Annual Report 2024 / 2025

Leibniz
Ferdinand
Braun
Institut

Technology meets know-how – from design to prototypes

...this is what the Ferdinand-Braun-Institut stands for: comprehensive expertise across the entire value chain – from initial design and chip development to manufacturing, and ultimately, to ready-to-use modules and prototypes. This vertical integration approach is one of our core strengths, enabling us to realize cutting-edge photonic, electronic, and quantum technology components for novel applications. The result is tailor-made, practical solutions that benefit society in many ways, be it in medical technology, sensor technology, material processing, and future technologies for space and quantum applications. As a research partner to both industry and science, we not only drive technological innovation but also provide significant scientific and technical impetus to the economy – in the region, throughout Germany, and internationally.

Our developments are based on FBH's excellently equipped cleanroom and laboratory infrastructure. In the future, we aim to increasingly open these facilities to external partners, particularly small and medium-sized enterprises. A key driver of this initiative is the recently launched APECS pilot line, part of the European Chips Act. It reflects our support for the European Union's goals of technological sovereignty, resilient supply chains, and global competitiveness. Within the Research Fab Microelectronics Germany (FMD), and in collaboration with other European partners, we are expanding EU-based production capacities for semiconductor chips through this cross-institutional production line for heterointegrated chiplet technologies.

Successful technology development depends fundamentally on skilled professionals. To this end, the nationwide flagship initiative skills4chips, funded by the German Federal Ministry of Education and Research, was launched in parallel with the APECS pilot line. Coordinated by FBH, an interdisciplinary team is establishing the Microtec Academy, a national training academy for microelectronics and microsystems technology. It will offer tailor-made qualification programs for both vocational and academic education and training.

Neither research, technology, administration nor other science-supporting areas are able to operate without the commitment of the people behind them. A big thank you therefore goes to our employees, whose knowledge, creativity, and commitment enable us to achieve so much together every day. We are also grateful to our loyal customers and long-standing partners for their trust and successful collaboration – we are already looking forward to many more exciting projects with you!

Our special thanks go to the State of Berlin and the Federal Government. Their continued funding forms the foundation of our research.

On the following pages, we invite you to explore what we have achieved in the past year. Enjoy reading and discovering!

Patrick Scheele & Karin-Irene Eiermann

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Profile & structure

Profile – driving the future with cutting-edge R&D

The Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) is an application-oriented research institute in the fields of high-frequency electronics, photonics, and quantum physics. It researches and realizes electronic and optical components, modules and systems based on compound semiconductors.

Specifically, we develop light sources from the near-infrared to the ultra-violet spectral range: high-power diode lasers with excellent beam quality, UV light sources, and hybrid laser modules. Applications range from medical technology, high-precision metrology and sensors to optical communications in space and integrated quantum technology. In the field of microwaves, our institute develops high-efficiency multi-functional power amplifiers and millimeter wave frontends targeting energy-efficient mobile communications, industrial sensing and imaging as well as car safety systems. In addition, we realize electronic devices based on wide- and ultrawide-bandgap semiconductors for efficient and compact power converter systems.

Another important part of our activities is to support next-generation scientists and skilled workers. We actively engage in academic teaching and training in close cooperation with different universities throughout Germany. Activities include, but are not limited to supervising, Bachelor's and Master's theses as well as PhD's.

Since more than 25 years we are committed to securing skilled workers in vocational education and training. We not only train microtechnologists ourselves, our education management team is currently establishing the nation-wide training platform Microtec Academy – covering all qualification levels, from entry-level to advanced specialist courses and accredited advanced training at Bachelor's and Master's level. (see page 19)

More about us and our profile.

How we are organized – FBH's structure

The Ferdinand-Braun-Institut organizes its research activities in labs and departments within its four research areas: III-V Technology, III-V Electronics, Photonics, and Integrated Quantum Technology. Here, FBH cooperates closely with universities in the framework of Joint Labs. It maintains an efficient administration that supports research and development in areas like human resources, finance and controlling, procurement, and IT services. The technical services team ensures the smooth operation of laboratories and cleanrooms. A process-oriented quality management system and the communications unit complement FBH competencies. With its science management, the institute additionally promotes vocational training and further education in high technology and related research in this field.

FBH gGmbH has been a 100 % subsidiary of the State of Berlin since 01.01.2021 and is a member of the Leibniz Association.

More about our organizational structure, including supervisory board, scientific advisory board, and the organizational chart.

Leibniz Association

The Leibniz Association connects 96 independent research institutions that range in focus from natural, engineering, and environmental sciences to economics, spatial and social sciences, and the humanities. Leibniz Institutes address issues of social, economic and ecological relevance. The Leibniz Institutes employ around 21,400 people. The financial volume amounts to € 2.3 billion.

leibniz-gemeinschaft.de

Leibniz Association

How we have developed – facts and figures

Founded 1992

2023	2024	
383	393	Staff
156	155	Scientists
49	47	PhD candidates
30	29	Student assistants & bachelor / master students
9	12	Trainees
180	163	Third-party funded projects
91	105	Peer-reviewed publications
316	273	Patents
138 (28)	161 (33)	Talks (of which invited)
Revenue (in million €) 19.3	19.6	Basic funding: State of Berlin & Federal Government (1 dot equals 100,000 €)
17.2	20.9	Public third-party funding
6.8	4.0	Industrial contracts

Your partner across the whole process chain

Ways of cooperating with us:

- Joint research project
- Industrial contract
- Direct sales or licensing

Interested?

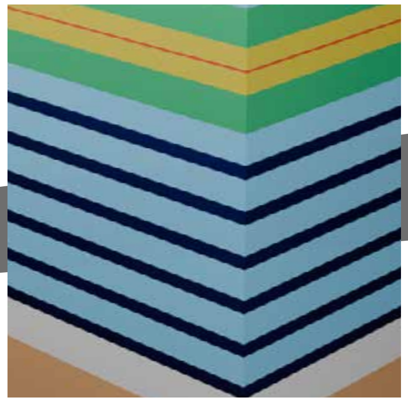
Get in touch with us sales@fbh-berlin.de

What we offer – advanced technologies and services

Based on our comprehensive know-how, dedicated staff, and more than 2,000 sqm excellently equipped cleanroom and lab facilities, we provide the full value chain inhouse: from targeted R&D services in epitaxy and processing through to customized chip and module development up to plug-and-play prototypes.

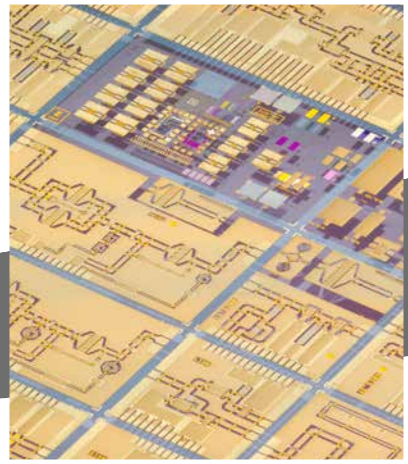
We have also joined forces with further research institutions. Among other initiatives, we are currently collaborating closely with researchers from various universities within ten Joint Labs. As part of the Research Fab Microelectronics Germany (FMD), we take European chiplet innovation together with 14 partners to a whole new level with the cross-institutional Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems (APECS) pilot line. APECS leads the way in advanced packaging and heterogeneous integration by providing diverse technologies on a single platform.

Learn more about our transfer activities and R&D services for customers and partners in industry and research.



Design

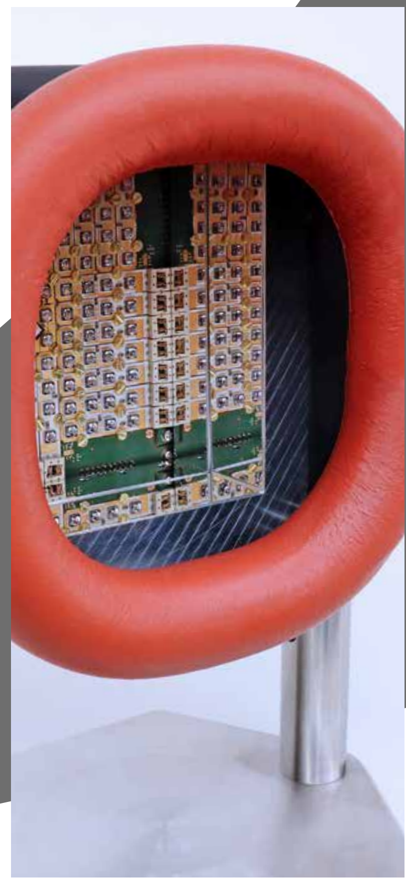
Epitaxy



Wafer processing

Packaging & module development

Reliability testing



Prototyping

Highlights

Technological sovereignty – more chips 'made in Europe' (APECS)

The European Union has set an ambitious goal: to double the share of semiconductors produced in Europe – from 10 to 20 percent – by 2030.

Against this backdrop, the pilot line for **Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems (APECS)** was launched at the end of 2024. APECS is a key element of the EU Chips Act, designed to accelerate innovation in chiplet technologies and strengthen Europe's semiconductor research and manufacturing capabilities.

We are proud to be one of the institutes within the Research Fab Microelectronics Germany (FMD) working closely with further European partners to set up the APECS pilot line. The shared mission: to bolster Europe's technological resilience and enhance global competitiveness in the semiconductor industry. Cutting-edge semiconductor technologies and applications will also play a central role in driving digital transformation and advancing green tech.

APECS opens the door to next-generation technologies for both large industrial players and smaller businesses – including SMEs and start-ups – ensuring low-barrier access to cutting-edge technologies. The initiative also contributes to building reliable and robust semiconductor supply chains in Europe. APECS is co-funded by Chips Joint Undertaking along with national funding from Belgium, Germany, Finland, France, Greece, Austria, Portugal, and Spain as part of the Chips for Europe initiative. Total funding for the pilot line amounts to € 730 million over 4.5 years, with around € 33 million directed toward reinforcing FBH's technological capabilities.

As part of this effort, we are strengthening our portfolio in two key areas: bipolar chiplets for mm-wave applications in the W and D bands based on indium phosphide (InP), and laser chiplets based on gallium arsenide (GaAs). The funding supports upgrading our equipment to cutting-edge technological standards and developing a user interface for the InP process (Process Design Kit).

APECS
European Chiplet Innovation

Ultrapure water is produced through a highly sophisticated purification process and is indispensable for chip production. As part of the ERDF project "Application Laboratory III-V Components for Aerospace", which is funded with €3 million, we are currently installing a **state-of-the-art ultrapure water system** for our cleanroom-1 (RR-1). It will allow us to manufacture semiconductor components with the required performance for the aerospace industry – in more energy-efficient and sustainable processes. The technical room itself will be equipped with energy-efficient lighting and ventilation systems. This complex project involves many people: from project management, procurement management and process managers to the technical staff who oversees the installations. From summer 2026, RR-1 will be just as modern as RR-2, where this picture was taken.

Hands-on experience in high-tech training.

Securing skilled talent in the high-tech sector – skills4chips and Microtec Academy

Resilient semiconductor value chains with increased production capacities depend on a well-trained workforce. That's why **skills4chips,** a nationwide flagship project coordinated by the Ferdinand-Braun-Institut, was launched concurrently. The initiative aims to secure skilled professionals for microelectronics and microsystems technology. It builds on the long-standing experience and strong industry connections of ANH Berlin, the training and education network operated by FBH. The project is funded by the German Federal Ministry of Education and Research (BMBF) with €12 million over four years. As part of the project, the skills4chips team is expanding the Microtec Academy, which was initiated during the BMBF predecessor project BM = x^3, into a national education hub for microelectronics and microsystems technology. Its programs address the growing demand for skilled professionals across the entire education pipeline – ranging from career and higher education orientation to lateral entry pathways, advanced training, and targeted upskilling and reskilling.

With accredited advanced training programs at both Bachelor's and Master's level, the Microtec Academy also bridges the gap between vocational and academic education.Together with a nationwide network of vocational schools, universities, and technology experts, new, targeted training programs are being developed for all qualification levels.

The academy's infrastructure combines hands-on cleanroom and lab environments with a virtual technology lab. Following a modular approach, it offers needs-based training and professional development through a blended learning format that combines in-person and online instruction.

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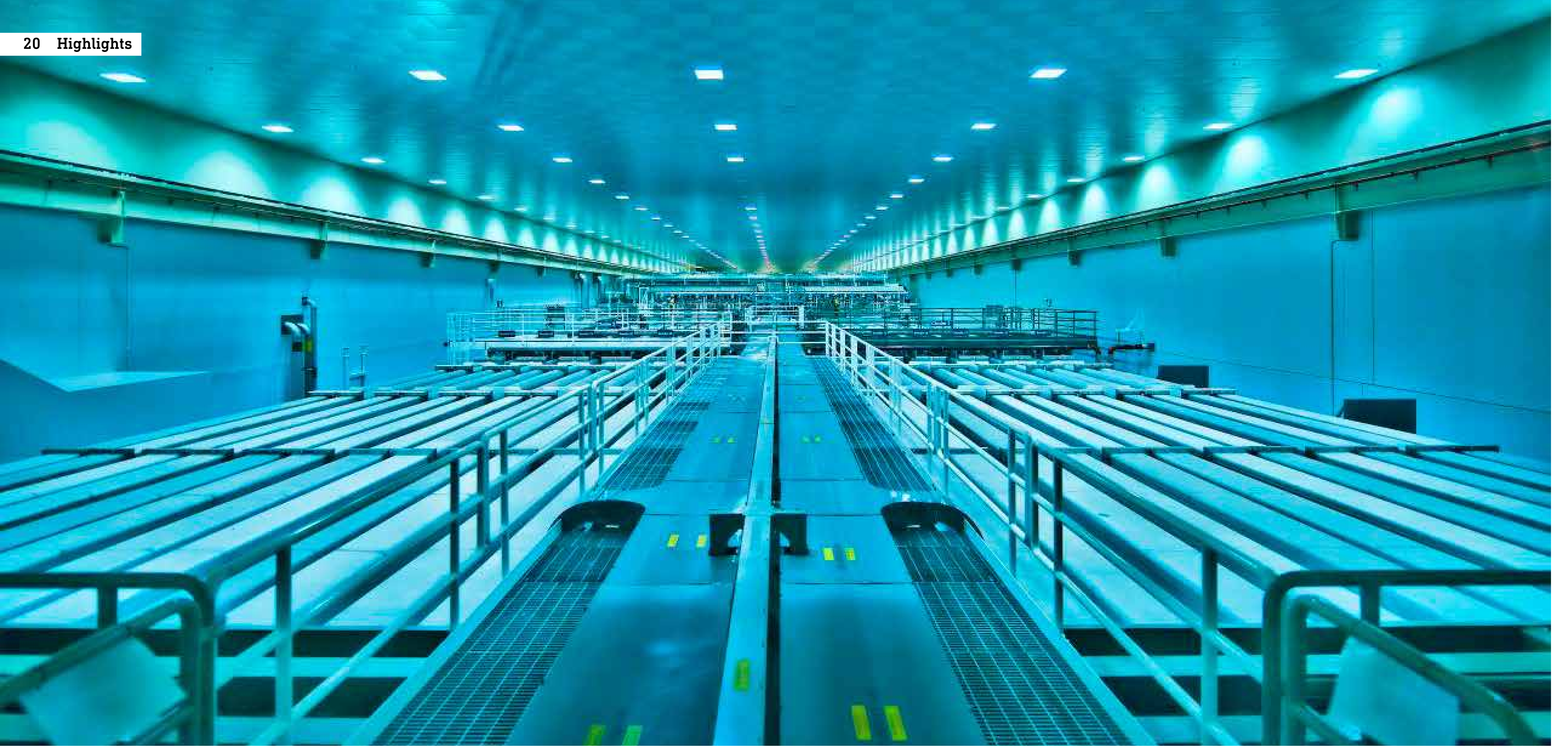


One of the rooms at National Ignition Facility, a laser-based inertial confinement fusion (ICF) research device in which the laser is amplified..

