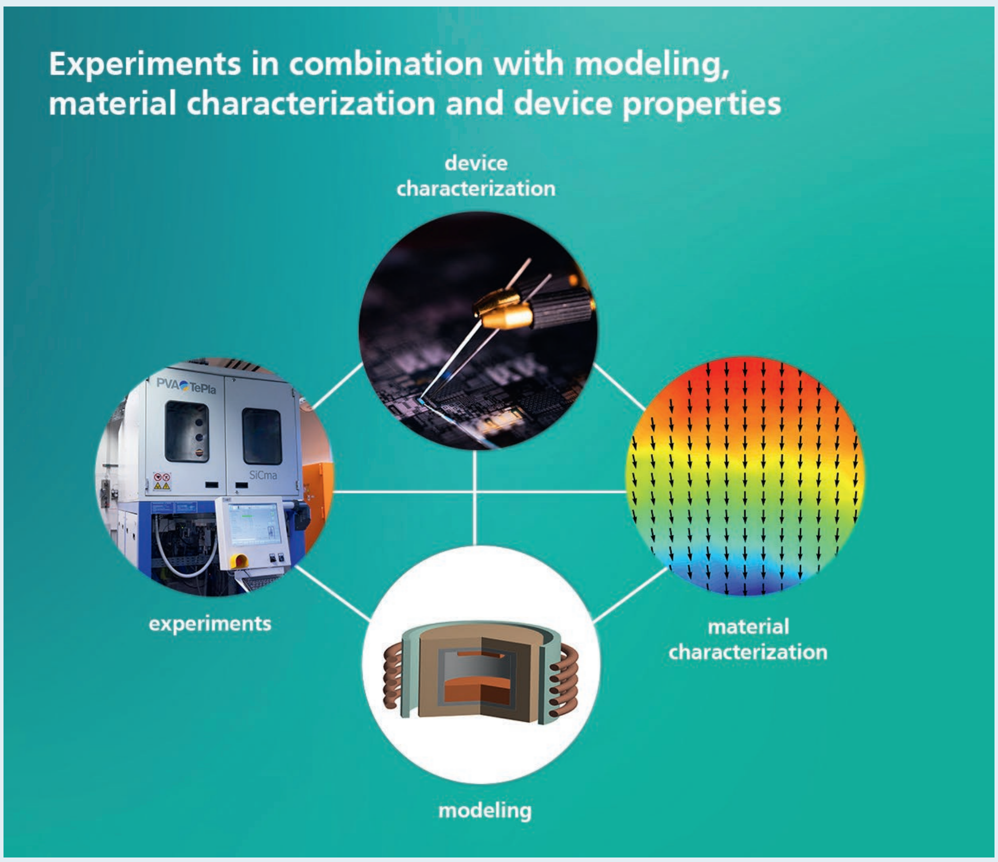
Our strategy is the optimization of the manufacturing processes through a combination of thorough experimental process analysis, tailored characterization techniques, and numerical modeling. For that purpose, we have a well-suited infrastructure at hand, which consists of R&D type furnaces and state of the art epitaxial reactors, newest metrology tools for the investigation of the physical, chemical, electrical, and structural material properties as well as powerful simulation programs, well suited for heat and mass transport calculations. Prototype devices can be processed in house in our qualified 150 mm SiC line (0.8 µm) or in our flexible R&D line.

Strategy



Strategy of the Materials departement © Fraunhofer IISB

Approach



Approach of the Materials departement © Fraunhofer IISB

Joint Labs

Joint Labs offer industry the opportunity to collaborate with Fraunhofer IISB in form of a cross-organizational development team, which works together on the industry’s key topics. This promotes a deeper understanding of the technology, which in turn facilitates technology transfer and accelerates integration into the product. To enable the team to work together successfully, premises are provided as well as the correspondingly necessary technical infrastructure, in which the team members can work together on the problems and develop new technologies and products. The Joint Labs functions also as a demo and application center for newly developed tools and equipment.

Examples

SiC Epitaxy Demolab

AIXTRON SE and Fraunhofer IISB jointly operate the SiC Epitaxy Demolab to optimize the epitaxy process on 150 and 200mm SiC substrates on the latest G10WW system generations. The aim of the collaboration is an efficient, economical, high-throughput epitaxy process that meets the SiC material requirements of tomorrow’s SiC power devices.

Insight in the SiC Epitaxy Demolab jointly operated with Aixtron © Daniel Karmann / Fraunhofer IISB

Center of Expertise for X-ray Topography

Rigaku Corporation and Fraunhofer IISB support the semiconductor industry worldwide in improving and better understanding their wafer quality and yield by employing the Rigaku XRTmicron advanced X-ray topography tools. The aim is to develop industrial applicable measurement routines and defect counting algorithms which can be used in high volume production and for R&D purposes.

Center of Expertise for X-ray Topography jointly operated with Rigaku © Kurt Fuchs / Fraunhofer IISB

Next Level (U)WBG Metrology Lab

Semilab Zrt. and Fraunhofer IISB will develop state-of-the-art metrology and inspection solutions for (ultra-) wide-bandgap semiconductor materials within their joint lab. The goal is to take semiconductor metrology to a next level along the value chain, from base material to die. By bringing new features and tools from lab to market, new standards for SiC, GaN and other (U)WBG semiconductors will be set.

Next Level (U)WBG Metrology Lab jointly operated with Semilab © Daniel Karmann / Fraunhofer IISB

300 mm Si Cz crystal © Kurt Fuchs / Fraunhofer IISB

Crystallization Technologies

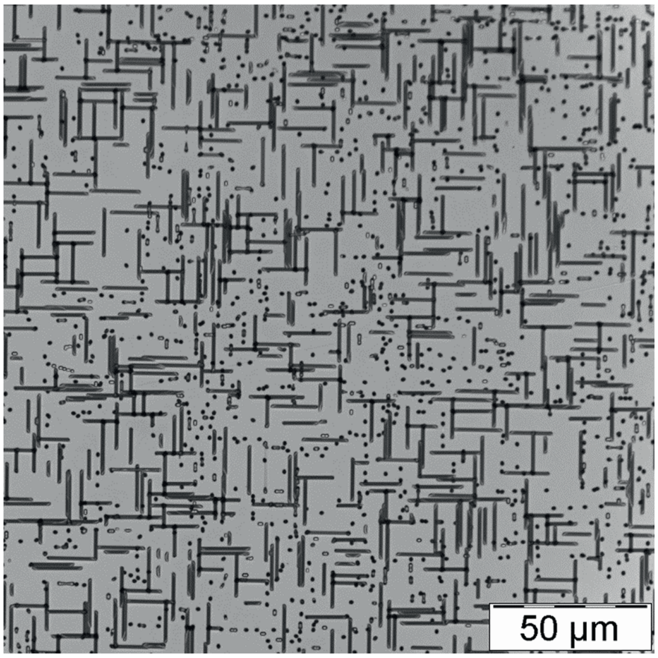
Reserach topics

We perform specific research for our customers on the growth and characterization of a variety of classical semiconductor materials (Si, Ge, GaAs, InP, CdTe) as well as of optical, laser and scintillator crystals with respect to higher yield and improved material quality. For example, in Cz silicon crystal growth we push the pull speed to its limit by optimizing the hot zone using numerical modeling. Besides, we unlock the secrets of the growth ridge to detect structure loss during crystal pulling. We support our customers in the development of new crystal growth equipment and processes based on our broad material expertise and by using numerical simulation. Furthermore, we offer specific characterization services for crystals and wafers.

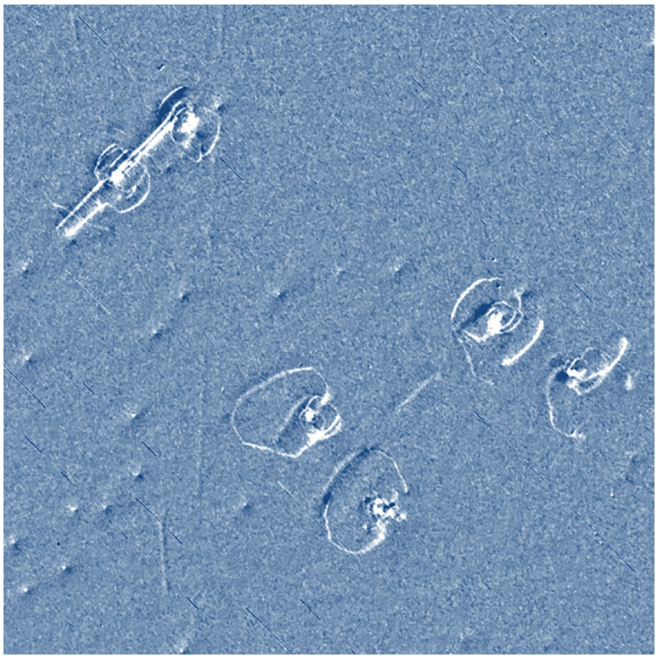
Services

- Specific crystal growth experiments in special R&D furnaces in house and at partners' sites
- Investigation of melt-crucible interaction phenomena
- Sample preparation for the analysis of the properties of the materials
- Spray coating of crucibles-, or furnace parts based on Si_3N_4, SiO_2, SiC and TaC suspensions
- Simulation of heat and mass transport phenomena for various crystal growth configurations including magnetic fields
- Characterization of structural, optical, physical, chemical, and electrical properties, e.g.
  - Shape of the solid-liquid interface by lateral photovoltage scanning (LPS)
  - Microstructural analysis of defect selectively etched samples
  - Imaging of structural defects by X-Ray Topography (XRT)
  - Analysis of growth ridge geometry
  - Minority carrier lifetime mappings (µPCD)