Clean and safe energy – diode laser pump modules for future fusion power plants

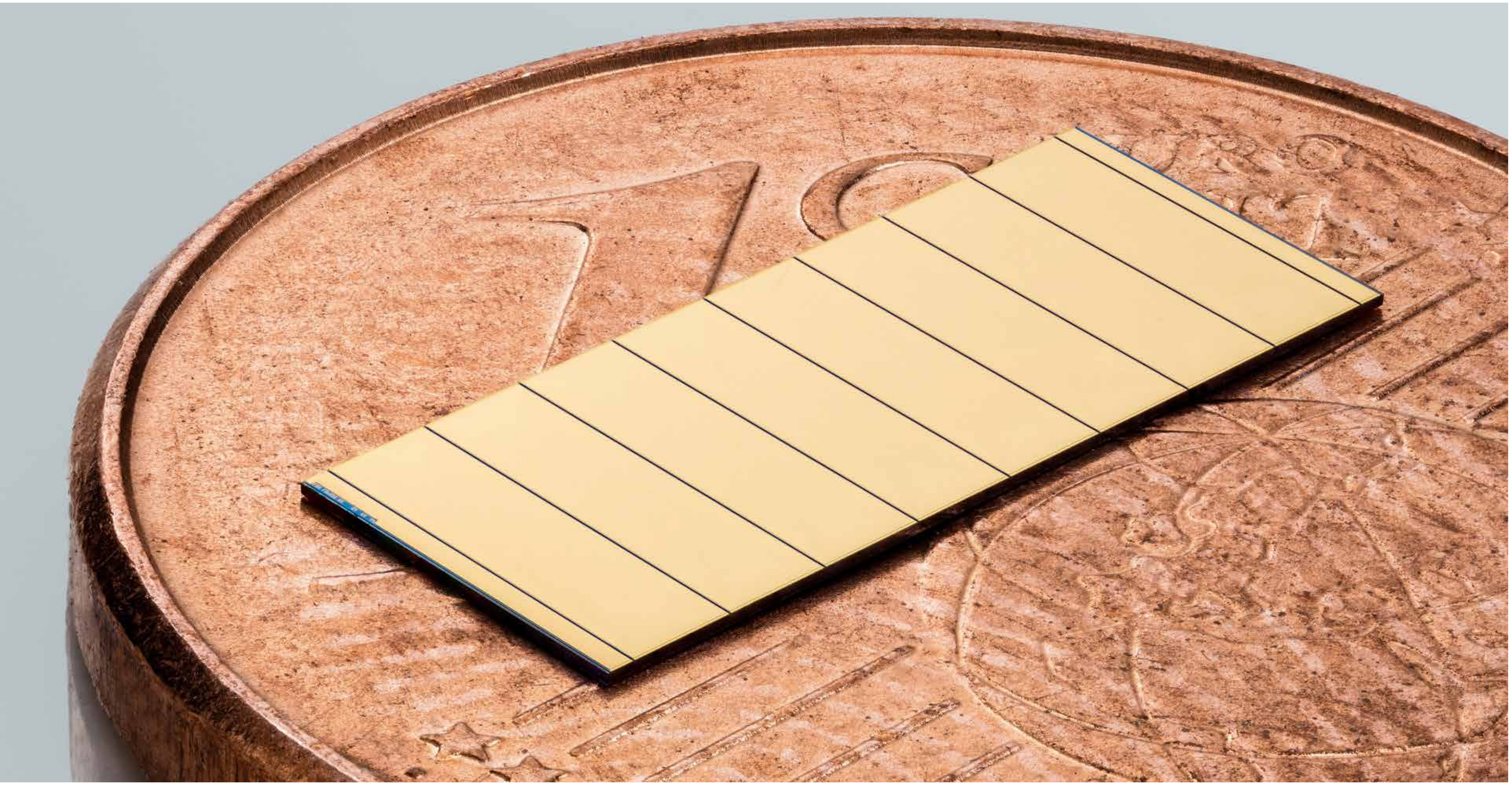
At the end of 2022, researchers in the U.S. achieved a scientific milestone: for the first time, a fusion reaction produced more energy than was used to ignite the plasma with high-energy laser systems. This success marks a major step toward realizing fusion as a clean, safe, and virtually limitless energy source – and has sparked renewed momentum in fusion research worldwide.

High-power diode lasers are a key component for future fusion power plants. They will be needed in massive quantities, with high output power and exceptional efficiency. With these challenges in mind, the joint project **DioHELIOS** was launched in fall 2024. Its goal: to further improve laser performance at chip level, supported by novel automation processes and cost-efficient packaging technologies.

Funded by the BMBF, the project brings together leading players from research and industry, including ams-OSRAM, the Ferdinand-Braun-Institut, Fraunhofer ILT, Jenoptik, Laserline, and TRUMPF. Together, they are tackling the particularly ambitious requirements for pump modules in fusion applications.

Systems will need to deliver 30 to 50 gigawatts of laser power, while costs must drop by a factor of ten to twenty – to around $0.01 per watt. At the same time, production capacity must increase at least tenfold. We bring many years of extensive experience to the table to help meet these ambitious project goals. For years, we've been pushing the efficiency and performance limits of our diode lasers for high-power applications. We are developing kilowatt-class laser bars that are increasingly being used not only for pumping but also in direct industrial applications.

For materials processing, FBH's grating-stabilized laser bars are used to pump solid-state and fiber lasers. Our grating-stabilized multi-junction diode lasers deliver particularly high output powers for short-pulse LiDAR applications. On top of that, we offer patented facet technology and are boosting production yield with the help of artificial intelligence.



High-power laser bars like these are a key component for fusion power plants of the future.

Things are always busy in our **IT Services team.** Six colleagues and one trainee ensure that everything runs smoothly in terms of IT security, telephone systems, media technology, and software at the institute. More than 1,600 requests were processed via the institute's in-house IT ticket system in 2024 alone – no wonder, with over 700 end-user devices, 120 servers, 150 active network components, and much more. Important ongoing projects at the institute include the expansion and renewal of the network infrastructure in our cleanroom facilities, the introduction of a new ERP software system, and an instant messaging system. In addition, comprehensive measures are being taken against brute force attacks, viruses, and malware – in short, everything that secures our IT infrastructure and its end-user devices in the best possible way.

Hady Yacoub is presenting the latest findings on the environmental impact of the indium phosphide process during his talk at the Green ICT Connect conference.

FMD focus topics: Green ICT, QNC Space and related projects

The FBH is one of 15 institutes collaborating within the Research Fab Microelectronics Germany (FMD). With over 5,400 employees in total, the FMD brings together a unique range of expertise and infrastructure under one roof. This makes it a key point of contact for all matters related to micro- and nanoelectronic research and development in Germany and across Europe, targeting green communication technologies, novel computing approaches, and technological sovereignty.

Shining a light on the environmental footprint of semiconductor processes

As part of the large-scale BMBF-funded Green ICT @ FMD project, FBH is coordinating the hub Energy-Efficient Communication Infrastructures. The focus at our institute is on wireless communication (digitalization, mm-wave transceivers, and 140 GHz links) as well as power converters. In this context, we've also been taking a closer look at the environmental footprint of our indium phosphide process since early 2024 – examining every step from materials used to energy consumption during fabrication.

With its high electron mobility, indium phosphide (InP) and its compounds are a highly attractive semiconductor material for high-frequency and broadband electronics. InP outperforms other conventional semiconductors at high frequencies, delivering higher output power and improved efficiency. This means that less chip area is required to achieve the same performance. But whether these advantages also translate into a better CO_2 footprint has largely gone unexplored so far.

As part of the FMD initiative, we are therefore taking a closer, exemplary look at our own process for fabricating InP heterojunction bipolar transistors (HBTs). For each individual process step, we are currently tracking material, chemical, and energy consumption, including the power usage of the specific equipment involved and the overall resource demand of the cleanroom infrastructure. Our analysis focuses on the most energy- and resource-intensive front-end and back-end steps, such as deposition, lithography, wet chemistry, and plasma processing. Detailed modeling helps us understand where the most emissions occur within the process chain – and how we can optimize accordingly. Our goal is to compare the environmental impact of InP-based devices with that of conventional silicon chips. We shared initial findings at **Green ICT Connect** in October 2024, where the topic attracted significant interest. The expert conference explored key questions around environmentally conscious digitalization and sustainable microelectronics.

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The **6G Research and Innovation Cluster (6G-RIC),** funded by Germany's Federal Ministry of Education and Research (BMBF), is laying the scientific and technological groundwork for the next generation of mobile communications (6G). This effort spans all layers of technology – from radio access to fiber-optic transport networks to hardware, protocols, and applications. At FBH, cross-departmental R&D work is underway to advance the hetero-integration of indium phosphide (InP) HBT chips onto BiCMOS platforms. Combining these two technologies is a key step toward leveraging InP for vital functions in 6G systems, such as developing efficient power amplifiers that boost range in the sub-terahertz frequency domain.

Hands-on session with Adam Rämer and FBH's terahertz scanner during the Green ICT Camp.

Sustainable technologies in focus: the first Green ICT Camp

Whether it's video conferences, streaming, or cloud data – digital content is meanwhile available at lightning speed. As data volumes continue to grow, the demands on their availability rises in parallel. But how do these developments affect our resources, energy consumption, and environmental footprint? These were the questions 40 students explored in September 2024 during the first-ever **Green ICT Camp**, hosted at our institute as part of the FMD initiative. Funded by the BMBF, the event offered a wide range of hands-on workshops, training sessions, and excursions to other FMD partners, including the Fraunhofer Institutes HHI and IZM.

For an entire week, students brought in their perspectives from a variety of fields – from electrical engineering and computer science to environmental technology, resource management, and product design. Wolfgang Heinrich, Head of the FBH's Microwave Department and coordinator of the FMD Hub Energy-Efficient Communication Infrastructures, was happy with the outcome: "Everyone really enjoyed the camp. With the mix of theory and hands-on sessions, we managed to show these young talents that anyone working on technology needs to think about sustainability from the very beginning – no matter their discipline."

greenict.camp24

E-beam lithography system in FBH's cleanroom to create innovative device concepts – enables structuring down to the sub-µm range.

Quantum technologies and neuromorphic computing: enabling technologies for next-generation applications

As a deep-tech accelerator, the **QNC Space** funding program offers research groups, start-ups, and SMEs low-barrier access to high-end technology infrastructure needed for quantum and neuromorphic computing developments. The goal is to provide the best possible support for young companies and research teams – whether in advancing their research or building a viable business. High-end infrastructure is often far beyond the financial reach of these early-stage players – and with typically small production volumes, not yet economically feasible. QNC Space helps bridge that gap: with funding up to € 200,000, participants develop tailored processes and modules – all the way to functional prototypes. This is backed by intensive technological consulting and support, preparing these young teams for the next steps toward real-world application and market readiness.

To provide the necessary technological infrastructure, FBH has acquired a high-performance i-line wafer stepper. This fully automated exposure system is essential for photolithographic processing – one of the key steps in semiconductor chip fabrication. With the new ASML stepper, substrate sizes of 4", 6", and 8" can be processed flexibly. The system stands out with its exceptional alignment precision and, thanks to its powerful exposure optics, is capable of producing structure sizes below 280 nanometers. This paves the way for fabricating optical light sources with precisely aligned waveguides and producing chips that operate at higher cutoff frequencies.

qnc.space

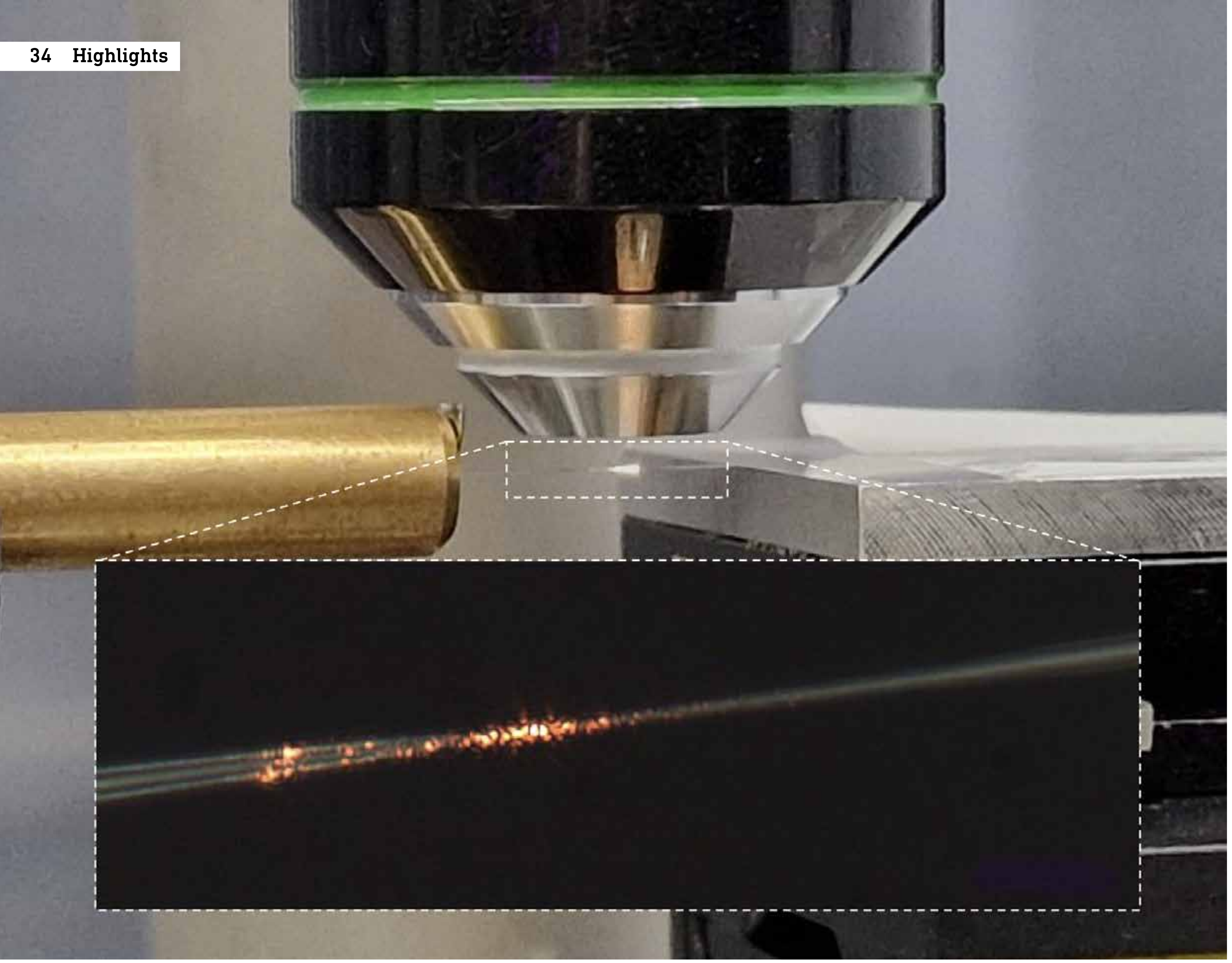

Fig. 1. Testing of a tapered fiber tip for transmitting light into a second light-guiding, also tapered structure. The total transmission efficiency from fiber to fiber exceeds 80 %.

Fig. 2a) Diode laser with orange emission typical for this wavelength.

Laser sources and fiber-chip couplers for quantum computing

We are currently contributing our expertise and infrastructure to two projects within the QNC Space funding program.

In the project **Cryogenic Fiber to Chip Coupling – CF2CC**, we are developing an integrable fiber-to-chip coupler that achieves efficiencies beyond 80 % (Fig 1). This coupler is a key technology for all forms of photonic computing. It enables highly efficient coupling of optical fibers to computer chips – without the need for in-situ alignment. With our cross-platform approach, the goal is to create virtually lossless connections between cryogenic photonic integrated circuits and optical fibers. Efficient fiber coupling at cryogenic temperatures – that is, at extremely low temperatures – has so far not been technologically feasible. The project is supported by Attocube, a company that develops cryostat systems and has a commercial interest in this type of fiber coupling.

In the project **Barium Laser Systems for Quantum Computers – BaSyQ,** we are developing a laser source specifically tailored to the barium ion (Fig 2). This lightweight metal is increasingly gaining ground over competing ion candidates – becoming the preferred qubit for ion-based quantum computing. So far, however, there is a lack of laser sources that are affordable, stable, compact, and scalable. The 614 nanometer (nm) wavelength poses a particular challenge, as room-temperature operation is not technologically feasible at this wavelength. That is why we are developing a compact laser source at 614 nm at FBH, which is cooled to well below 0 °C. The module is integrated into a hermetically sealed housing and implemented as an Extended-Cavity Diode Laser (ECDL) – consisting of a semiconductor gain chip and an external wavelength-selective element. The project goals are supported by the company NeQxt.

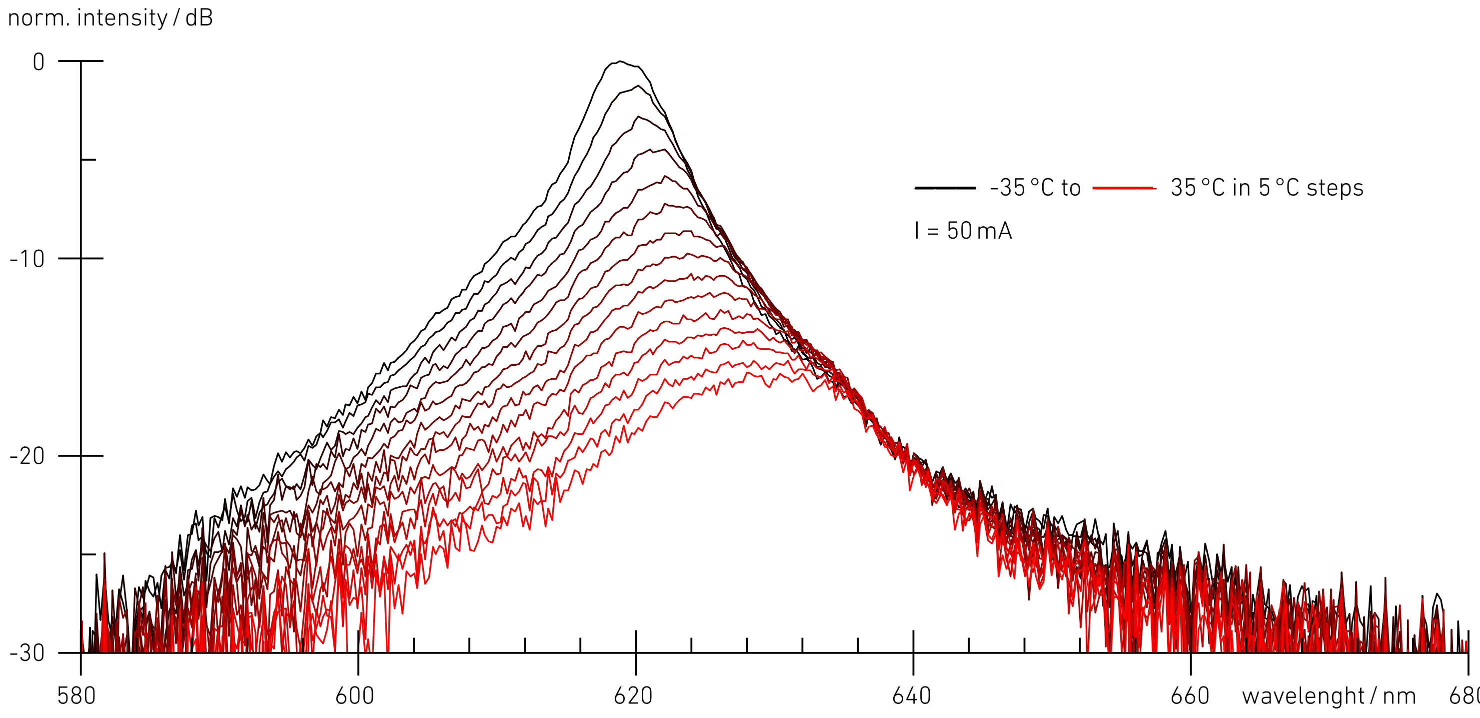

Fig. 2b) Amplified spontaneous emission curves of chip material for an external cavity diode laser aimed at the barium ion transition at 614 nm. The peak position shifts from 630 nm at +35 °C to 618 nm at -35 °C.