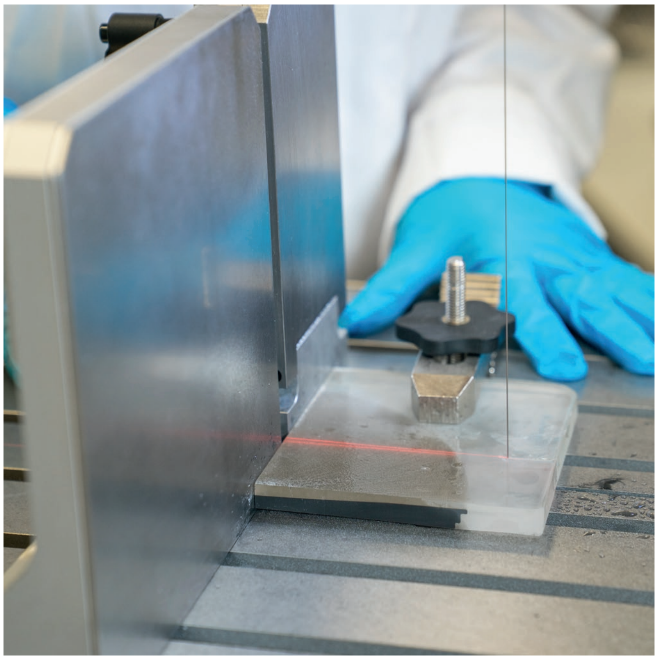
Lab furnace for directional solidification of silicon © Kurt Fuchs / Fraunhofer IISB



Stacking faults in crystallized Si, visualized by defect selectively etching and light microscopy © Matthias Trempa / Fraunhofer IISB



Frank Read type dislocation loops in VGF GaAs visualized by XRT © Christian Kranert / Fraunhofer IISB



Precise preparation of an epoxy resin embedded sample by a single wire saw © Elisabeth Iglhaut / Fraunhofer IISB

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Epitaxy on SiC substrates with 150 mm and 200 mm diameter © Daniel Karmann / Fraunhofer IISB

Silicon Carbide Epitaxy

Research topics

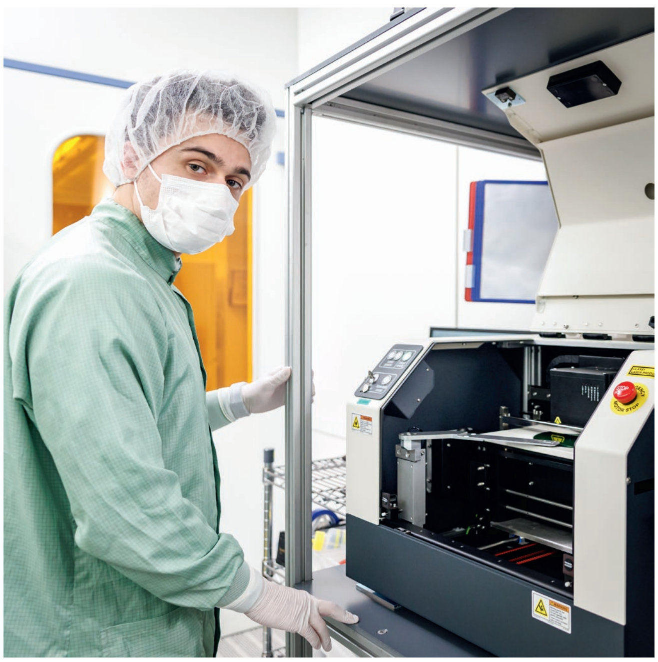
We are developping epitaxial growth processes for 150 mm and 200 mm SiC substrates with respect to the requirements of next generation power devices. We are focusing on improved material quality, thicker epilayers, p-type doping, enhanced minority carrier lifetime, and usage of engineered substrates. Latest generations of inspection & metrology tools such as UV-PL, XRT, FTIR and Corona non-contact CV, together with the possibility to process complete devices in our qualified 150 mm SiC pilot line, allow us to correlate the properties of the epilayer and the substrate with electrical device parameters.

Services

- n- and p-type service epitaxy on 4H-SiC wafers (150 mm, 200 mm)
- Correlation of material defects with device performance and reliability along the whole device processing chain
- Simulation of heat and mass transport for SiC epitaxy, and other high temperature SiC specific processes
- Characterization
  - Imaging of structural defects by x-ray topography and stress birefringence on full wafer scale
  - Imaging of structural defects by combined optical surface and PL mappings on full wafer scale
  - Doping and thickness measurements
  - Carrier lifetime measurements
  - Deep level transient spectroscopy (DLTS)
  - Defect selective etching

Several of the latest G10WW SiC CVD reactors
© Kurt Fuchs / Fraunhofer IISB

FTIR measurements for thickness uniformity.
© Daniel Karmann / Fraunhofer IISB



Carrier lifetime measurements on SiC epiwafers
© Daniel Karmann / Fraunhofer IISB

Corona non-contact CV measurements for doping uniformity.
© Daniel Karmann / Fraunhofer IISB

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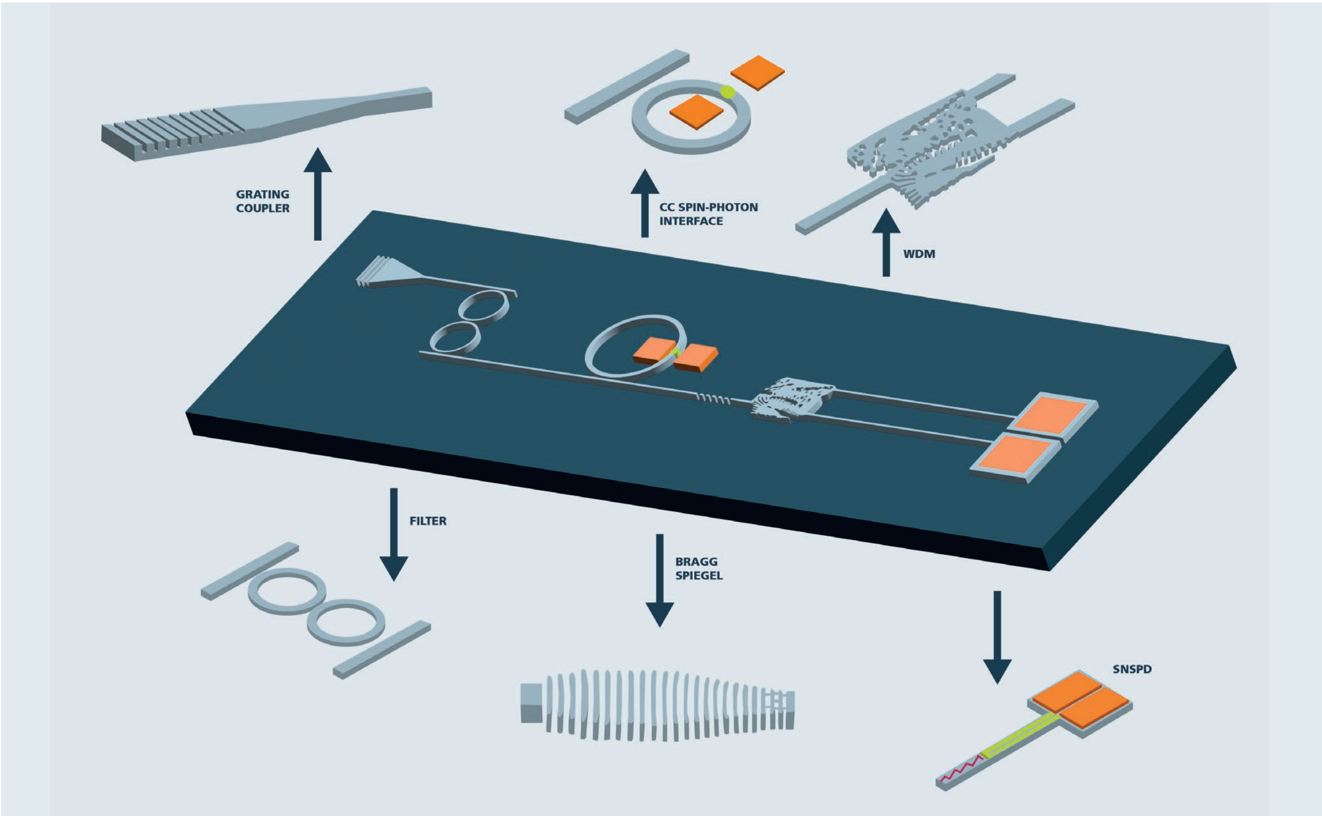


Sketch of a quantum photonic integrated circuit on a SiCOI substrate © Elisabeth Iglhaut / Fraunhofer IISB