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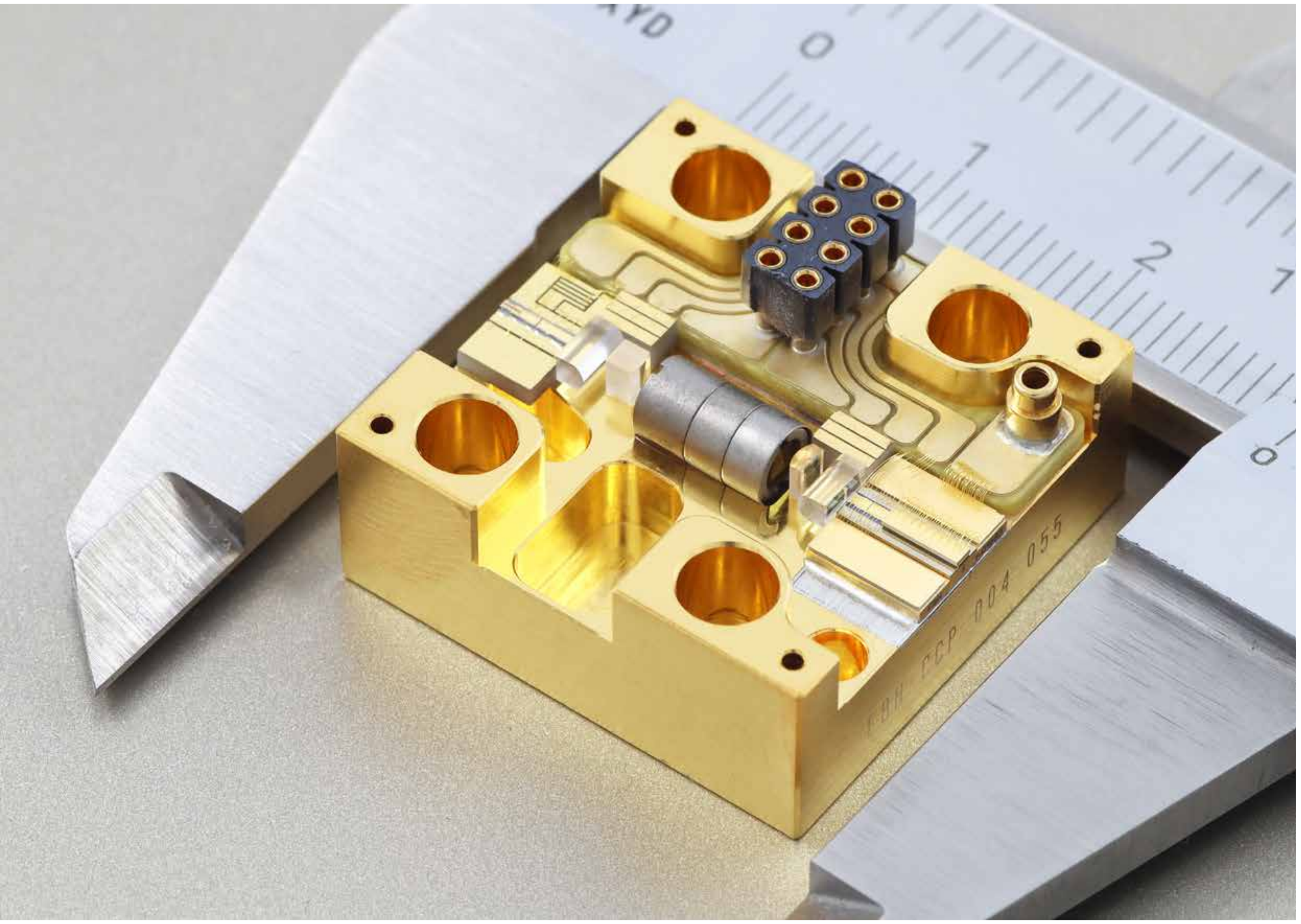
Collaborating for impact: Leibniz, FMD and more

Since its founding in 1992, the Ferdinand-Braun-Institut has been a member of the **Leibniz Association,** which brings together 96 independent institutes under one roof. Over the years, we have built strong and productive collaborations with several Leibniz institutes – partnerships that combine complementary strengths and drive forward scientific innovation. Among our closest partners are the Leibniz Institute for High Performance Microelectronics (IHP), the Leibniz Institute for Crystal Growth (IKZ), and the Weierstrass Institute for Applied Analysis and Stochastics (WIAS). Together, we contribute to nationally and EU-funded research projects and regularly deliver outstanding results. We also regularly succeed in the Leibniz Competition, which supports the association's strategic goals through ambitious, competitively funded projects. Most recently, our project proposal "Far-UVC compact laser module" – UV-COLA was awarded funding.

Within the Leibniz Association, we are actively involved in Leibniz Labs, strategic alliances, and interdisciplinary research networks. Since 2014, we have been part of the **Leibniz Research Alliance Health Technologies,** where we develop laser technologies for medical applications. This alliance brings together 14 institutes whose combined expertise spans photonics, medicine, microelectronics, materials science, economics, and applied mathematics – all working toward technological solutions for urgent healthcare challenges. To ensure the optimal design of laser systems and to model various application scenarios, we collaborate with partners in the **Leibniz Research Network for Mathematical Modeling and Simulation.** One example: the Weierstrass Institute (WIAS) has developed dedicated simulation tools for several of our projects. We are also one of 41 institutes contributing to the **Leibniz Lab Pandemic Preparedness,** which combines scientific and practical expertise from multiple disciplines. Its goal: to develop evidence-based strategies that enhance the long-term resilience of both science and society in the face of future pandemics.

We are also involved in a number of regional and national research networks. Among others, we are part of the **Research Fab Microelectronics Germany (FMD)** and contribute to the **APECS pilot line** established under the European Chips Act (see page 15). Within the **Innovation Campus for Electronics and Microsensorics in Cottbus – iCampμs,** we support regional structural transformation through research activities. This includes close collaboration – for example, through two Joint Labs – with the **Brandenburg University of Technology Cottbus - Senftenberg,** as well as participation in additional networks across the Lusatia region. Moreover, we are active in the **Optics and Photonics cluster** and a member of **OpTecBB,** the regional competence network for optical technologies and microsystems engineering.

The **Brandenburg University of Technology Cottbus-Senftenberg (BTU)** plays a key role in shaping structural transformation in Lusatia and, as a hub of technological innovation, creates new opportunities for skilled professionals and regional economic development. We are supporting this transition through our involvement in the iCampμs project. Our collaboration with BTU is built for the long term: in 2009, Matthias Rudolph (2nd from left) transitioned from FBH to take on the Chair of Radio Frequency and Microwave Technology – and has maintained close ties with us ever since through a joint lab. In 2024, Thomas Flisgen (right) was appointed Professor of Theoretical Electrical Engineering, also coming from FBH, and the second joint lab was soon established. This partnership is now being further deepened through a newly announced joint professorship in terahertz components and sensor technology.



A master oscillator power amplifier emitting in the blue spectral range is being developed in the UV-COLA project.

Far-UVC lasers for medical applications: UV-COLA selected in Leibniz Competition

Launched in 2025, the project aims to develop a compact far-UVC light source with a wavelength of 210 nm. The goal is to use this technology in the future as a portable medical device for application in the nasopharynx – the upper part of the throat – to neutralize pathogens directly at the site of infection. This region is known to be a preferred habitat for multidrug-resistant pathogens, which pose a serious threat to human health, as they are often no longer treatable with antibiotics. For disinfection directly on the skin, far-UVC light sources are ideally suited, as their radiation penetrates only minimally into the skin – making them potentially less harmful than other UV sources.

A light source of this kind, integrated into an endoscope and usable in clinical settings or even private households, would represent a major advance in disinfection and preventative healthcare. That is why our researchers are developing novel laser diodes that emit violet light. Their emission is amplified and then frequency-doubled into the far-UVC spectral range using a nonlinear crystal.

UV-COLA builds on our extensive experience in laser frequency doubling, as well as on prior collaborative projects with medical partners such as Charité – Universitätsmedizin Berlin. It expands and connects our previous activities under the Leibniz umbrella.

Nanosecond pulsed lasers are key components for applications such as automotive LiDAR. In autonomous driving, scanning LiDAR systems emit rapid laser pulses which are reflected by objects or road users and thus enable their detection. We have developed tailored laser sources specifically for these kinds of applications. They are based on laser bars with up to 48 emitters and a waveguide that contains one or more active areas with tunnel diodes. When combined with custom driver electronics – also developed at FBH – these sources deliver impressive performance: high pulse power, short optical pulses, high repetition rates, and excellent efficiency. That makes them a perfect fit for 3D object detection and a great example of FBH's bundled expertise.

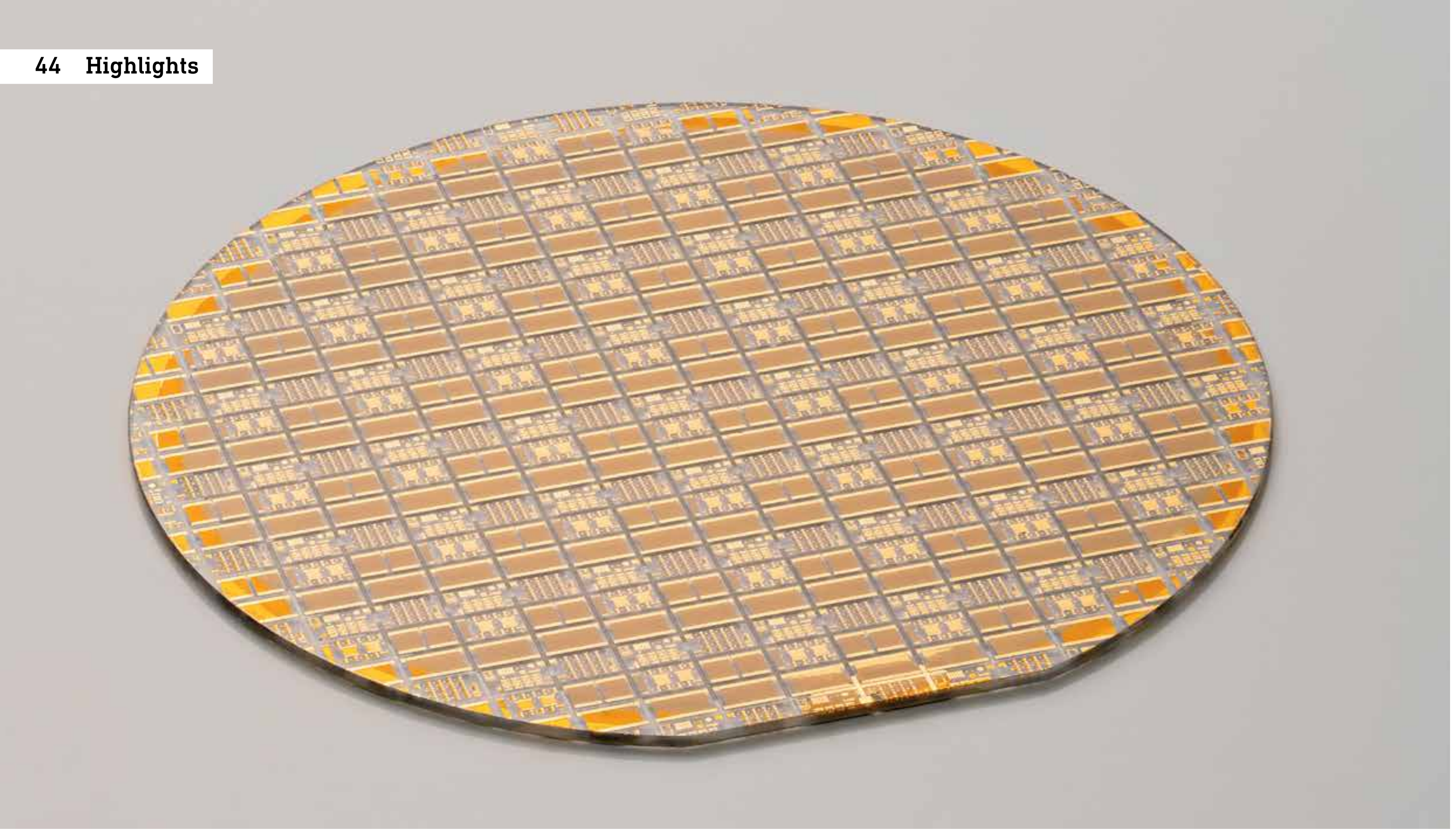
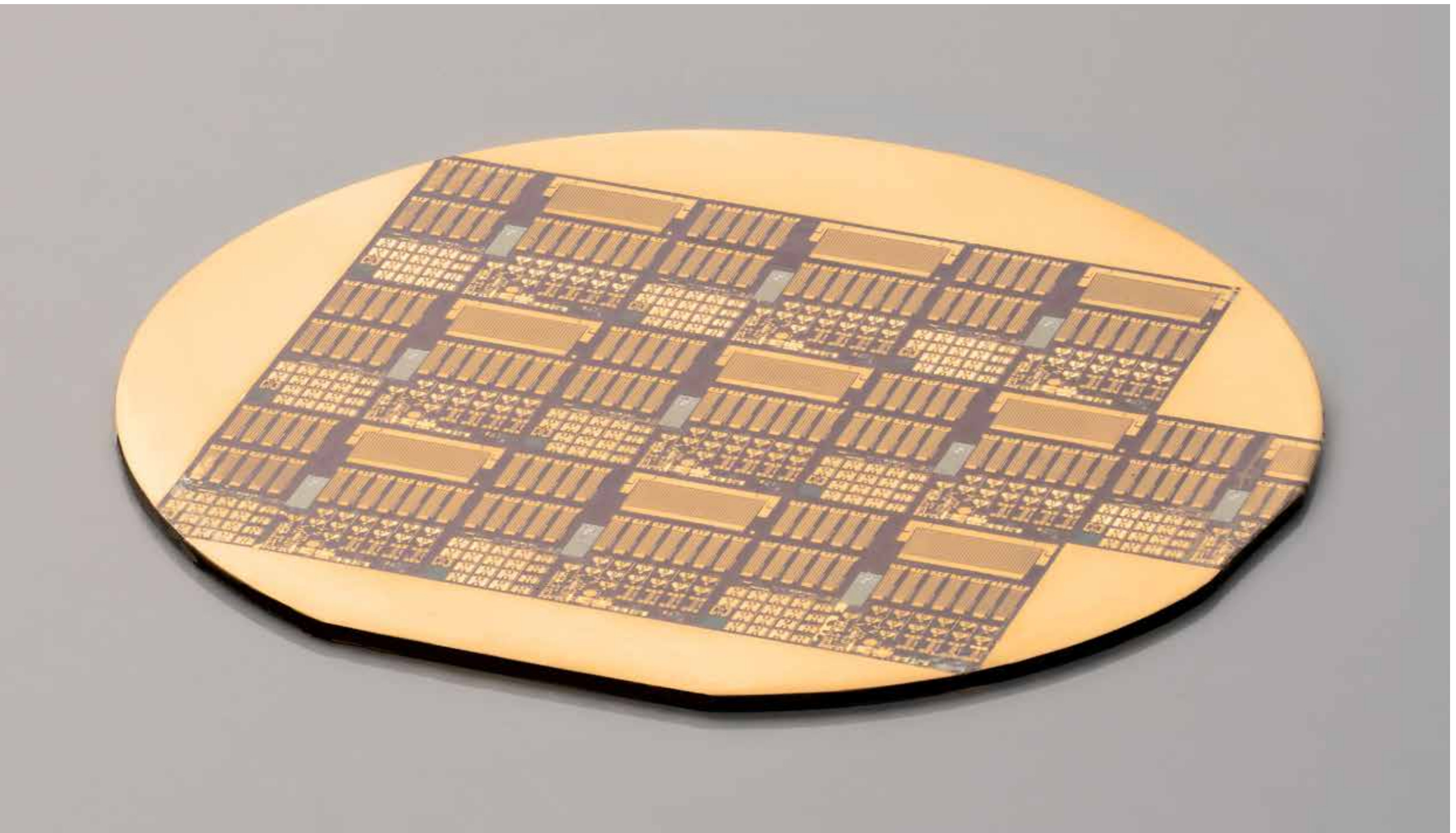


Fig. 1. Fully processed 2-inch gallium oxide wafer with 300 V / 10 A switching transistors.