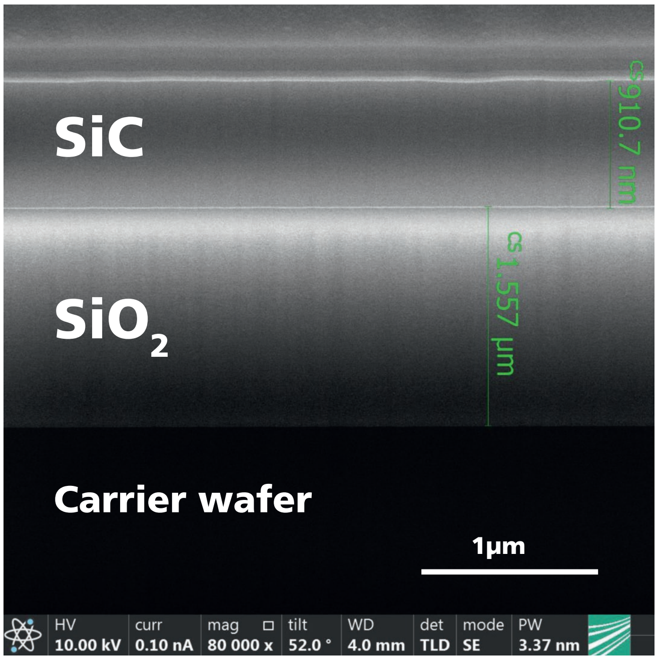
SiC for Quantum and Photonic Applications

Reserach Topics

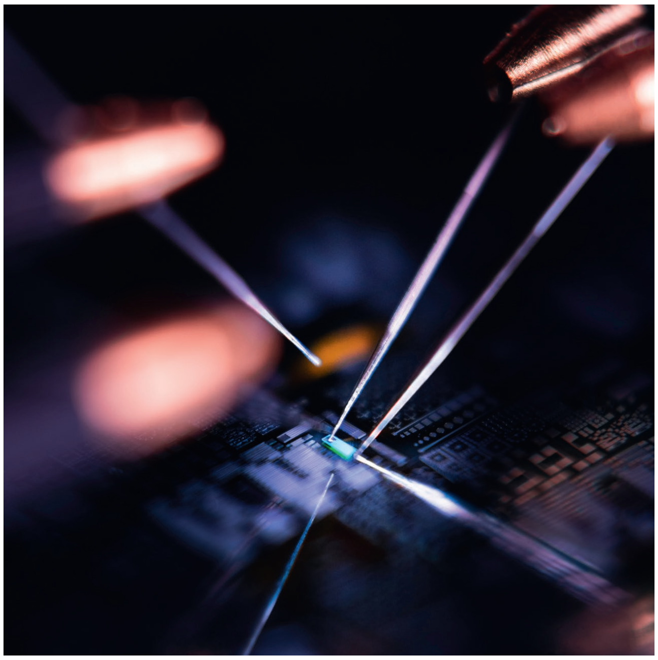
We pioneer the development of SiC for quantum and photonic applications. Our research covers the entire value chain, from material development, the creation of color centers, production of photonic nanostructures, design and processing of quantum and photonic devices, to their integration into system demonstrators. One focus is on the deterministic generation of high-quality color centers with long spin coherence on a nanometer scale. Special characterization set-ups are available to characterize the quantum systems. Furthermore, we use tailored simulation tools to support the material and technology development.

Services

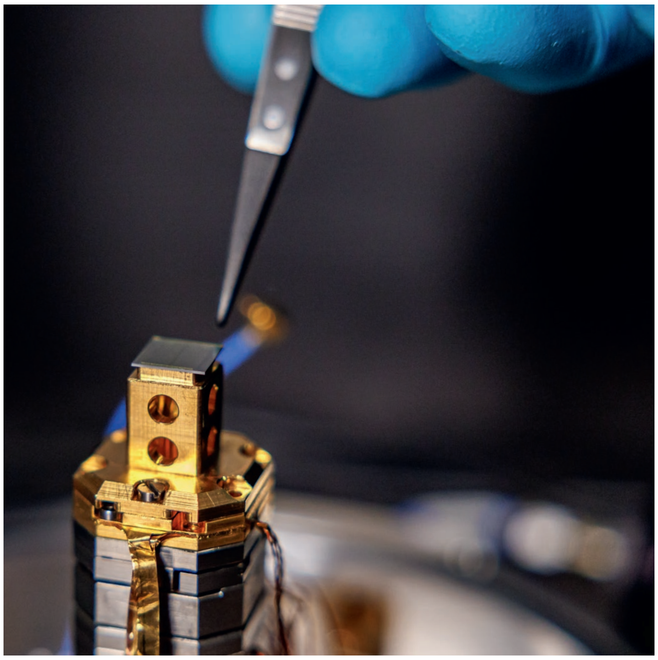
- Epitaxy of isotopically pure SiC on a- and c-plane substrates for quantum application
- Generation of color centers by ion implantation, E-beam, He-FIB
- Stabilization of color centers by surface conditioning
- Characterization of color centers by optical DLTS, cryogenic photoluminescence, ODMR
- Nanostructuring of SiC by E-beam, He-FIB
- First principle simulations of influence of material properties on spin properties
- Design of novel concepts for quantum and photonic applications
  - High-precision magnetic field sensors
  - Quantum repeater
  - Memory-assisted quantum network
  - Quantum computers



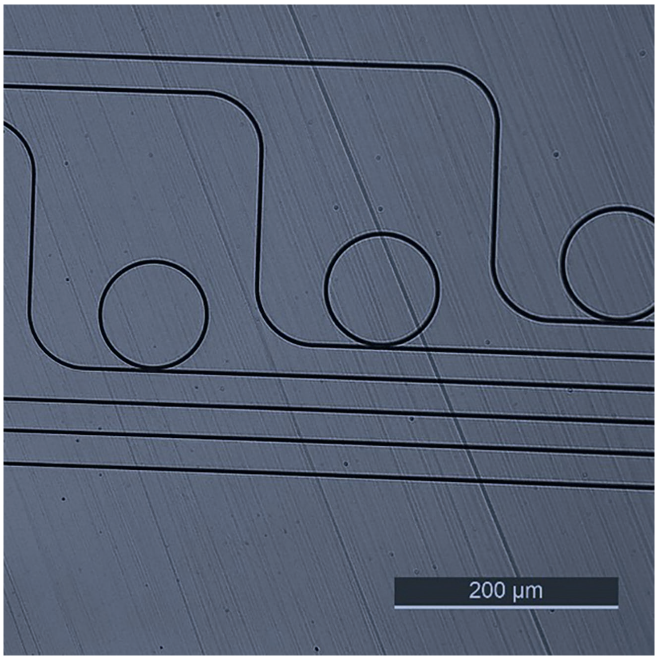
SiCOI substrate manufactured by thinning of a SiC epilayer and bonding to a carrier wafer © Martin Hofmann / Fraunhofer IISB



Luminous 4H-SiC pn-diode in the prober, contacted with measuring needles © Elisabeth Iglhaut / Fraunhofer IISB



PLE-ODMR set up for determination of color centers at cryogenic temperatures © Daniel Karmann / Fraunhofer IISB



SiC ring resonators for photonic and quantum devices © Martin Hofmann / Fraunhofer IISB

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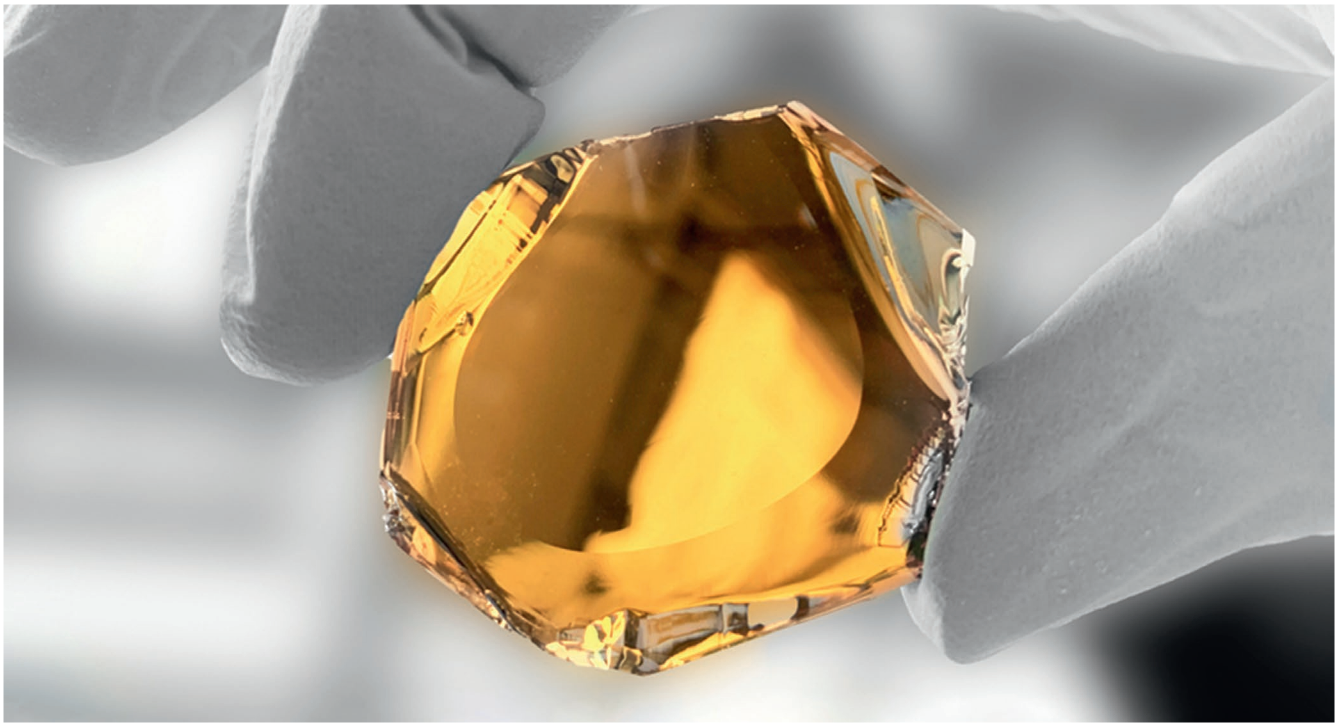


43 mm AlN crystal grown by PVT (Physical Vapor Transport) © Andreas Lesnik / Fraunhofer IISB

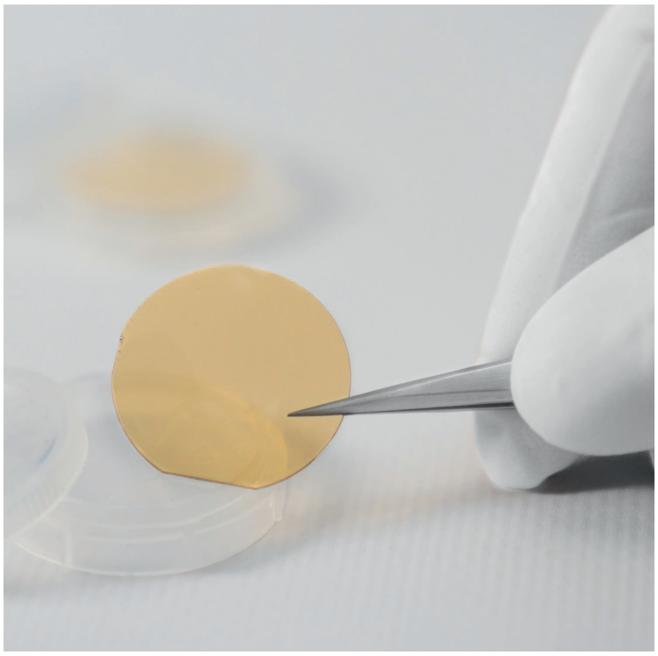
Gallium Nitride (GaN) & Aluminium Nitride (AlN)

Reserach Topics

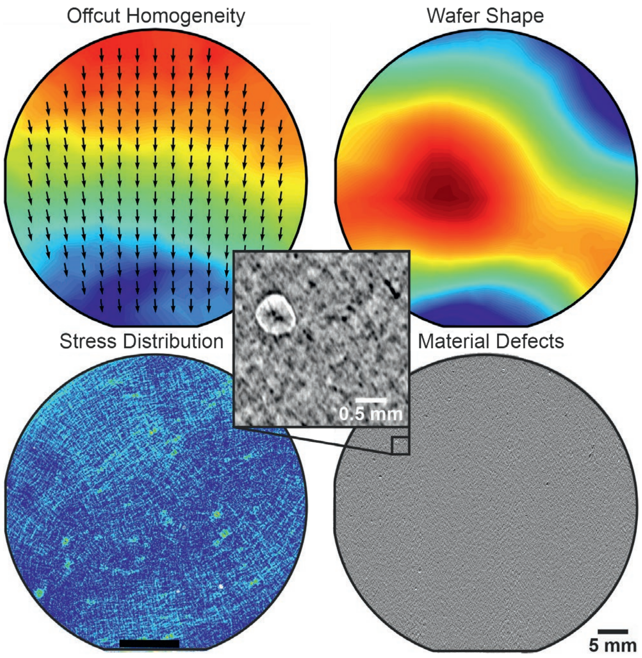
We pioneer the PVT growth of AlN crystals with focus on highest crystalline quality and upscaling towards 4" diameter. In our wafering line, we fabricate epi-ready AlN wafers for device layer epitaxy and manufacturing of RF- and power devices by our partners. We develop the growth of 3" and 4" GaN bulk crystals and the epitaxy of thick GaN drift layers on different types of substrates by hydride vapor phase epitaxy for the realization of vertical devices beyond state of the art. We offer a large variety of characterization techniques from fundamental, research-based microscopy to wafer scale metrology for nitride semiconductor wafers with a strong focus on the relevance of defects for performance and reliability of electronic devices.

Services

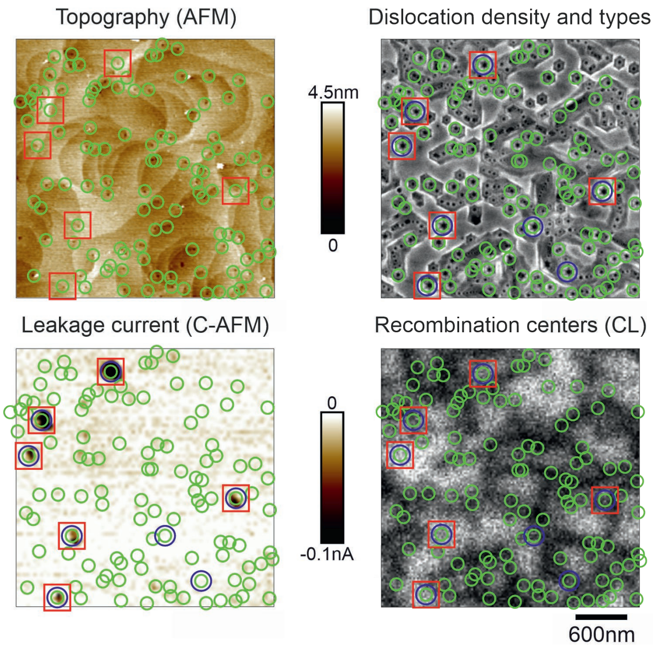
- Provisioning of single-crystalline AlN epi-ready wafers for research purposes
- Wafer-scale metrology for nitride semiconductors:
  - Imaging of defects by X-ray topography
  - X-ray diffraction
  - Stress distribution by stress birefringence
  - Wafer shape by optical profilometry
  - Roughness by tactile profilometry
- Microscopic techniques for fundamental research and development:
  - Scanning electron microscopy with the options for energy-dispersive X-ray spectroscopy (EDS), cathodoluminescence (CL) and backscattered electron microscopy (BSE)
  - Transmission electron microscopy (TEM)
  - Atomic force microscopy (AFM) with the option for conductive AFM (C-AFM)
  - Defect selective etching (DSE)
- Joint development of metrology solutions for nitride semiconductors



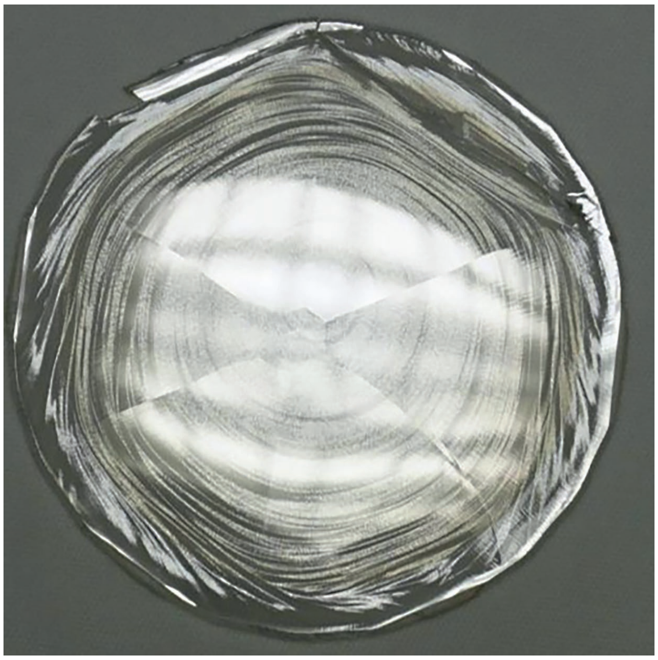
Single crystalline epi-ready AlN wafer with 1 inch diameter © Elisabeth Iglhaut / Fraunhofer IISB



Examples for nitride semiconductor wafer metrology capabilities © Sven Besendörfer / Fraunhofer IISB



Investigation of leakage current in GaN on Si and its relation to specific material defects by various microscopic techniques © Sven Besendörfer / Fraunhofer IISB