Fig. 2. 1-inch aluminum nitride wafer with processed high-voltage transistors.



Power through partnership – collaborative research on future materials for power electronics

Ultra-wide bandgap semiconductor materials such as β-gallium oxide (β-Ga_2O_3) and aluminum nitride (AlN) are increasingly coming into focus worldwide. Thanks to their unique properties, these materials are a great fit for the power electronics of the future. They enable even more compact and efficient transistor devices, offering lower switching and conduction losses than current technologies. Recent developments and advances leave no doubt: the next generation of technology is taking shape here.

At FBH, we have recently succeeded in creating electrically active layers on a semi-insulating 2-inch β-Ga_2O_3 wafer using ion implantation (Fig. 1). The properties of these layers are comparable to those produced by epitaxial growth. Building on this result, we were able to fabricate lateral metal-oxide-semiconductor field-effect transistors (MOSFETs) with a channel width of 92 mm for the first time. These MOSFETs achieve an on-resistance well below 1 Ω, enabling currents of up to 18 A – a new record.

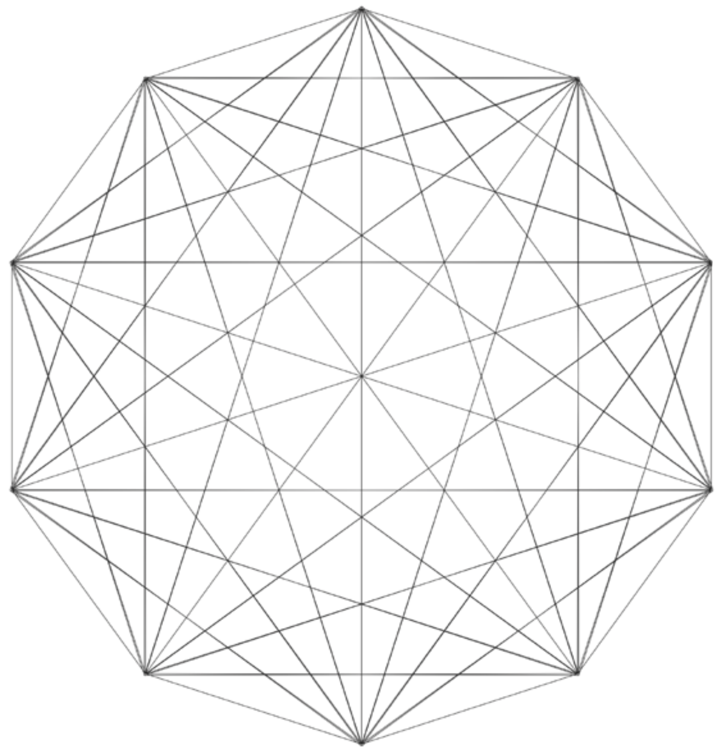
These promising results build on our long-standing collaboration with the Leibniz Institute for Crystal Growth (IKZ). Since 2015, we have been working together on Ga_2O_3-based devices for power electronic applications. While IKZ contributes its expertise in material development – particularly in bulk crystal growth and epitaxy for the production of β-Ga_2O_3 epitaxial wafers – we develop the corresponding processes for power electronic devices. As early as 2017, this collaboration led to the successful fabrication of our first lateral MOSFET.

Through continued material and process optimization, we set new benchmarks for β-Ga_2O_3 MOSFETs in 2019, demonstrating a record power density of 155 MW/cm^2. This milestone highlights our global leadership in β-Ga_2O_3 technology. Just one year later, we demonstrated switching transients at up to 400 V in hard-switching β-Ga_2O_3 MOSFETs – and we continue to hold the world record in this field to this day.

In parallel with the progress on lateral β-Ga_2O_3 power devices, we launched research activities in 2020 to develop vertical fin field-effect transistors (FinFETs). Thanks to our close and complementary collaboration with IKZ, we were once again able to achieve significant results. Together, we will continue to advance the development of both lateral and vertical β-Ga_2O_3 power devices. Our joint achievements in the field of β-Ga_2O_3 have been documented in more than ten peer-reviewed publications and numerous conference contributions. Research and development activities on this power semiconductor material have been supported by the German Federal Ministry of Education and Research (BMBF) through the projects OXIKON and GoNext.

We are now also collaborating on high-voltage transistors (Fig. 2) based on AlN – aiming at future power converters with even higher power density. Using AlN substrates provided by IKZ, we have realized transistors with a breakdown voltage of 1700 V and demonstrated switching transients at 600 V / 1 A.

ikz



Bridging basic research and application – how Joint Labs make it work

At the end of 2024, the tenth Joint Lab at FBH was launched – a collaborative format that links basic research at universities with our application-oriented R&D. In the new **Joint Lab Electromagnetic Fields**, we are working closely with Thomas Flisgen, Professor of Theoretical Electrical Engineering at Brandenburg University of Technology Cottbus-Senftenberg (BTU-CS). We look forward to continuing our close collaboration with him. Prior to his appointment at BTU-CS in fall 2024, Thomas Flisgen led the Electromagnetic Simulation Group at FBH for many years. The Joint Lab Electromagnetic Fields focuses on electromagnetic field calculations and the development of numerical analysis and simulation methods – with the aim of addressing questions that are closely tied to real-world applications. Key areas include modeling of components for radio-frequency technologies and field modeling for quantum technology systems.

Excellent news from the **Joint Lab Diamond Nanophotonics,** run in collaboration with Humboldt-Universität zu Berlin and led by Tim Schröder, Professor of Integrated Quantum Photonics since 2018: At the end of 2024, Tim Schröder was awarded a **Consolidator Grant** from the European Research Council (ERC) – one of the most prestigious honors in European research funding, awarded for outstanding scientific achievements. His research project HyperGraph (Multidimensional Hyperentangled Photon Graph States) will receive approximately € 2.5 million in funding over five years. Congratulations!

Find out more about our Joint Labs.

The colleagues from our **Human Resources Department** handle all personnel matters for the approximately 400 employees: from the recruiting of new specialists and staff development measures to controlling personnel-related procedures and processes. In 2024 alone, around 270 processes were handled in human resources, including hiring procedures, employee departures, and the projection of personnel costs. New training formats such as management seminars and training courses for employees were developed. Feedback was actively sought from employees through surveys, and the digitalization in the HR department was further advanced. The department's responsibilities also include occupational health management and business travel – with more than 320 requests and the subsequent accounting.

Patrick Scheele (r.) presents Ina Czyborra (l.) with a gift in the course of the Senate's summer tour.

Federal President Frank-Walter Steinmeier during his visit at BTU Cottbus-Senftenberg.

Delegation from the Federal Chancellery during their lab tour at FBH.

Special moments, visits, and international networking

For many years, FBH has been working closely with partners from both research and industry – locally, across Germany, and internationally. On the industry side, collaborations range from start-ups and SMEs to major global players. In 2024 alone, we carried out over 160 third-party funded projects and industrial research contracts together – a strong reflection of the breadth and strength of these partnerships.

There was also strong interest from the political sphere. In August 2024, we had the pleasure to welcome Berlin's Senator for Science, **Ina Czyborra,** along with State Secretary Henry Marx and other colleagues from the Senate Administration to our institute. During the summer tour organized by the **Senate Department for Science, Health and Care,** we had the fantastic opportunity to present our research at the Adlershof science and technology hub.

As part of his informational and outreach tour, **Federal President Frank-Walter Steinmeier** visited the Brandenburg University of Technology Cottbus-Senftenberg (BTU-CS) at its Cottbus campus in June 2024. He was accompanied by the Diplomatic Corps and Brandenburg's Minister President Dietmar Woidke. In the context of the **structural transformation initiative iCampµs** in Lusatia, we presented our novel portable Raman sensor system.

In December 2024, we had the exciting opportunity to exchange ideas with a delegation from **Division 621 (Fundamental Issues of Digital Policy) of the Federal Chancellery.** The discussion focused on current and future applications of quantum technologies, with a particular emphasis on quantum sensing. We were also able to give a direct demonstration of how such sensors are developed – right in our Joint Lab Integrated Quantum Sensors.

High-level working meeting at FBH, discussing the concept of a quantum-based gravity gradiometer.

l.t.r.: Patrick Scheele, Karin-Irene Eiermann, Arif Havas Oegroseno.

International networking

At the international level, the past year saw a variety of research stays, visits from guest scientists, and high-level meetings.

FBH has been engaged in **national and international collaborations in the field of space applications** for many years. Quantum experiments aboard missions like MAIUS rely on the robustness of our laser modules. Working meetings took place with partners including NASA's Jet Propulsion Laboratory (JPL) and the German Aerospace Center (DLR). As part of the German-American BECCAL collaboration, FBH is supplying 55 laser modules for experiments involving ultracold atoms and Bose-Einstein condensates on the International Space Station (ISS).

In June, we also hosted a working meeting with representatives from NASA, NASA's Jet Propulsion Laboratory (JPL), the Goddard Space Flight Center, Airbus Defence & Space, the University of Texas at Austin, the German Aerospace Center (DLR), and the GFZ German Research Centre for Geosciences. The focus of this meeting was the conceptual design of a **quantum-based gravity gradiometer** for potential use on an Earth observation satellite.

In the field of materials technology, we are collaborating on a joint project with the group led by Markus Pristovsek at Nagoya University's IMaSS institute, founded by 2014 Nobel Laureate Hiroshi Amano. The project focuses on the **growth of a new compound semiconductor:** aluminum phosphorus nitride (AlPN). Our activities are supported by the German Research Foundation (DFG), while the Nagoya team receives funding from the Japan Science and Technology Agency (JST) as part of the Advanced Technologies for Carbon-Neutral program. To support the collaboration, Markus Weyers, Head of Materials Technology at FBH, spent ten weeks on-site in Japan starting in early October 2024. The research stay aimed to deepen mutual understanding of each group's expertise, drive the joint project forward, and explore further opportunities for collaboration.

Researchers from our RF Power Lab have maintained a close exchange for several years with Gian Piero Gibiino and his group from the University of Bologna, focusing on **microwave measurement technology and circuit design** – both in terms of content and personnel. Two PhD candidates from Bologna have already conducted part of their doctoral research at our institute in connection with their degree programs in Italy. Another student came to FBH for his master's thesis – and stayed: in April 2024, he began his PhD at our institute. Results from this Berlin-Bologna collaboration have been presented at conferences such as European Microwave Week, and shared in scientific publications, workshops, and short courses. The partnership is set to continue with new activities underway.

In 2024, we welcomed several delegations from Asia. In June, we engaged in dialogue with representatives from Indonesian research institutions, universities, ministries, and members of the embassy and consulate, to explore opportunities for **collaboration in semiconductor technology and in academic exchange** – from bachelor's to doctoral level. A memorandum of understanding, signed with the Government of the Republic of Indonesia and represented by Ambassador Arif Havas Oegroseno, highlights the shared commitment to building a close and lasting partnership.

Neysha Lobo Ploch, head of FBH's Prototype Engineering Lab, during her presentation.

Adlershof campaign motif supporting tolerance and diversity.

FBH teams participating in the 2024 Adlershof company relay race.

In September 2024, we welcomed a delegation from the Institute of Nano Optoelectronics Research and Technology (INOR) at Universiti Sains Malaysia. The visit focused on exploring a potential **collaboration in the field of group III-nitride epitaxy.** Prior to this, Malaysian professor Norzaini Zainal had already completed several multi-month research stays at FBH, supported by a fellowship from the Alexander von Humboldt Foundation.

A delegation led by Taiwan's Minister of Science, Wu Cheng-wen, also visited the German Federal Ministry of Education and Research in search of potential avenues for collaboration. Patrick Scheele took part in the September 2024 meeting with then Federal Research Minister Bettina Stark-Watzinger, where topics included **cooperation in the field of semiconductors,** among others.

We have been collaborating with Taiwan for several years on the development of **power electronics and microwave devices based on gallium nitride** (GaN). Most recently, Joachim Würfl from FBH traveled to the East Asian island as part of the DAAD – NSTC (National Science and Technology Council) exchange project Kaleo (High power Ka-band transceiver module with improved heat management using AlN-based interposer technology for LEO applications). There, he gave two tutorials on wide-bandgap semiconductor devices at National Yang Ming Chiao Tung University (NYCU).

In December 2024, we welcomed a delegation from Steinbeis GmbH & Co. KG for Technology Transfer, along with rectors and research managers from the universities of Gdańsk, Malta, and Split, as well as from the Central European Research Infrastructure Consortium. The visit focused on our Prototype Engineering Lab, which plays a key role in accelerating the **transfer of excellent research results into market-oriented products.**

...and here's what else is worth sharing

We are especially proud to have received the **TOTAL E-QUALITY award** for the sixth time – recognizing our commitment to a personnel and organizational policy that promotes equal opportunities. A particular highlight: despite declining applicant numbers, the proportion of female professionals and leaders at our institute has continued to grow – especially in leadership roles.

Because lived diversity matters to us, we are supporting the Adlershof Technology Park's location campaign, launched in July 2024 under the motto: "35,000 people, 35,000 stories. One goal: crafting future from diverse perspectives". The campaign promotes **tolerance and diversity.** We have also joined the #Zusammenland initiative, alongside around 700 companies, foundations, associations, universities, and NGOs. The campaign, launched by leading German media, aims to take a united stand for diversity and democracy.

There were also great **chances to connect** – whether in a relaxed atmosphere at our summer party or with a bit of competitive spirit at the 12th Adlershof company relay race, where six teams from FBH hit the track in 2024.

Research – results & developments

FBH's four research areas

The Ferdinand-Braun-Institut organizes its R & D activities within Labs and Departments in four research areas:

III-V Technology

The research area III-V Technology forms the technological backbone of our institute, combining extensive expertise with a state-of-the-art cleanroom and lab infrastructure. Our competencies range from epitaxy of nitrides and arsenides to processing of a wide variety of devices and materials. Devices are fully mounted and packaged, ready for seamless integration into modules and systems. All developments are supported by thorough analysis and rigorous reliability testing. This broad skill set underpins our advancements in the fields of photonics, III-V electronics, and integrated quantum technologies.

Find out more about our developments in this field.

Photonics

Within our photonics research area, we cover a broad range of diode laser and light-emitting diode (LED) developments that are tailored precisely to fit individual requirements. The portfolio ranges from research into fundamental performance limits to the development of ready-to-use modules, prototypes, and systems. It comprises gallium-arsenide-based diode lasers (620 – 1180 nm) and modules, emitting from the near-infrared to the visible spectral range. We also realize modules that use these devices and convert their emission into the ultraviolet (UV) spectral range. Moreover, we develop laser diodes and LEDs based on gallium nitride with direct emission in the UV and violet spectral range. Current results can be found starting on page 61.

Find out more about our developments in this field.

Integrated Quantum Technology

Within our research area Integrated Quantum Technology, we carry out R&D activities to bring quantum technology (QT) from proof-of-concept demonstrations in a quantum optics lab to industry. This paves the way for the second quantum revolution so that QT can unfold its potential for tomorrow's society. Applications include quantum sensing, quantum communication, and quantum computing, with usage in both laboratory settings and space environments. Current results can be found starting on page 73.

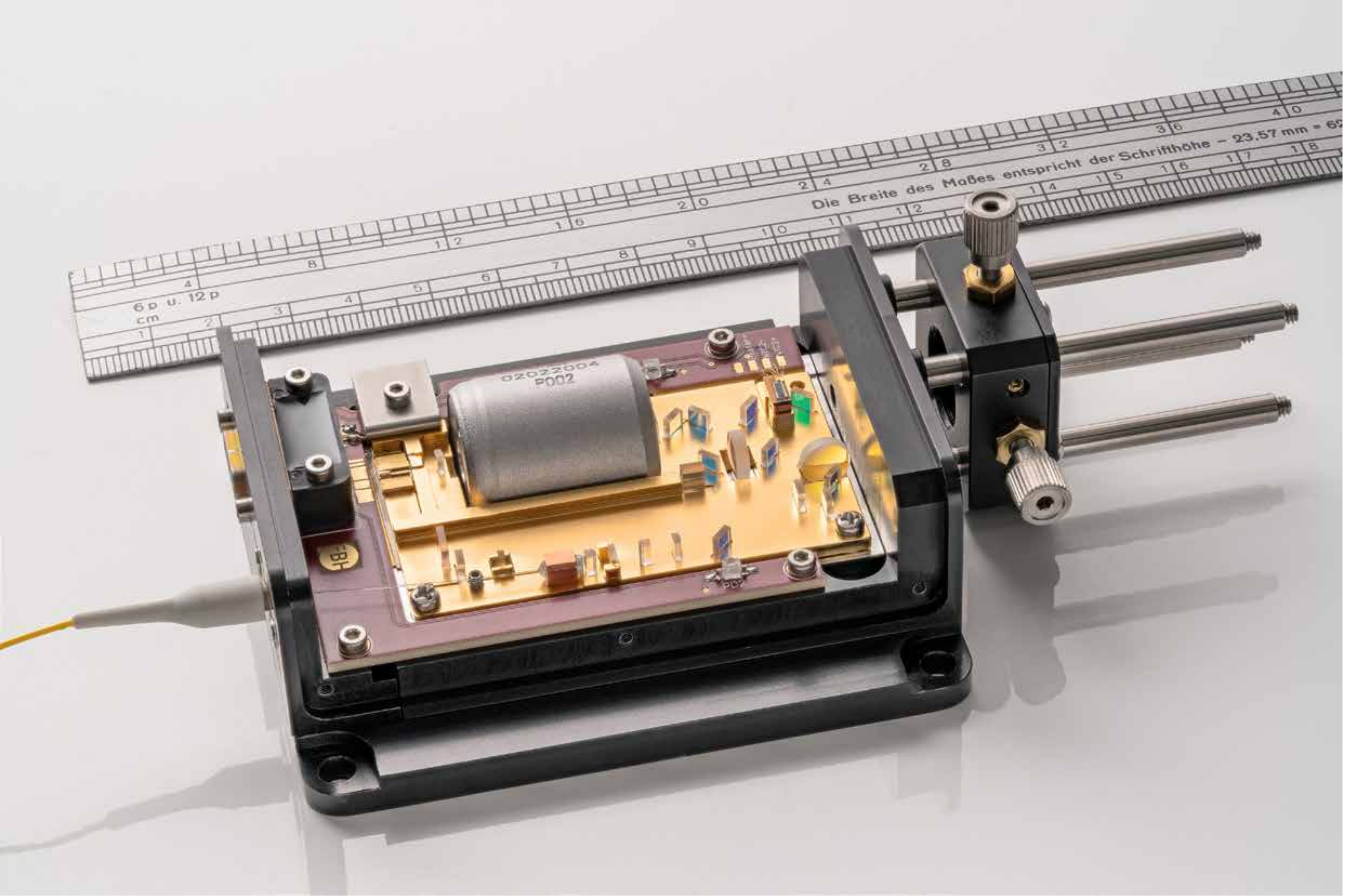
Find out more about our developments in this field.