GaN crystal with 3 inch diameter grown by HVPE © Jonas Beer / Fraunhofer IISB

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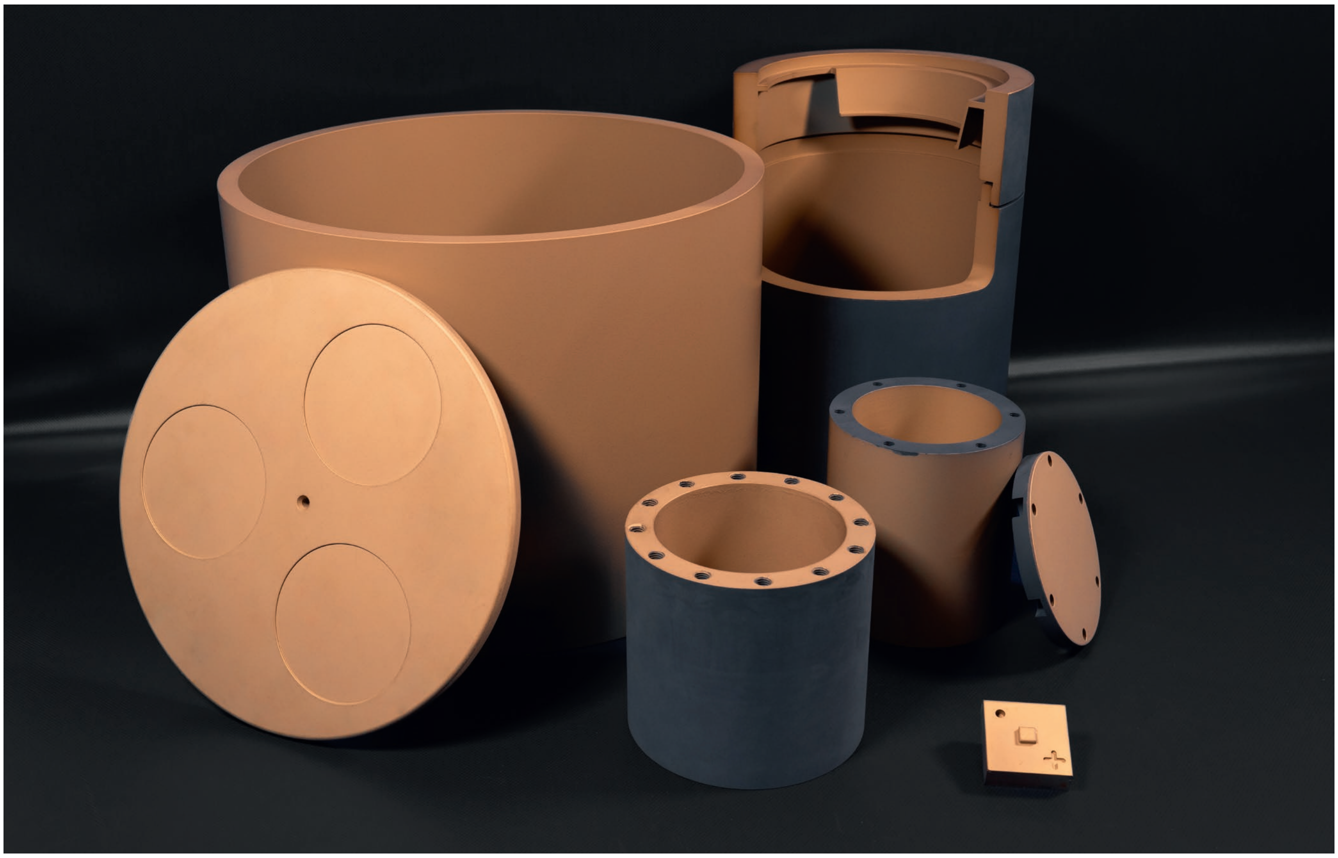


Variety of graphite parts coated with tantalum carbide (TaC) for semiconductor applications © Elisabeth Iglhaut / Fraunhofer IISB

Functional Coatings (SiC, TaC, SiO_2, Si_3N_4)

Research Topics

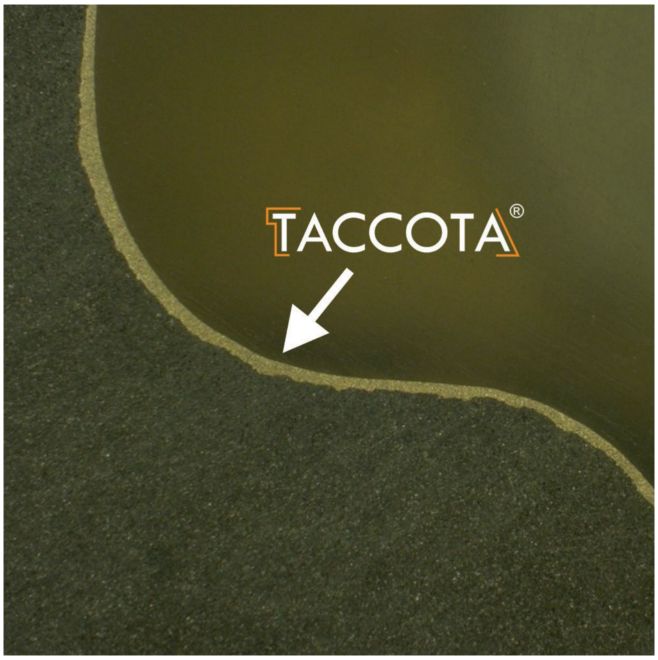
We use spray coating and modified techniques to apply e.g. SiC, TaC, SiO2, and Si3N4 to crucibles and other furnace/reactor parts in order to reduce harmful defects, impurities and particles and to increase the lifetime of the parts. One focus is on ultra-high-temperature and chemical resistant protective TaC and SiC coatings on graphite and other materials. We develop this novel patented technologies TACCOTA® and SICCOTA® for applications in semiconductor industry, e.g. for SiC epitaxy, SiC PVT crystal growth or oxidation processes, but we address also other applications. Further, we are doing research on SiO2 and Si3N4 based coatings on silica crucibles and ceramics.

Services

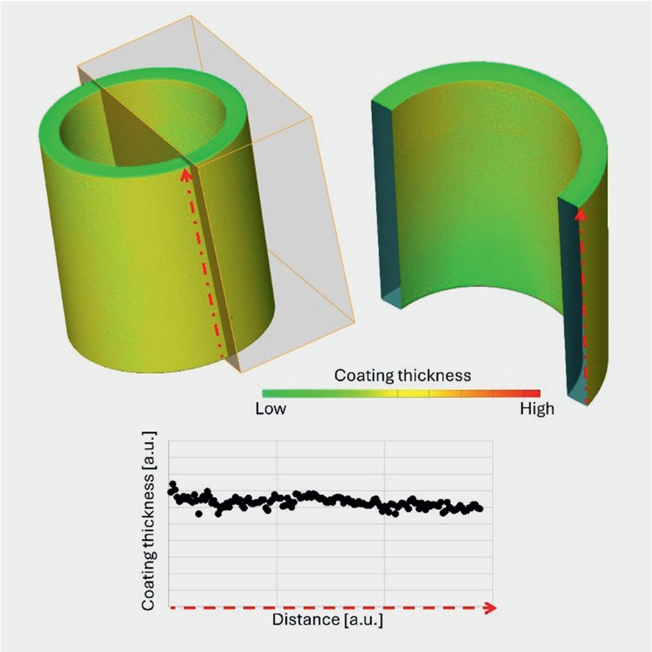
- Spray coating of SiC, TaC, SiO_2, and Si_3N_4 on graphite, silica, ceramics, refractory metals
- Microstructural characterization of coatings
- Coating development on customer specific parts according to their application requirements
- Coating of small series for customer specific applications tests
- In-house tests of coatings under application condition
- Quality management by non-destructive analyzing methods
- Analysis of wetting behavior of silicon and other melts according to the sessile drop method

Spray coating of graphite parts with TaC
© Eisabeth Iglhaut / Fraunhofer IISB

Graphite parts coated with SiC
© Elisabeth Iglhaut / Fraunhofer IISB



TaC coating of complex geometrical graphite parts
© Kevin Schuck-Bühner / Fraunhofer IISB



Geometrical measurement of crucible and coating thickness by non-destructive optical scanning method
© Christina Ende / Fraunhofer IISB

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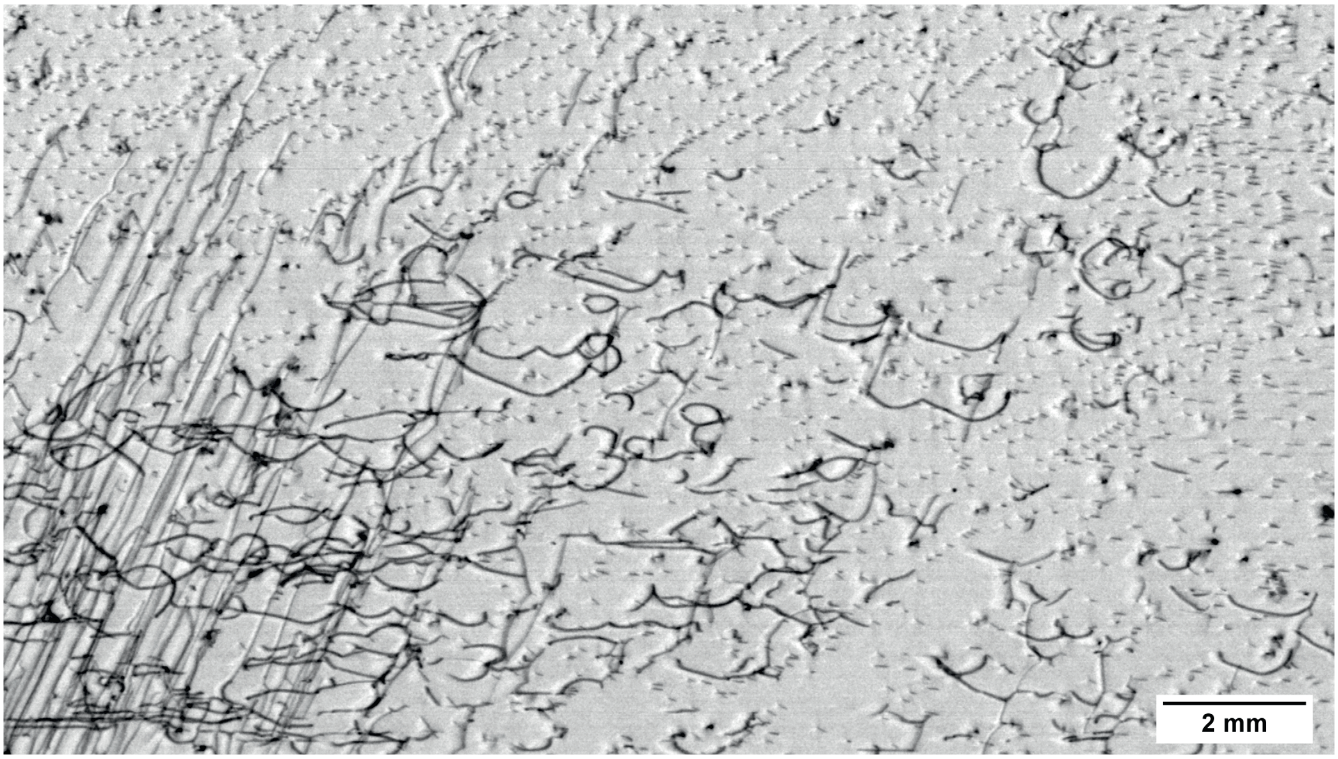


High resolution x-ray topographic image showing different types of dislocations in 4H-SiC © Christian Kranert / Fraunhofer IISB

Crystal and Wafer Analysis

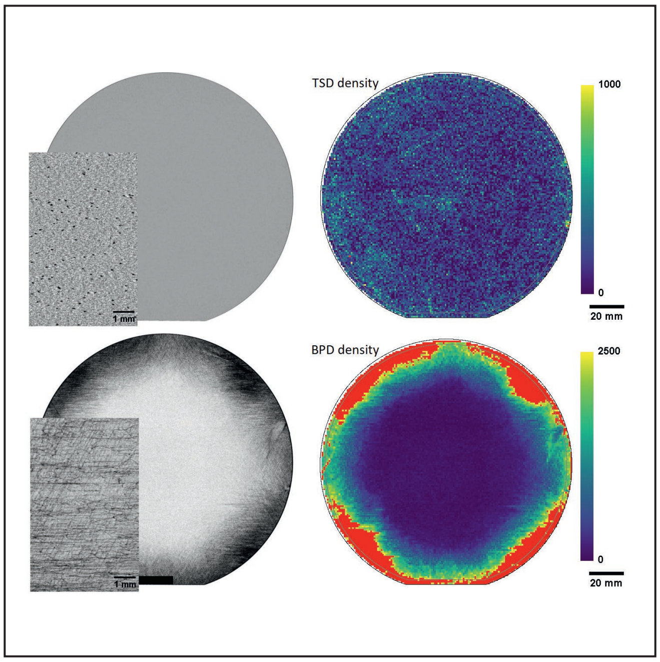
Research Topics

We are experienced with the characterization of the optical, electrical, structural, physical, and chemical properties of different crystal, wafer and epi materials as well as of partially and fully processed devices. On the one hand we perform service measurements within a fast return time for our customers. On the other hand we use our metrology toolbox in combination with the possibility to process test devices in house and at partners' site to identify defects critical for device performance and reliability. The understanding of their origin allows us to find solutions together with our customers to overcome the critical defects.

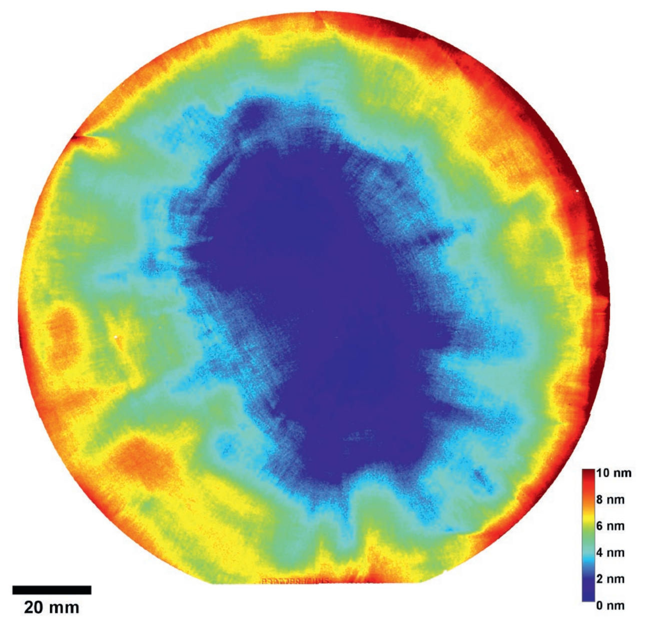
Services

- Identification of device critical materials defects and correlation with device performance
- Characterization of crystals, epitaxial structures and devices:
  - X-ray topography, X-ray diffraction
  - Optical microscopy, scanning and transmission electron microscopy
  - Stress birefringence
  - Various atomic force microscopy methods
  - Lateral Photovoltage Scanning (LPS) to determine interface shapes
- Electrical and optical defect spectroscopy
  - Deep Level Transient Spectroscop (DLTS), optical DLTS
  - Cathodoluminescence, photoluminescence
  - UV photoluminescence (UVPL) scanner for full wafer imaging
  - Electron Beam-Induced Current (EBIC), Raman and FTIR
  - Minority lifetime measurements (µPCD)
  - IV & CV measurements
  - and much more
- Development of tailored metrology techniques together with metrology manufacturer

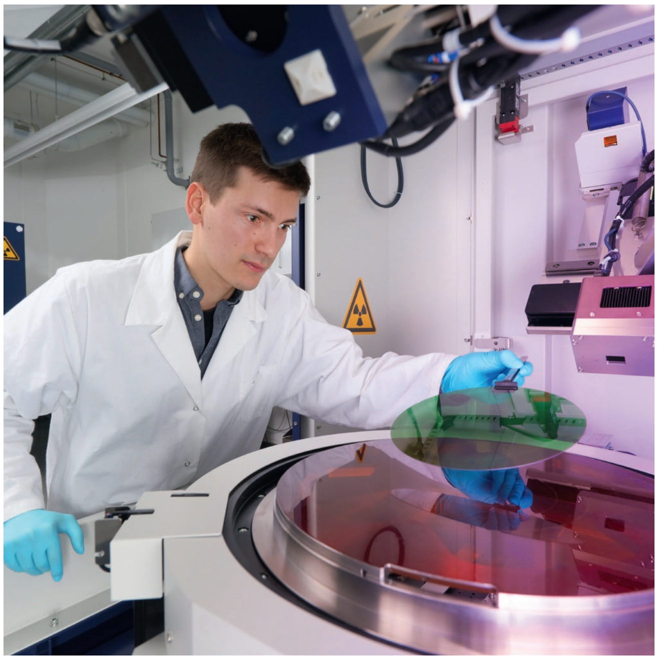
Software for defect analysis of SiC substrates in accordance with SEMI standards © Elisabeth Iglhaut / Fraunhofer IISB



TSD and BPD mappings of SiC wafers by x-ray topography © Christian Kranert / Fraunhofer IISB



Stress birefringence image of a 6“ SiC substrate © Paul Wimmer / Fraunhofer IISB



Fraunhofer IISB researcher places a 200 mm SiC wafer on the sample stage of a Rigaku XRTmicron © Kurt Fuchs / Fraunhofer IISB

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Supporting of our customers by modeling high temperature equipment and processes © Elisabeth Iglhaut / Fraunhofer IISB