III-V Electronics

The overall target of FBH's research activities in the field of III-V electronics is to push the limits of electronic devices in terms of efficient power generation at high frequencies, high voltages, and short switching times. The frequency spectrum ranges from high-speed power electronics through the mobile communication bands in the lower GHz range to sub-millimeter waves. This way, we offer new solutions for the steadily growing needs of wireless communications (5G, 6G, ...), radar sensing, as well as efficient power converters. Energy efficiency to reduce the carbon footprint is a cross-sectional goal for these developments. Current results can be found starting on page 85.

Find out more about our developments in this field.

Photonics



Quantum light module with internal pump laser, optical isolator, non-linear SPDC crystal, a folded reference path, a large number of micro-optics and externally attached MIR optics as well as an optical fiber to the NIR spectrometer.

Quantum light modules for advanced sensing systems

The Ferdinand-Braun-Institut is at the forefront of developing miniaturized quantum light modules designed for seamless integration with mid-infrared (MIR) hyperspectral imaging and optical coherence tomography systems. These modules harness the unique properties of entangled photons to transfer MIR information to the near-infrared (NIR) domain, enabling measurements with conventional silicon (Si)-based spectrometers. This concept allows for rapid and efficient sensing applications, for in vitro cancer diagnostics, and the detection of micro-plastics in field studies.

In our modules, intense pump laser light is precisely directed onto a periodically poled potassium titanyl phosphate (PPKTP) crystal, generating pairs of entangled photons by spontaneous parametric down-conversion (SPDC). This process produces MIR photons spanning a range from 3.3 to 10 µm and NIR photons with a detection range from 780 to 930 nm. The entangled photons, together with the residual pump light, are emitted collinearly. Subsequently, a dichroic mirror separates the MIR photons, directing them toward the sample for interaction, while the NIR photons and pump light remain within the module along a reference path.

After interacting with the sample, the backscattered MIR light recombines with the reference beam at the PPKTP crystal. Here, they interfere in a manner analogously to a Michelson interferometer. Owing to the correlation of the photon pairs, information from the MIR domain is effectively transferred to the NIR photons. These NIR photons are then detected using spectrometers with conventional Si-based detectors, while the MIR photons remain undetected during the process.

A critical requirement for initiating SPDC is a high-power ($P \geq 1$ W), highly coherent ($l_c \geq 1$ m) laser with a specific emission wavelength. In response to this need, we have successfully developed new single-mode distributed Bragg reflector (DBR) tapered diode lasers emitting at 660, 720, and 1170 nm. These innovative laser sources, previously unavailable, are vital for our quantum light generation process.

Integrating a sophisticated interferometric setup within a compact module is not only a remarkable engineering achievement but also paves the way for novel applications. The enhanced miniaturization and performance of these quantum light modules offer immense potential for advancing technologies in biomedical imaging, environmental sensing, and other fields that require precise quantum-enhanced detection. Additionally, the diode laser pump source can be seamlessly integrated into the interferometric module. Overall, the novel laser sources and compact design of our quantum light modules represent a major technological breakthrough, setting new standards in the field of quantum optics and imaging.

This work is supported by the German Federal Ministry of Education and Research (BMBF) within the projects QUIN (FKZ 13N15403), Sim-QPla (FKZ 13N15943), QEED (FKZ 13N16381).

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Fig. 1. Raman probe of the portable SERDS sensor system directly immersed into a milk sample.

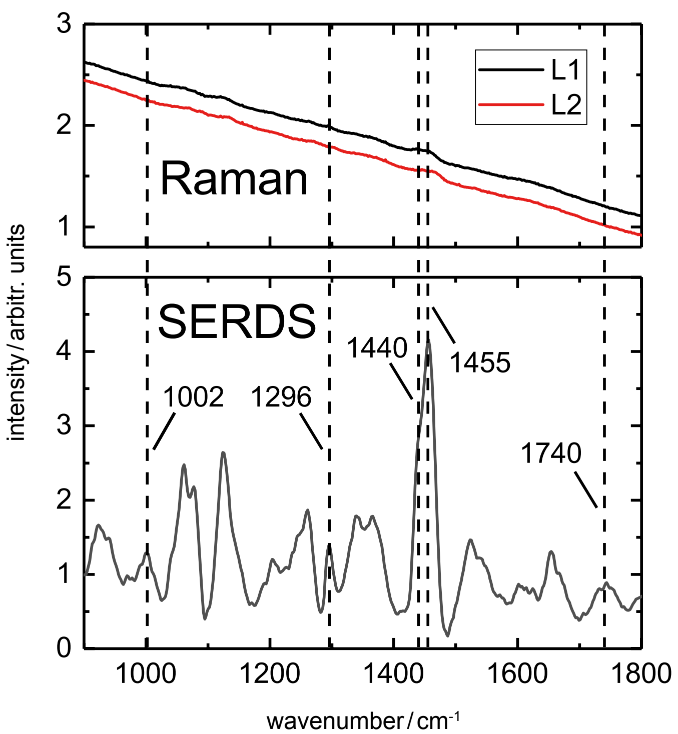

Fig. 2. Averaged Raman spectra of blueberry yoghurt with 2.8 g/100 g fat content excited with L1 and L2 (t) and corresponding SERDS spectrum (b), P_{ex} = 25 mW, t = 30 x 1 s.

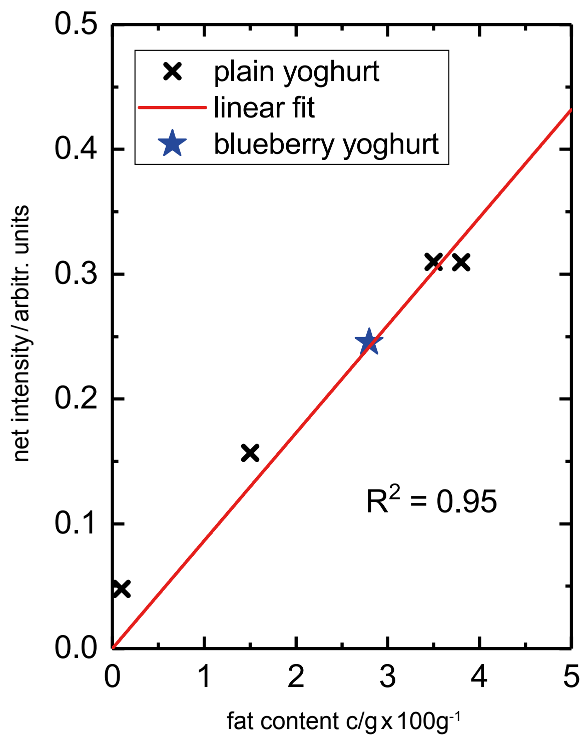

Fig. 3. Net SERDS intensities derived from the Raman signal at 1740 cm^{-1} for plain and blueberry yoghurt samples versus fat content as given by the manufacturer.

Analyzing dairy products with diode laser-based Raman spectroscopy

Milk and dairy products contribute significantly to global nutrition and trade. Ensuring high product quality, safety, and efficient production is critical for food control. Optical sensors based on Raman spectroscopy are well-established analytical tools, utilizing Raman signals as molecular fingerprints for both qualitative and quantitative analysis. However, the weak Raman signals are often masked by background signals like fluorescence and ambient light, especially in on-site investigations. Moreover, optically turbid samples, such as milk and other dairy products, complicate the access for optical sensors.

Shifted excitation Raman difference spectroscopy (SERDS) efficiently separates Raman signals from background signals and can be used as physical approach to overcome these drawbacks. For SERDS, two slightly shifted laser lines are used to successively generate two corresponding Raman spectra. While the Raman lines follow the wavelength shift, background signals remain unchanged. Subtracting these spectra separates the desired Raman signals for subsequent evaluation.

As excitation light sources for SERDS, we have developed and fabricated dual-wavelength diode lasers emitting at 785 nm. These one-chip devices provide narrowband laser light over the entire operating range with a spectral distance between laser line L1 and L2 of about 0.6 nm (10 cm^{-1}) for SERDS and an optical power up to 150 mW. Their compact size and low power consumption enable an integration into portable, battery-driven sensor systems. We have successfully demonstrated the capability of such in-house realized sensor systems with integrated dual-wavelength diode lasers for laboratory and on-site SERDS investigations.

To evaluate potential application fields, we have conducted exemplary pilot Raman experiments on bovine milk and yoghurt samples. For this purpose, we purchased milk and plain yoghurt samples with different fat content from supermarkets. Additionally, fruit yoghurts (e.g. blueberry) were selected for the investigations. These samples contain pigments in the fruit content, which lead to laser-induced fluorescence and thus further complicate Raman measurements. In our experiments, we immersed the probe head directly into the sample without any prior sample preparation, as illustrated exemplarily in Fig. 1.

Fig. 2 exemplarily shows two Raman spectra of blueberry yoghurt with 2.8 g/100 g fat content. This sample was excited with 25 mW excitation power and an exposure time of 1 s alternately from both laser lines. The Raman spectra exhibit an average of 30 accumulations and are vertically offset for clarity. A huge background signal from laser-induced fluorescence masks the Raman signals, preventing reliable analysis. SERDS efficiently separates the Raman from background signals and thus enables a clear assignment of protein, carbohydrate, and fat signals. Their spectral positions correspond to literature values and are indicated by dashed lines in Fig. 2 (bottom).

We also exemplarily investigated plain and blueberry yoghurt samples with respect to their fat content. Fig. 3 shows the net SERDS signal intensity at 1740 cm^{-1} (C=O stretch) versus fat content as given by the manufacturer for the different yoghurt samples. A linear fit for the plain yoghurt values reveal a linear correlation with an estimated limit-of-detection of 0.6 g/100 g fat content using the 3-sigma criterion. The value of the blueberry yoghurt fat content with its significantly higher proportion of fluorescence background signal also follows the linear correlation.

These results demonstrate the potential of SERDS for both qualitative and quantitative analysis of dairy products. The method thus could serve as a valuable analytical tool for the dairy industry, spanning the entire supply chain from farm to fridge.

Activities are financially supported by the German Federal Ministry of Education and Research (BMBF) within the projects iCampμs (16ES1132, 16ME0420K), OASYS (16ME0871), and within the Research Fab Microelectronics Germany (FMD) framework (16FMD02).

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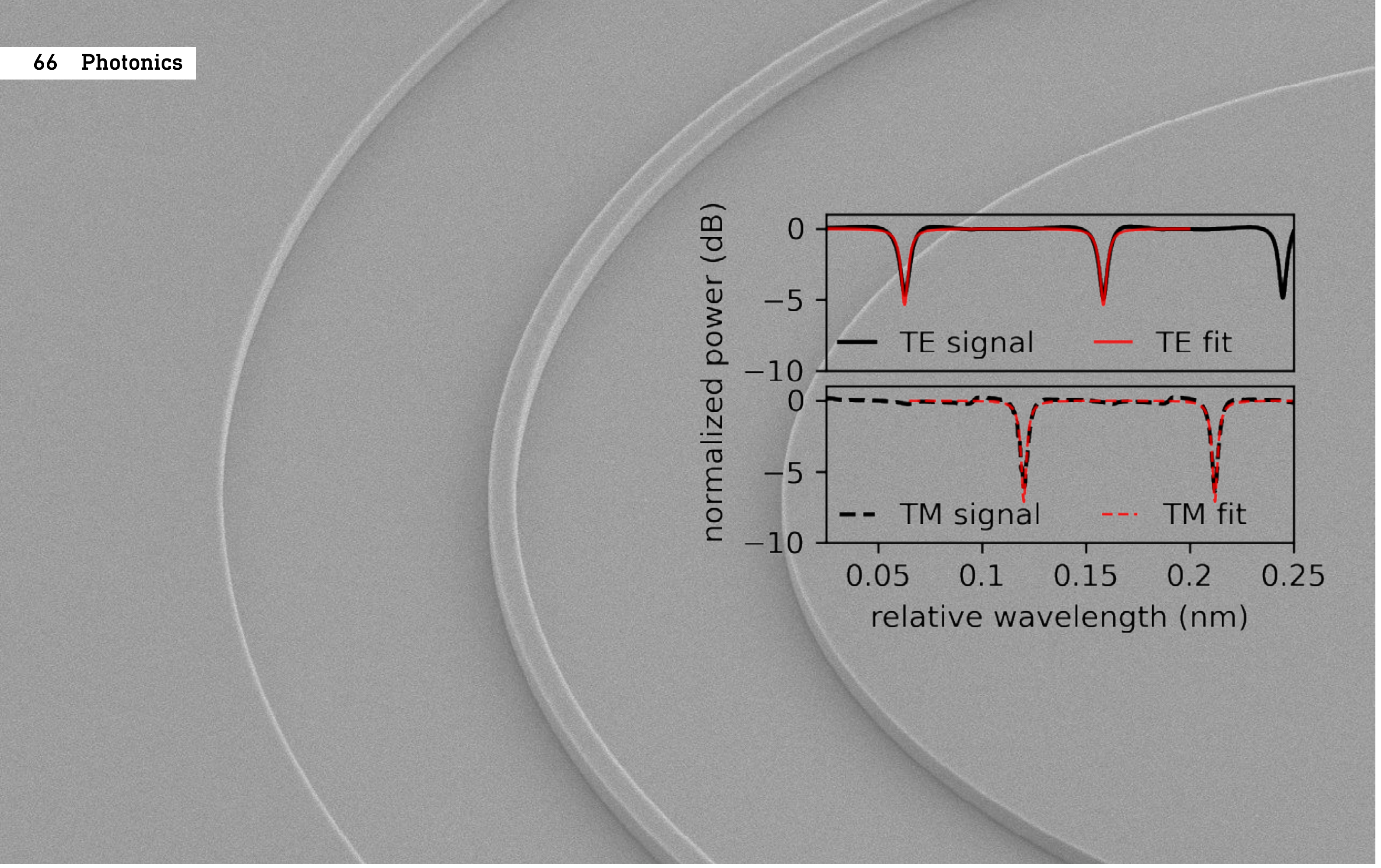

Fig. 1. Scanning electron microscope image of a ring resonator segment formed by a deep-etched ridge waveguide. The embedded graph shows the resonances of the ring resonator for TE and TM polarized light at wavelengths relative to 1064 nm.

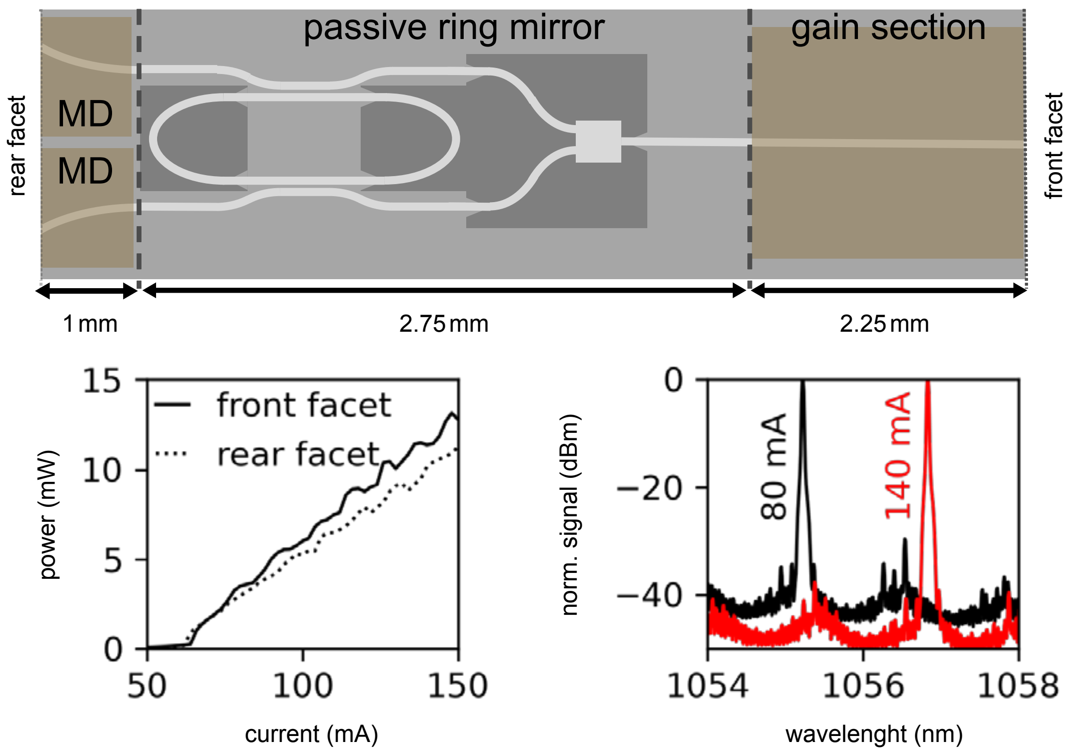

Fig. 2. Top: Schematic representation of the realized ring-resonator-coupled (RRC) lasers. Bottom: Selected experimental results of an RRC laser, including its power-current characteristics and optical spectra.