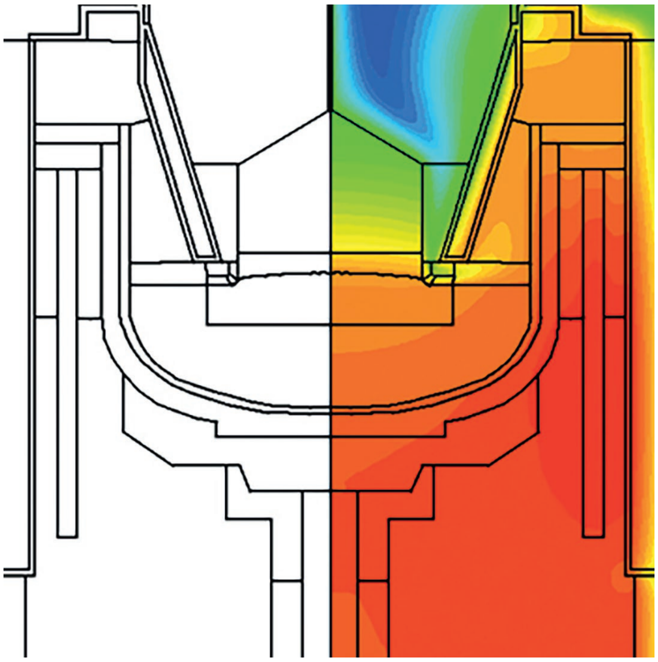
Equipment, Process, Defect Simulation

Research Topics

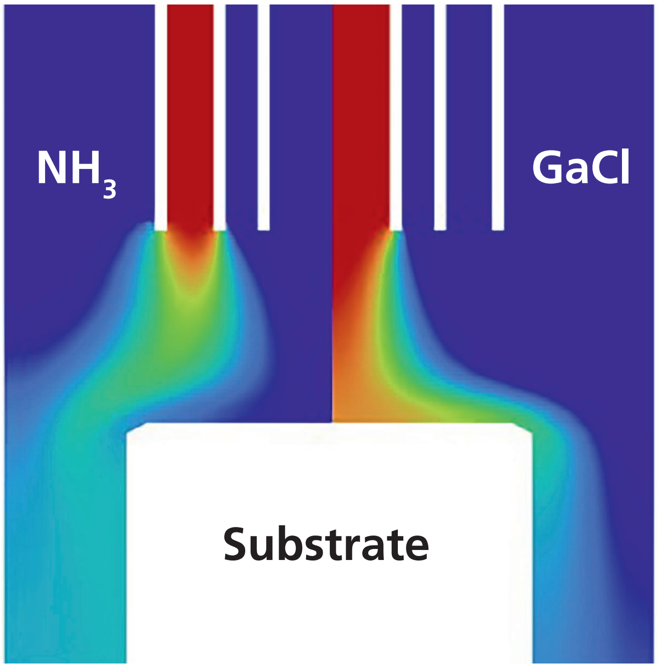
We support the development of high-temperature equipment and processes with our expertise in numerical modeling of heat and mass transport phenomena, and, in particular in the area of crystal growth and epitaxial processes. We are experienced with other thermal processes like crystal or wafer annealing as well. We elaborate solutions for furnace modifications partially assisted by AI/ML techniques to optimize the systems for the respective application and we give new insights into the processes, especially for parameters that are hardly accessible via measuring techniques like species distributions or convection patterns.

Services

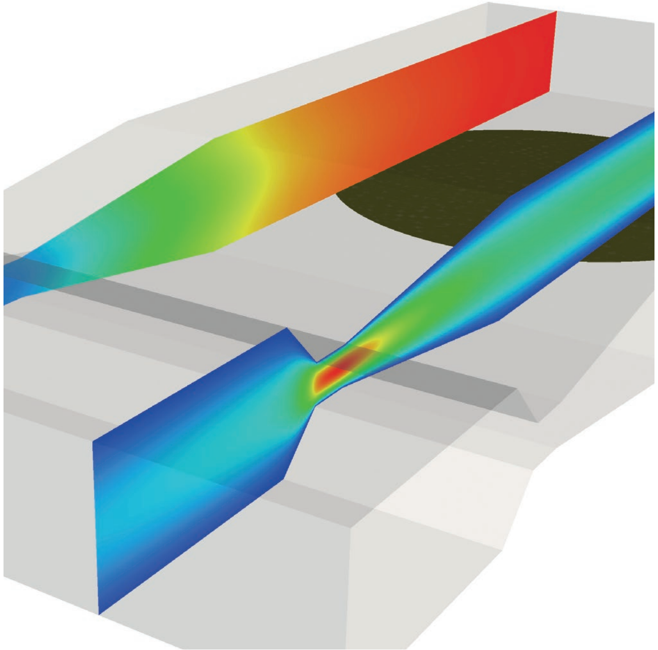
- Thermal simulations (conduction, convection, radiation)
- Flow simulations (gas, melt, turbulence including magnetohydrodynamics)
- Stress simulations
- Electromagnetic field simulations
- Simulation of species transport including chemical reactions
- *Software tools:* CrysMAS, OpenFOAM, Ansys
- *Processes:* Cz, VGF, DS, FZ, EFG, LPE, THM, CVD, PVT, HVPE, Annealing
- *Materials:* Si, Ge, GaAs, InP, CdZnTe, SiC, GaN, AlN, Diamond, Halides, Oxides



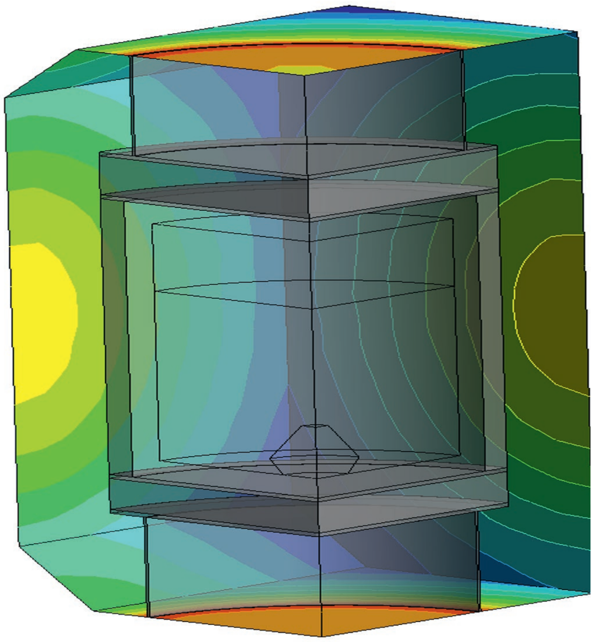
Global simulation of a Czochralski puller for Si crystal growth
© T. Jung / Fraunhofer IISB



NH_3 and GaCl distribution in a downflow HVPE GaN reactor
© Markus Zenk / Fraunhofer IISB



3D CFD model of a CVD SiC epi reactor
© Jan Seebeck / Fraunhofer IISB



Temperature field during HPHT synthesis of diamond crystals
© Marc Hainke / Fraunhofer IISB

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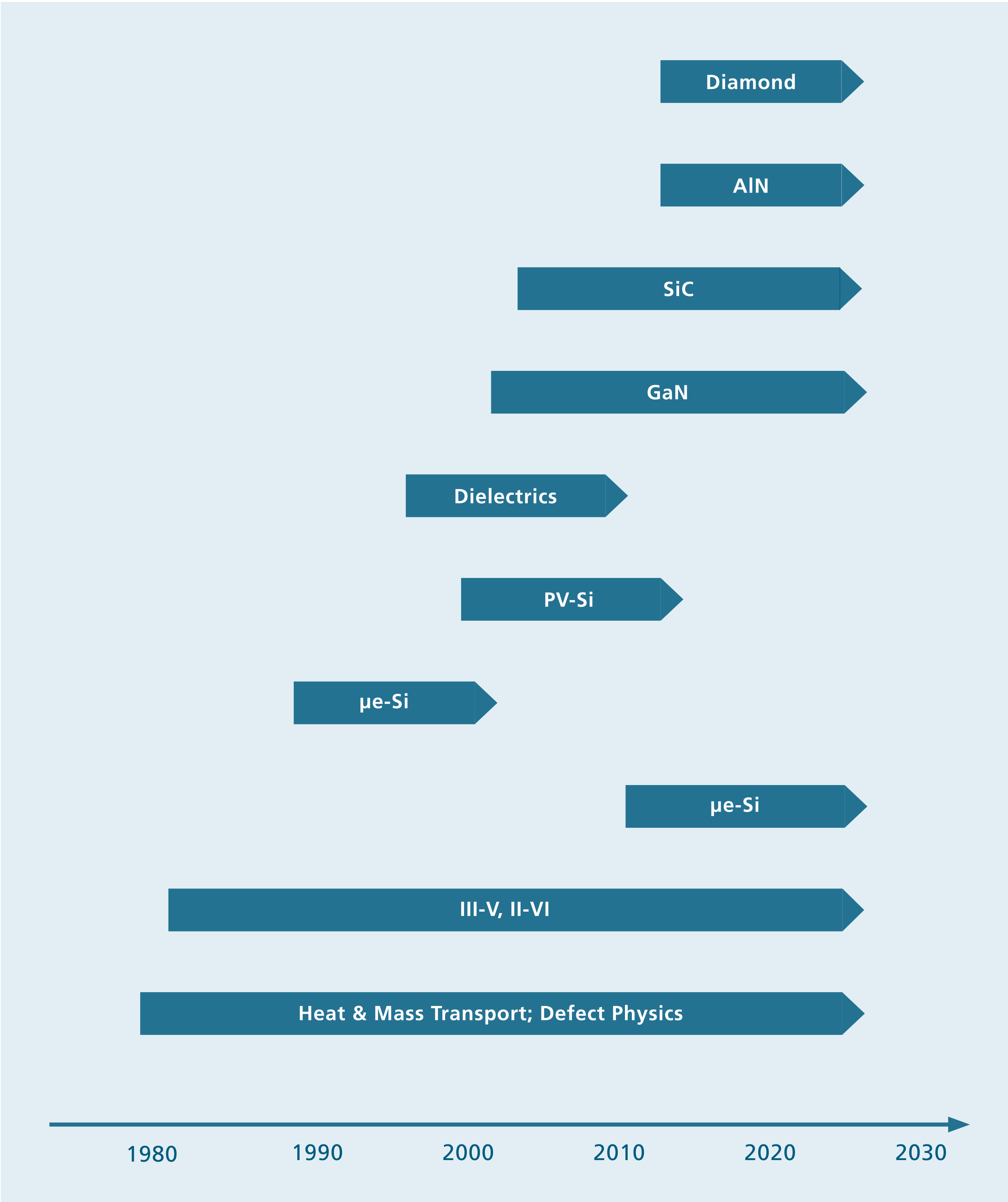
Development of the Materials Department