Novel GaAs-based PIC laser sources for quantum, spectroscopic, and biosensing applications

The most established monolithic photonic integrated circuit (PIC) platforms are based on indium phosphide (InP) and commonly used in telecommunication systems. However, various applications in quantum photonics, biosensing, and spectroscopy rely on wavelengths that can be achieved with quantum well devices based on gallium arsenide (GaAs), enabling wavelengths between 630 nm and 1180 nm.

To address the limitations in system complexity of devices using standard GaAs laser technology, which are restricted to straight waveguides and large bend radii, we are actively working on establishing a monolithic GaAs PIC technology. Currently, our efforts focus on an emission wavelength of around 1064 nm, which is suitable for optical coherence tomography and LiDAR applications. The foundation for our PIC platform lies in FBH's excellent III-V technology and years of experience in spatially selective quantum well removal and two-step epitaxial growth. This enables the formation of PICs which can provide optical gain and passive waveguides on the same chip. In addition, the platform supports shallow and deep-etched waveguides, enabling both low loss propagation with losses below 2 dB/cm and tight waveguide bends. Another key advantage of the presented platform is its full compatibility with the established GaAs laser facet technology, including the application of high-quality facet coatings.

Additionally, the deep etched waveguides supported by the platform enable to realize high-Q ring resonators. We have characterized the quality factor to $Q > 10^5$, which is higher than for established InP PIC platforms. These ring resonators can be used as basis for monolithically integrated widely tunable low-linewidth ring-resonator-coupled (RRC) lasers. We demonstrated their capability by fabricating RRC lasers, resulting in one-sided output powers of up to 14 mW and single-mode operation with 40 dB side-mode suppression.

In addition to our activities on monolithic GaAs PICs, we are also working intensively on the heterogeneous integration of GaAs-based chiplets on passive waveguide platforms such as low-loss silicon nitride (SiN) PICs. Our long-standing experience in simulation, design, and manufacture of high-power GaAs lasers helps us in this endeavor. The integration approach we focus on is micro-transfer printing. This process relies on sub-micron precision transfer of laser or amplifier coupons from a III-V source wafer to a target wafer containing the passive waveguide circuit. The approach offers several advantages compared to monolithic PICs, including enhanced flexibility, efficient utilization of the III-V wafer space, and scalability. It opens the door to the next generation of fully integrated GaAs-based laser sources with improved functionality and performance. Together with project partners, we have already demonstrated 10 dB of light amplification at 921 nm by transfer-printed GaAs-based amplifiers, which were evanescently coupled to an a-Si:H waveguide.

Part of these activities received funding from the VISSION project within the Horizon Europe program of the European Union (grant agreement ID: 101070622).

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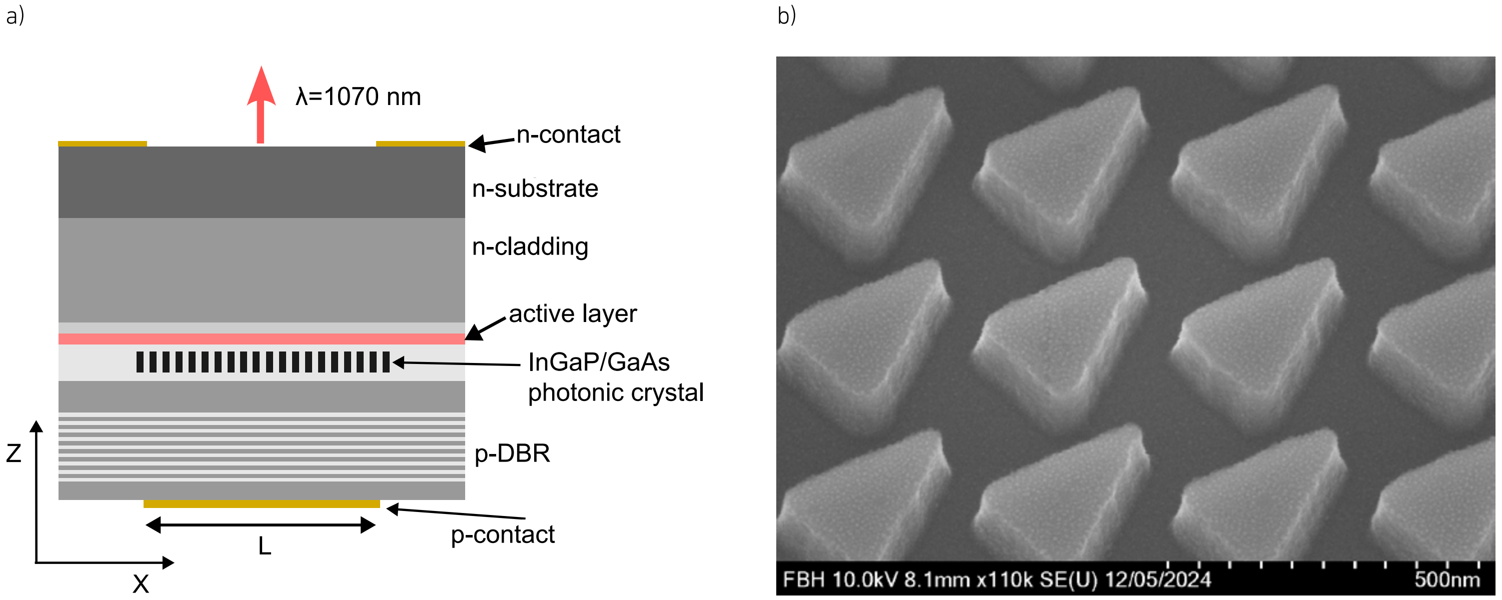

Fig. 1. Schematic depiction of a) the final PCSEL device structure, and b) scanning electron microscope image of a part of the photonic crystal after etching.

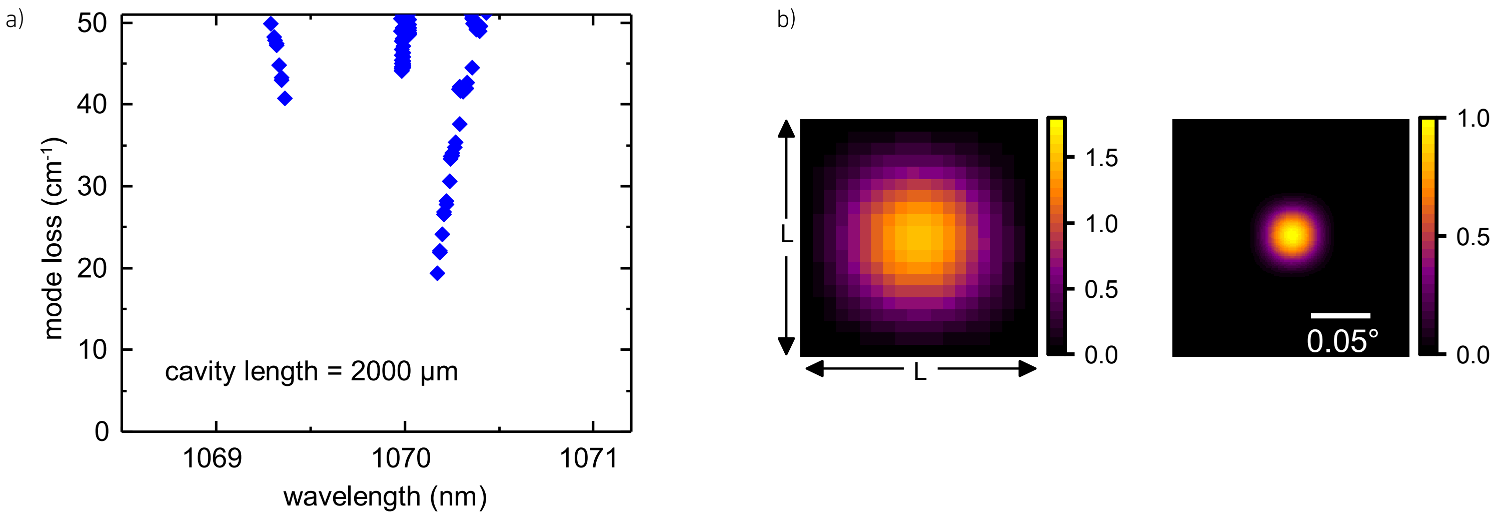

Fig. 2. Plots of a) the mode spectrum of the device, mode loss as a function of wavelength, and b) the near- and far-field distributions of lowest loss fundamental mode.

Design and technology for all-semiconductor photonic crystal surface emitting lasers

High-power diode lasers are crucial components for use in material processing, medicine, automotive applications, and more, due to their ability to supply optical power at high conversion efficiency. However, these lasers often suffer from low beam quality at high power levels, operating with low brightness compared to fiber and solid-state lasers. Recent advances in GaAs-based photonic crystal surface emitting lasers (PCSELs) have addressed this challenge by using a two-dimensional photonic crystal in the laser structure. This enables scaling of output power while maintaining emission in a narrow, circular beam.

Until now, all reported high-power PCSELs have utilized a high-index-contrast photonic crystal (PC) structure, where air-voids embedded in the semiconductor structure are realized through two-step epitaxial growth. Such PCs provide very strong two-dimensional optical feedback and successfully pin these large-area structures in a single coherent optical mode, for vertical emission via the substrate. However, this approach comes at the cost of reduced power conversion efficiency.

Currently, our scientists are developing an alternative scheme for realizing such large-area, high-power PCSELs: a so-called all-semiconductor design. Instead of using air-voids, this approach realizes contrast in the photonic crystal by combining two different semiconductor materials. The method is similar to the one used in semiconductor laser gratings in edge emitters, e. g., in distributed feedback lasers, where such gratings enable devices to be realized with very low loss and high conversion efficiency. However, until now it has been claimed that PCs based on such low-index-contrast gratings are not suitable for use in PCSELs due to the need for strong coupling in the photonic crystal to realize 2D coherence and surface emission.

In cooperation with the Weierstrass Institute in Berlin, we have developed efficient simulations tools that allow the rapid computation of the optical modes of large-area (many cm^2) all-semiconductor PCSELs. The tools enabled a new design of the PC unit cell to be developed based on an innovative stretched isosceles triangle (SIT) approach with index contrast in the PC supplied by InGaP/GaAs materials. Even for the cavity lengths of L = 2 mm, for a L x L square cavity PCSEL, a sufficiently large spacing of the mode losses as well as circular near field and narrow far field distributions could be obtained. A corresponding patent application has been filed.

In parallel, our team at FBH has started developing the fabrication process to realize PCSELs. The lattice constant of the PC is 320 nm, designed for an emission wavelength around 1070 nm. The most critical technological step is to integrate the PC layer near the active layer. The fabrication starts with a first epitaxial growth with metal-organic vapor phase epitaxy (MOVPE) on a GaAs substrate ending with an InGaP layer. The PCs are introduced into the InGaP through (i) e-beam lithography, (ii) reactive ion etching followed by (iii) MOVPE overgrowth to complete the epitaxial layer structure of the PCSEL. We have demonstrated strong technological progress, with an etching approach identified that allows PCs using a SIT design to be realized with low damage to the active region. The technological results achieved until now pave the way for the fabrication of PCSELs with all-semiconductor integrated PCs with a SIT unit cell. Both design and technology provide a new and exciting route toward realizing highly efficient, high-power, and easily manufacturable PCSELs.

This work was performed in the frame of the project PCSELence (K487/2022), funded by the German Leibniz Association.

Publications

[1] M. Radziunas, E. Kuhn, H. Wenzel, B. King, P. Crump, "Optical Mode Calculation in Large-Area Photonic Crystal Surface-Emitting Lasers", IEEE Photonics J., vol. 16, 1–9 (2024).

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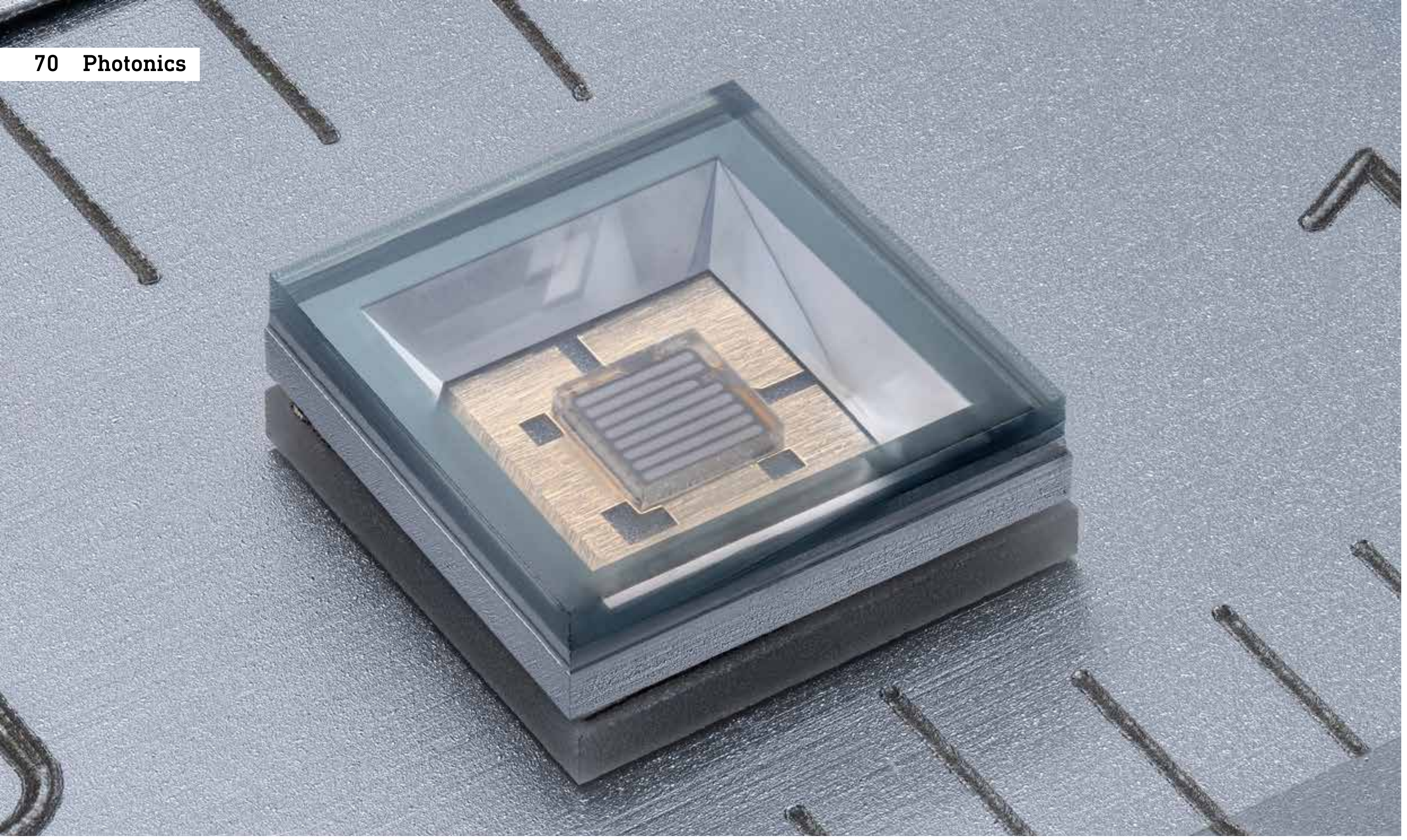

Fig. 1. Far-UVC LED chip in a hermetic package with reflecting sidewalls. The package has a footprint of 3.5 mm x 3.5 mm.

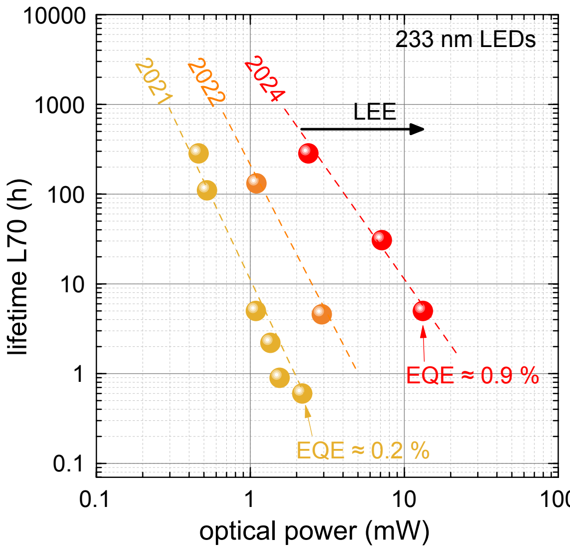

Fig. 2. L70 lifetime and emission power of 233 nm LEDs from different development periods. The L70 lifetime corresponds to the operation time after which the emission power decreases to 70 % of the initial value.