Erlangen

In the 1950s Siemens engineers pioneered the semiconductor technology in the Erlangen area. Innovations were made such as the Siemens and the Floating Zone process or the discovery of the compound semiconductors. This work promoted R&D at FAU Erlangen-Nuremberg which resulted in the foundation of the Crystal Growth Laboratory in 1974. This led to a Crystal Growth working group at Fraunhofer IISB, that became the Materials Department in 1999.

Today, the Materials Department consists of approximately 50 material experts plus 30 students. The historic development of the research topics at the Crystal Growth Laboratory and Fraunhofer IISB is shown on the right side.

The real Silicon Valley – Pretzfeld



Developement of the Materials Departement © Fraunhofer IISB

Milestones

2025 First 2" AlN crystal grown @ IISB

2024 Successful demonstration of AlGaN/GaN HEMTs on AlN wafers from IISB

2023 In-house qualification of TaC coating for SiC epitaxy

2022 Growing the first aluminum nitride crystal with 43 mm diameter as a research facility

2021 SEMI standard on TSD determination of SiC by XRT

2020 V-Pits identified as root cause for leakage currents in GaN HEMT structures

2019 Generation of NV centers in diamond by ion implantation @ IISB

2018 Laser writing of color centers in SiC epilayers grown @ IISB

2017 Root causes for dislocation formation in heavily doped Cz Si found

2016 First AlN PVT crystal grown

2015 First 6" SiC epilayers grown within the framework of Joint Lab with Aixtron

2014 First 2" thick, crack free HVPE GaN crystals grown within the framework of Joint Lab with FCM

2013 Prediction of bipolar degradation of pin SiC diodes by using UV PL scanner

2012 Coupled 2D-3D Cz simulation software validated for 200 kg Si Cz process

2011 Twin formation during DS of quasi mono PV Si clarified

2010 BPD free SiC epitaxial layers on 3" substrates demonstrated

2009 Advantages of time-dependent magnetic fields in DS of PV Si demonstrated

2008 Doping effects on etch pit geometry of DSE SiC substrate and epilayers clarified

2007 Root cause for Si_3N_4 and SiC formation during DS mc Si understood

2006 First SiC epilayers grown on 2" SiC substrate in VP508

2005 Reduction of dislocation density in VB CZT crystals achieved by the help of numerical simulation

2004 20 µm thick 2" LPE GaN grown on sapphire with EPD ~ 107 cm^{-2} demonstrated

2003 Advantages of time-dependent magnetic fields for VGF grown GaAs crystals demonstrated

2002 In-situ temperature and oxygen measurements during 300 mm Si Cz growth

2001 First 6" VGF CaF_2 crystal grown

2000 Need for 2D-3D modeling for CZ Si and MCZ Si realized

1999 Inverse modeling concept introduced into the field of crystal growth

1998 First 4" VGF GaAs single crystal with a weight of 10 kg grown

1997 3" VGF GaAs sinlge crystal with EPD=50 cm^{-2} (Si doped) demonstrated

1996 First software license granted

1995 Compensation mechanisms in s.i. InP clarified

1994 First 3" VGF GaAs single crystal grown

1993 FZ GaAs single crystal with 20 mm diameter grown during German Spacelab Mission D2

1992 First 2" VGF InP single crystal grown

1991 Comparison of different MHD models on the damping effects of static magnetic fields

1990 Determination of the critical Marangoni number for GaAs

1989 Worldwide first LEC InP single crystal with 3" diameter grown

1988 Novel model for description of the dislocation dynamics in semiconductor melt growth

1987 Root cause for non-uniformities in semiconductor melt growth clarified

1986 Proof of the theory of Jackson and Hunt by data from space experiments

1985 Directional solidification experiments with InSb-NiSb onboard German Spacelab Mission D1

1984 Tenfold growth rate for THM GaSb achieved by growth on a centrifuge

1982 Suppression of doping striation by forced convection demonstrated

1983 Directional solidification experiments with InSb-NiSb onboard 1. Spacelab Mission

1981 First use of a time-dependent magnetic field to enhance convection

1980 First GaSb and InSb crystal grown by Fraunhofer Technolgy Center High Performance Materials THM

1974 Foundation of the Crystal Growth Laboratory

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We have profound experience in the areas of semiconductor crystal growth, epitaxy, and device processing including characterization and modeling.«

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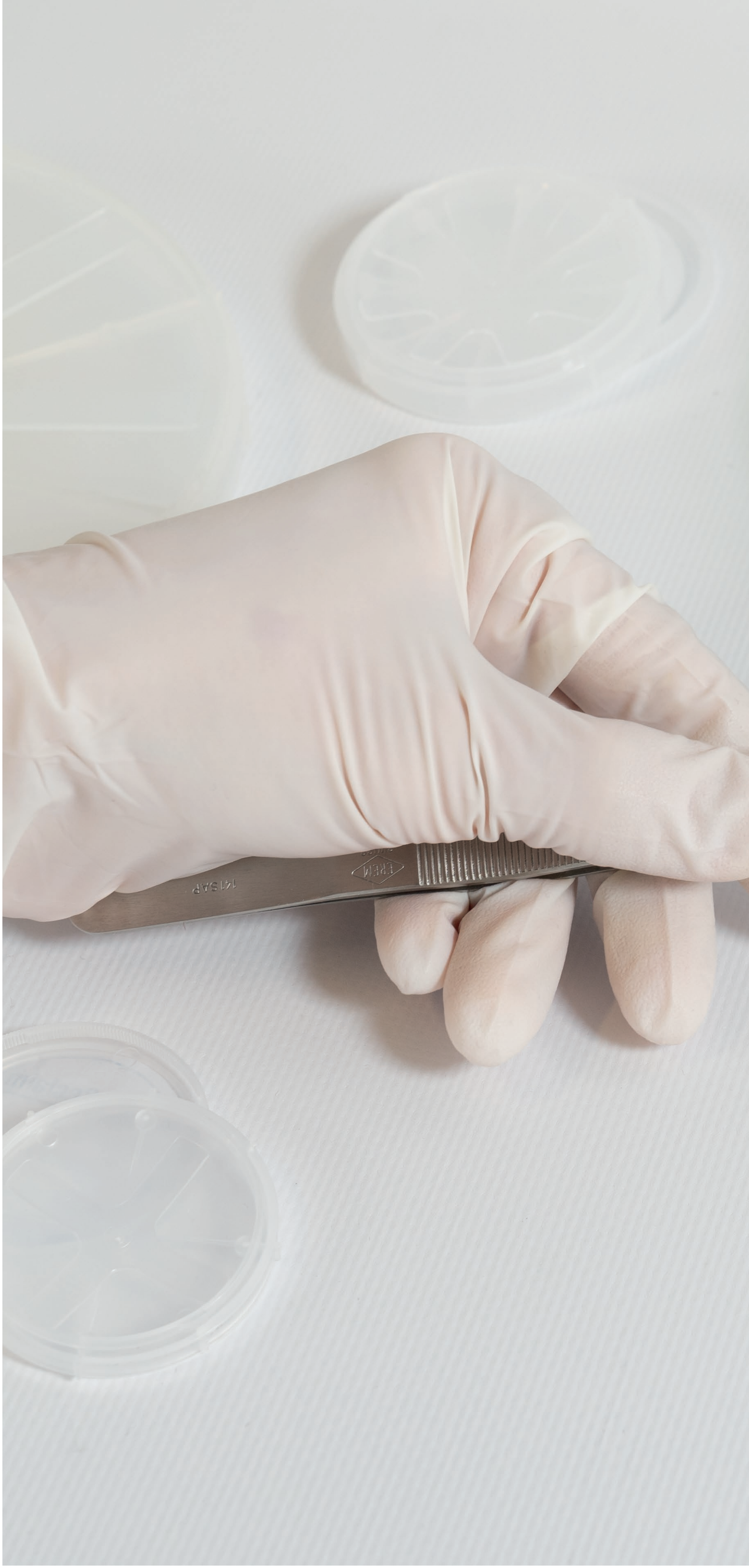

Cover picture:
150 mm silicium carbide wafer,
2 Inch galium nitride wafer and
1,5 Inch aluminum nitride wafer