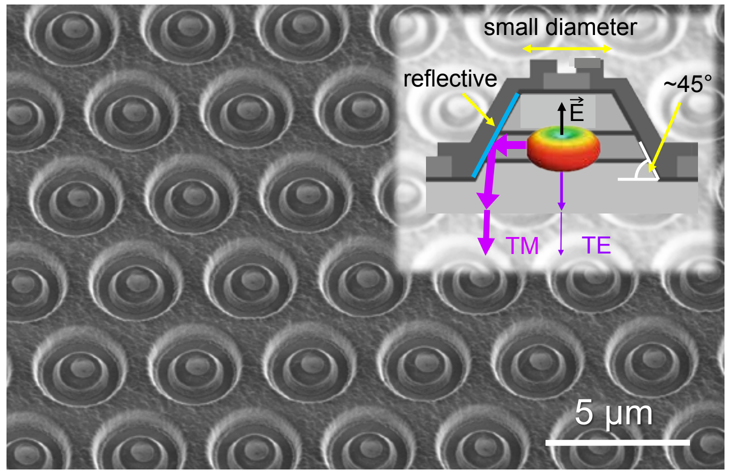

Fig. 3. Hexagonal array of micro-LEDs with 1.5 µm diameter, emitting at 234 nm, for enhanced light extraction of the in-plane emitted TM polarized photons.

Far-UVC radiation in everyday applications: LEDs with improved performance and reliability

Far-UVC LEDs with very short wavelengths < 235 nm enable new applications and offer a compact alternative to traditional gas discharge lamps. They can be used, for example, to measure the concentration of nitrogen oxide as the gas exhibits characteristic absorption lines within this wavelength range. In addition, far-UVC radiation has the ability to inactivate pathogens (e.g. multi-resistant germs) while not penetrating deep into the skin. These LEDs could therefore be used for skin-friendly disinfection directly on humans. Furthermore, fast-switching far-UVC LEDs could be used for short-range tap-proof non-line-of-sight communication.

However, the emission power of far-UVC LEDs remains insufficient for many of these applications, and lifetimes need to be increased. Performance improvements are challenging as optical power and lifetime often change in opposite directions when the LED chip design is varied (Fig. 2). Increasing the efficiency usually comes at the cost of reliability. The same can be observed when operating LEDs at different currents. Small operating currents lead to long lifetimes but also to low emission powers.

In recent years, we have made considerable progress in overcoming existing performance limitations. Our investigations on degradation mechanisms revealed that charge carrier density and defect density in the semiconductor are key factors influencing lifetime. To address this, we optimized the semiconductor layer design, e.g., by increasing the number of quantum wells [3]. Additionally, modifications to the chip layout resulted in a low and more uniform current density. We also varied the AlN/sapphire template technology used for epitaxial growth of the LED structure to influence defect density in the material as well as the polarization and thus the extraction of the emitted light [4]. As a result, we have increased the emission power tenfold over the past three years without compromising lifetime.

Another way to improve the output power while maintaining device durability is to enhance the light extraction efficiency (LEE), the ratio between photons extracted from the chip and photons generated inside of it, by microstructuring. The LEE in far-UVC-LEDs is comparatively low, since many generated photons are emitted in the chip plane, leading to a high probability for internal total reflection and absorption in the chip. We have successfully applied a micro-pixel approach that consists of an array of densely packed LED pixels with small diameters and inclined reflective sidewalls (Fig. 3) [1]. In this way, the photons emitted in the chip plane can be redirected to the back of the chip via the side walls and then be extracted through the transparent sapphire substrate. To achieve a significant effect, the micro-LEDs need to have very small diameters of just 1.5 µm, corresponding to around 50,000 micro-LEDs on a 1 mm x 1 mm chip. Furthermore, the sidewall angle needs to be close to 45°. This requires a very high accuracy in the chip fabrication, especially in photo lithography, plasma etching, and metal deposition. We have successfully produced micro-LED chips emitting at 234 nm and demonstrated an LEE improvement by the factor of two to three. The same enhancement was achieved in the external quantum efficiency (EQE) with a record peak EQE of 2.7 % for 234 nm LEDs. The chips were operated up to a maximum current of 200 mA and showed an emission power of 18 mW [2].

This work was partially supported by the German Federal Ministry of Education and Research (BMBF) through the CORSA project under contract 03COV10E and by the European Union/Investitionsbank Berlin (IBB) through the Pro FIT project UV-Multi under contract 10203290.

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[1] Jens Rass, "UV LEDs go micro", Compound Semiconductor, vol. 30, no. 3, 22-25 (2024).

[2] J. Rass, S. Hagedorn, H. K. Cho, T. Kolbe, M. Guttmann, S. Breuer, J. Ruschel, S. Einfeldt, "Influence of the AlN-sapphire template on the optical polarization and efficiency of AlGaN-based far-UVC micro LED arrays", Semicond. Sci. Technol., vol. 40, no. 1, 015019 (2025).

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Integrated Quantum Technology

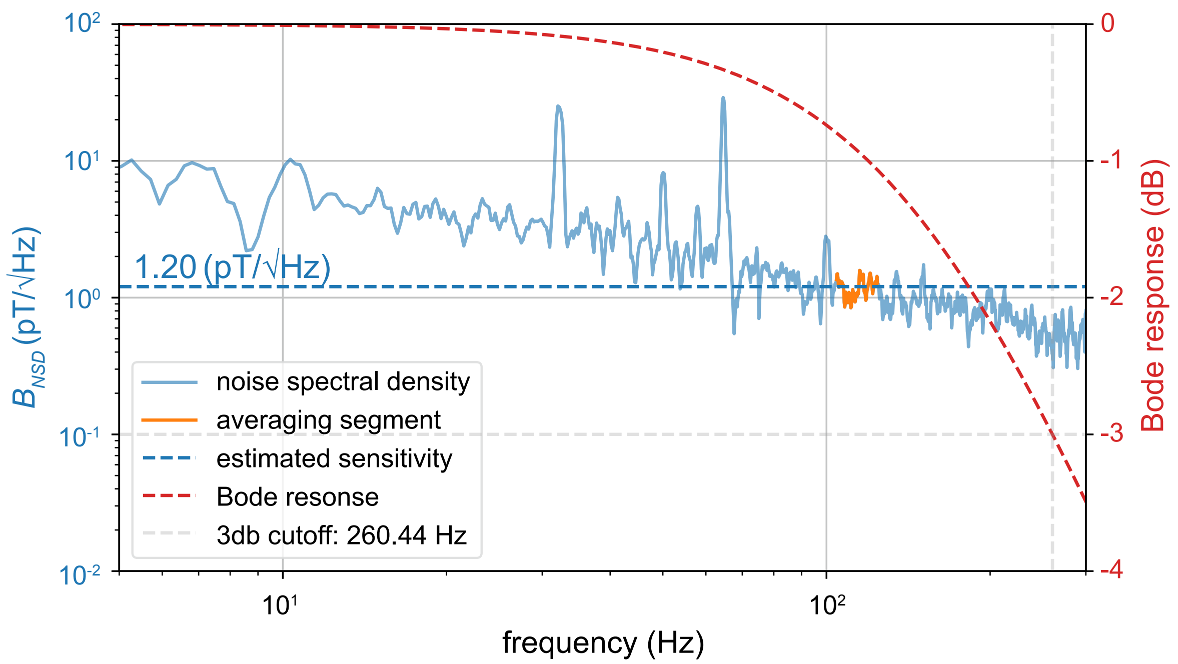
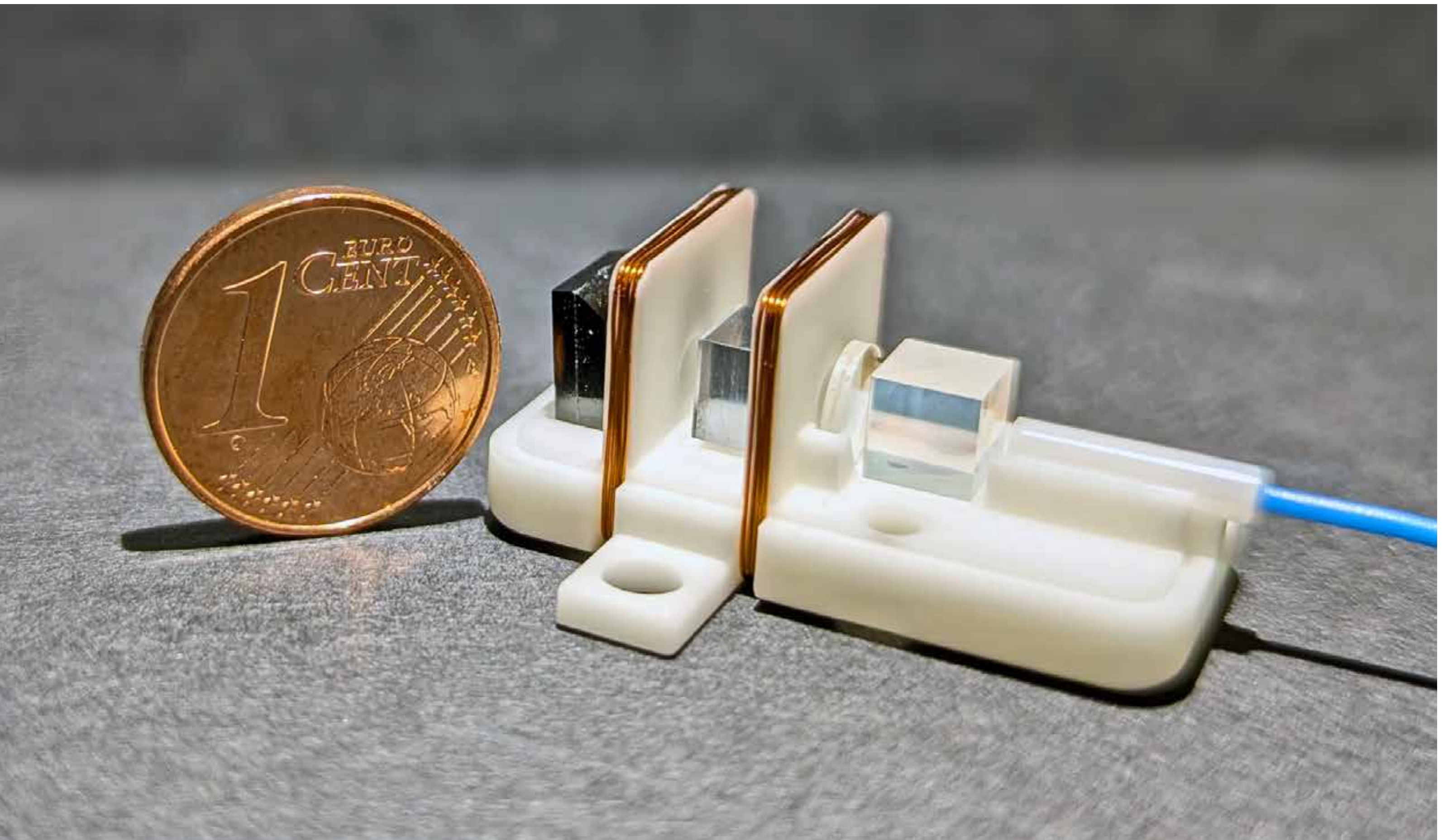


Fig. 1. Magnetic noise spectral density of our first miniaturized OPM demonstrator. The sensitivity is 1.2 pT/√Hz, estimated from the averaging segment over relevant measurement frequencies below the 3 dB cutoff frequency of 260 Hz.

Fig. 2. Prototype model of a MEMS vapor cell-based OPM, micro-integrated on an additively manufactured ceramic bench with a total volume of 7 ml.



Development of a micro-integrated optically pumped magnetometer for biomedical applications

Atomic quantum sensors use the principles of quantum mechanics and the unique properties of atoms to measure physical quantities with extraordinary precision and sensitivity. These advanced sensors address diverse applications, ranging from navigation and timekeeping to temperature monitoring and detecting gravitational or electromagnetic fields. In the Joint Lab Integrated Quantum Sensors, we focus our research on developing miniaturized physics packages, aiming to transition quantum technologies from large-scale laboratory setups to compact, portable solutions for real-world applications.

One prominent example of an atomic quantum sensor is the optically pumped magnetometer (OPM). It measures magnetic fields by leveraging the interaction of light with electron spins in alkali vapors, aligning the electron spins of the alkali atoms using polarized laser light. In presence of an external magnetic field, the polarized spin ensemble precesses around the field direction, slightly altering the properties of light transmitted through the atomic vapor. By detecting these subtle changes, magnitude and direction of the magnetic field can be determined with high precision.

In the MyoQuant project, we develop a portable OPM for magnetomyography (MMG), aiming to provide a non-invasive measurement tool to monitor and diagnose the neuromuscular condition of astronauts in space. Resolving such biomagnetic fields requires magnetic field probes with sensitivities in the sub-picotesla range at measurement frequencies of a few kilohertz.

We have established a laboratory setup to validate sensor concepts, test individual components, and benchmark sensor performance in a controlled environment. This setup helps us to evaluate key operating parameters and optimize the sensitivity of the sensor. Based on the results obtained, we progressed towards miniaturization by leveraging additive manufacturing of technical ceramics, such as aluminum oxide. We use these materials as structured optical benches, onto which optical and electronic components are precisely aligned and bonded using our advanced hybrid micro-integration techniques. The ceramic substrates provide well-matched thermal expansion with optical components, high mechanical robustness, and low electromagnetic interference – properties essential for high-performance sensors and quantum technologies, particularly in space applications. By combining these advanced manufacturing techniques, we successfully realized a first demonstrator of a miniaturized sensor package with a volume of 11 ml, achieving a sensitivity of 1.2 pT/√Hz, see Fig. 1. Our current work on advanced sensor integration focuses on utilizing wafer-based alkali vapor cells (MEMS cells) with optimized cell parameters. With these activities we aim to reduce the volume even further while increasing sensitivity and overall performance, see Fig. 2.

Beyond biomedical solutions, highly sensitive magnetometers are required for navigation, geophysical exploration, and various further applications in the industrial sectors. This gives OPMs significant commercialization potential, which we explored through technology transfer initiatives and participation in the Berlin Quantum Pioneer incubation program. Our proposal was recognized with the jury award, highlighting its capability.

This work is funded by the German Space Agency (DLR) through the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grants 50WM2169 (MyoQuant) and 50WM2070 (CAPTAIN-QT).

Publication

M. Christ, C. Zimmermann, S. Neinert, B. Leykauf, K. Döringshoff, M. Krutzik, "Additively Manufactured Ceramics for Compact Quantum Technologies", Adv. Quantum Technol., vol. 7, no. 12, 2400076 (2024).

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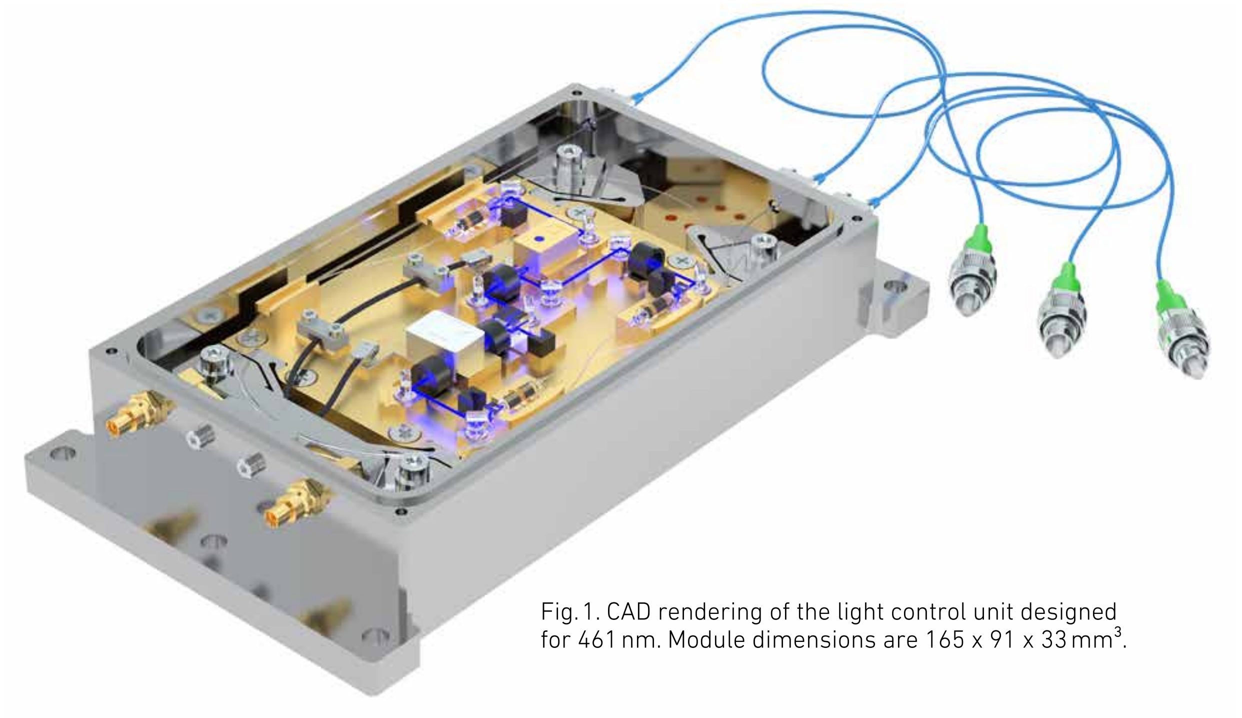


Fig. 1. CAD rendering of the light control unit designed for 461 nm. Module dimensions are 165 x 91 x 33 mm³.

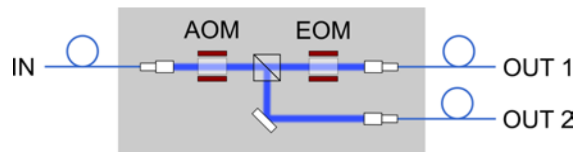
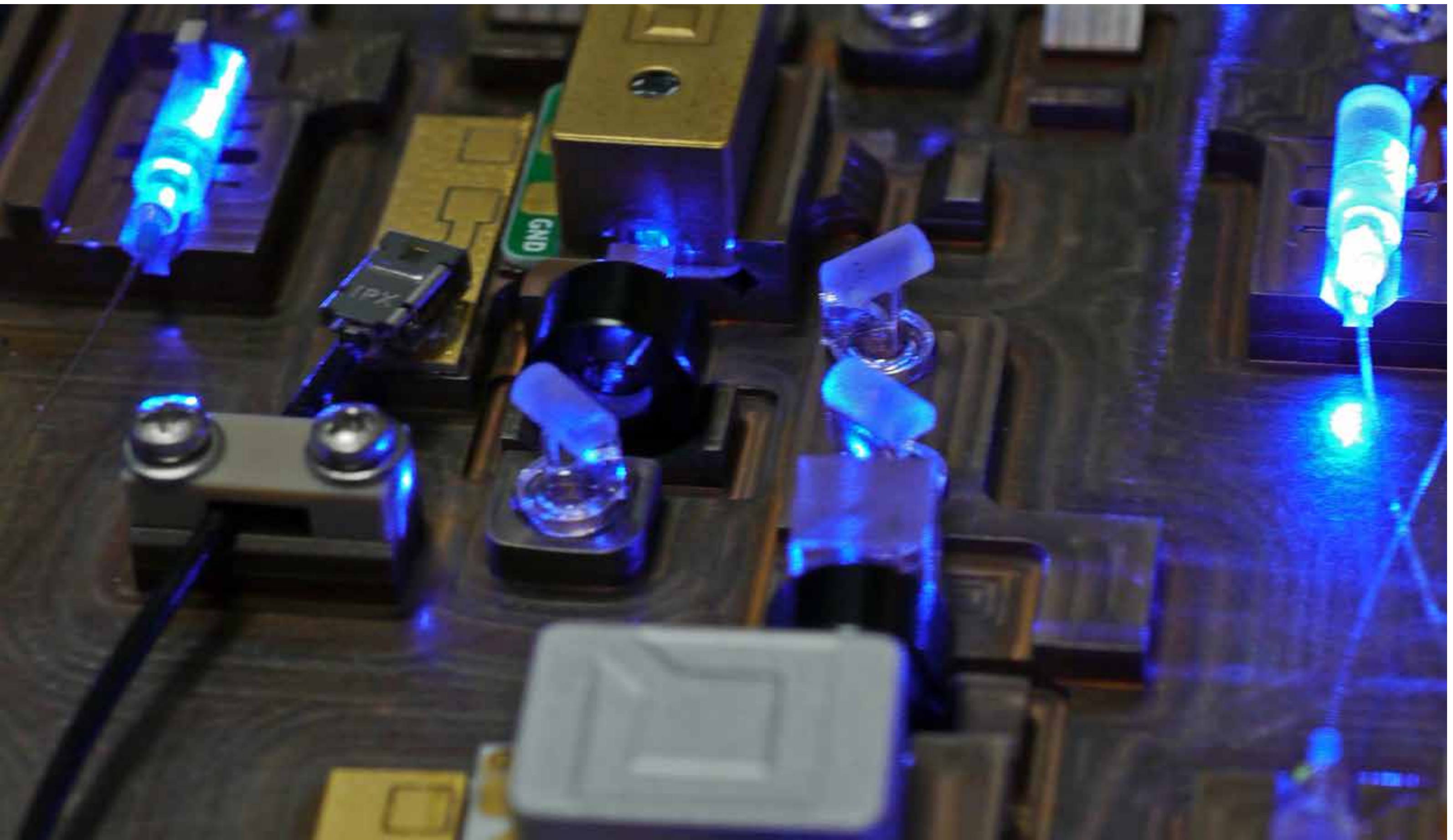


Fig. 2. Schematic layout of the 461 nm light control unit featuring one optical input (IN) and two output (OUT 1 and 2) ports, as well as acousto- and electro-optic modulators (AOM and EOM) for amplitude- and phase-modulation, respectively.

Fig. 3. Miniaturized modulators and optical elements integrated in the light control unit operating at 461 nm.



Micro-integrated light control unit featuring phase and amplitude modulators for application in a compact strontium optical atomic clock

Quantum sensors, such as optical atomic clocks, are increasingly deployed in metrology applications beyond the confines of laboratory environments. Their unparalleled stability and accuracy are unlocking new possibilities in communications technology, geophysics, and fundamental research. Applications range from synchronizing data networks and providing reference signals for global satellite navigation systems to implementations in relativistic geodesy. Expanding from terrestrial applications to space, high-performance optical clocks are envisioned as platforms for groundbreaking fundamental physics experiments, including tests of general relativity and advanced searches for dark matter.

To leverage their precision in challenging environments – whether in the field or in space – transportable optical clocks must feature compact, robust, and ruggedized designs. In collaboration with our project partners, Humboldt-Universität zu Berlin (HU Berlin), Menlo Systems GmbH, QUBIG GmbH, Vacom GmbH, and Layertec GmbH, we are developing a highly integrated optical clock based on a thermal beam of strontium atoms. Within our Joint Lab Quantum Photonic Components, we address the miniaturization of the required laser system by developing compact ultra-narrow linewidth diode laser modules and light control units. These are assembled using our unique hybrid micro-integration technology. Our light control units incorporate miniaturized acousto-optic and electro-optic modulators (AOMs/EOMs), enabling precise switching and modulation of optical signals.

Fig. 1 shows a rendered design of our first micro-integrated light control unit, developed for operation at a wavelength of 461 nm. The module has a compact volume of just 0.5 liters and a mass of 1 kg. As shown in Fig. 2, it features a single optical input and two optical output ports, both implemented using polarization-maintaining single-mode fibers. Inside the module, a collimated free-space laser beam passes through an ultra-compact AOM, which enables optical power stabilization for both output ports. Thanks to its resonant design, the integrated anisotropic AOM achieves a high efficiency of nearly 90 %, while requiring only 40 mW of RF power at a frequency of 78 MHz. For one of the output ports, a miniature EOM operating at 24 MHz provides phase-modulation, enabling applications such as laser locking via frequency-modulation spectroscopy. The overall insertion loss of the micro-integrated light control unit is approximately 6 dB. Fig. 3 shows the modulators and optical elements bonded to a prototype micro-optical bench. The total RF power required to operate both modulators within the module is less than 150 mW. This makes the light control unit a power-efficient building block of a compact and ruggedized laser system – a prerequisite for realizing low-SWaP (size, weight, and power) optical atomic clocks.

As a next step, the light control unit assembled at FBH will be integrated into the strontium optical clock demonstrator and tested at system level at HU Berlin. Successful assembly and demonstration of this micro-integrated light control unit pave the way for realizing similar modules for other wavelengths and functionalities essential for optical atomic clocks.

This work is supported by VDI Technologiezentrum GmbH with funds provided by the German Federal Ministry of Education and Research (BMBF) within the funding program "Quantum technologies – from basic research to market" under grant number 13N15724.

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[1] J. Hamperl, M. Gärtner, N. Goossen-Schmidt, B. Arar, M. Bursy, S. Hariharan, A. Liero, S. Nozinic, M. Schiemangk, S. Szermer, C. Tyborski, A. Wicht, "Micro-integrated laser distribution modules for low-SWaP optical atomic clocks", Proc. of SPIE, vol. 13392, Quantum Sensing, Imaging, and Precision Metrology III, 133920E (2025).

[2] J. Hamperl, N. Goossen-Schmidt, B. Arar, M. Bursy, S. Hariharan, S. Kubitza, A. Liero, S. Nozinic, M. Schiemangk, S. Szermer, C. Tyborski, A. Wicht, "Compact laser distribution modules for future optical atomic clocks in space", submitted to SPIE Proceedings of the International Conference on Space Optics (ICSO) 2024

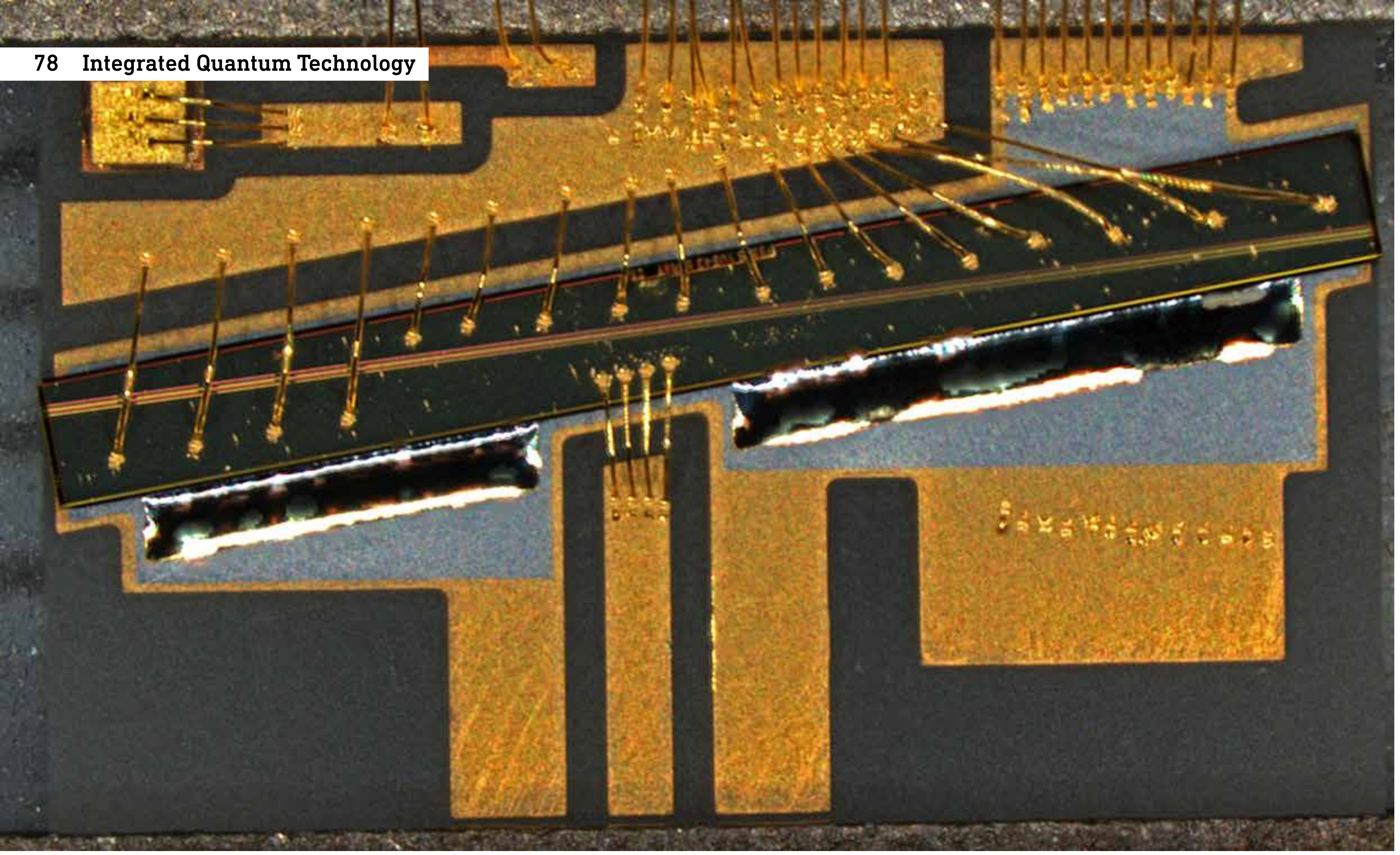

Fig. 1. Image of a single-pass semiconductor optical amplifier operated at 767 nm.

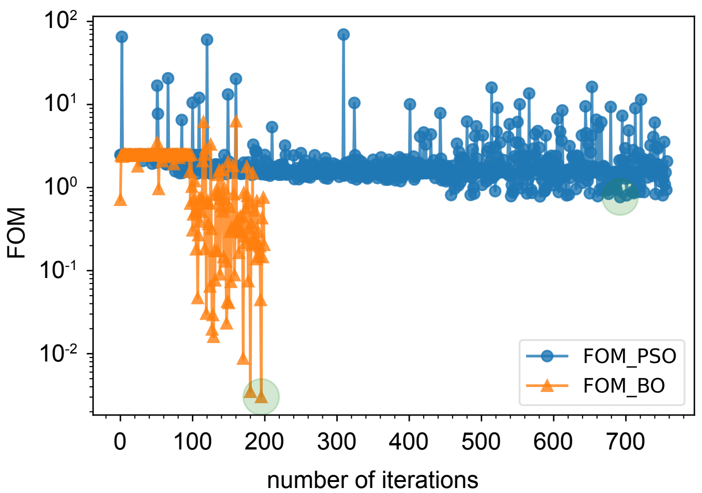

Fig. 2. Convergence comparison of particle swarm optimization and Bayesian optimization.

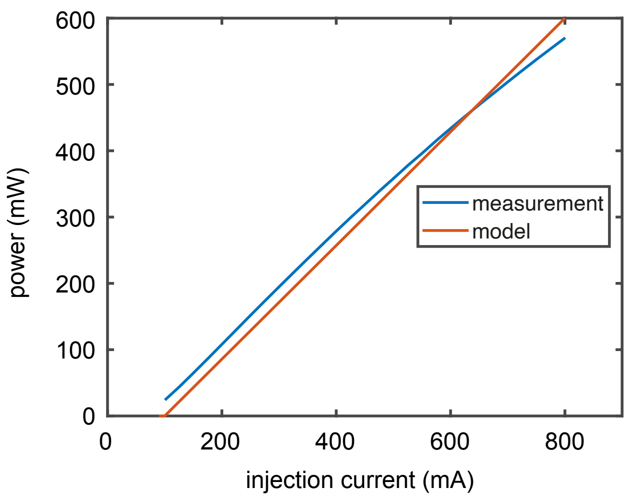

Fig. 3. Experimental and simulated data for the output power vs. injection current at 10 mW seed power and an optical feedback level of -44 dB.

Optimized laser system for quantum technologies with data-driven modelling

Building upon FBH's diode laser and microintegration technology, we develop high-performance laser modules that are essential for space applications and quantum computing. These systems are highly complex, which renders simulations based on first principles impractical due to their computational intractability. Hence, data-driven simulation techniques become indispensable to optimize their design [1]. Here, simplified models are applied, and corresponding model parameters are extracted from experimental data. We collect the data from various measurements under a wide range of operating conditions and across vastly different physical properties of the device.

By integrating metaheuristic and probabilistic optimization algorithms, we derive accurate model parameters for single-pass, ridge-waveguide semiconductor optical amplifiers (Fig. 1) from diverse experimental datasets. These include forward and backward emission spectra, forward and backward power output, and feedback-induced parasitic effects, allowing us to capture the full spectrum of device behavior. By leveraging sophisticated optimization methodologies, such as particle swarm optimization (PSO) and Bayesian inference (BO) [2,3], we systematically extract the key parameters of a simplified laser model, ensuring precise alignment with experimental data. The simplified laser model is based on the traveling wave laser model, which describes the evolution of forward- and backward-propagating optical waves inside a laser cavity, accounting for gain dynamics, dispersion, and nonlinear effects. We have implemented this model into the Lumerical INTERCONNECT design environment.

Model optimization was performed using a MATLAB script to fit the parameters of the 10-dimensional model parameter space to the experimental data. For comparison, two methods were used: PSO and BO. To evaluate the performance of different sets of model parameters and to optimize the model, a figure of merit was used, defined as the root mean square difference between measured power and simulated power across different injection currents, seed levels, and feedback levels. Our study demonstrates that significantly faster convergence is achieved with BO, as shown in Fig. 2. Fig. 3 shows, as an example, experimental and model data for the output power vs. injection current at 10 mW seed power and an optical feedback level of -44 dB. The model predicts the experimental data with an accuracy of ~20 %, which is sufficient to address system-level design tasks.

This work plays a crucial role in advancing multi-physics computer-aided engineering (CAE) methodologies for the design of the next generation of laser modules, particularly for quantum sensing. The high-fidelity models facilitate the predictive simulation of the opto-electronic performance of devices and modules under arbitrary operating conditions, thus supporting the development of robust, high-efficiency laser systems tailored for demanding quantum tech applications.

These activitites were supported by the DLR Space Administration with funds provided by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under grants no. 50WM2152 and 50WK2272.

Publications

[1] Y. Rahimof, I. Nechepurenko, R. Mahani, A. Tsarapkin, A. Wicht, "The study of 3D FDTD modelling of large-scale Bragg gratings validated by experimental measurements", J. Phys. Photonics, vol. 6, no. 4, 045024 (2024).

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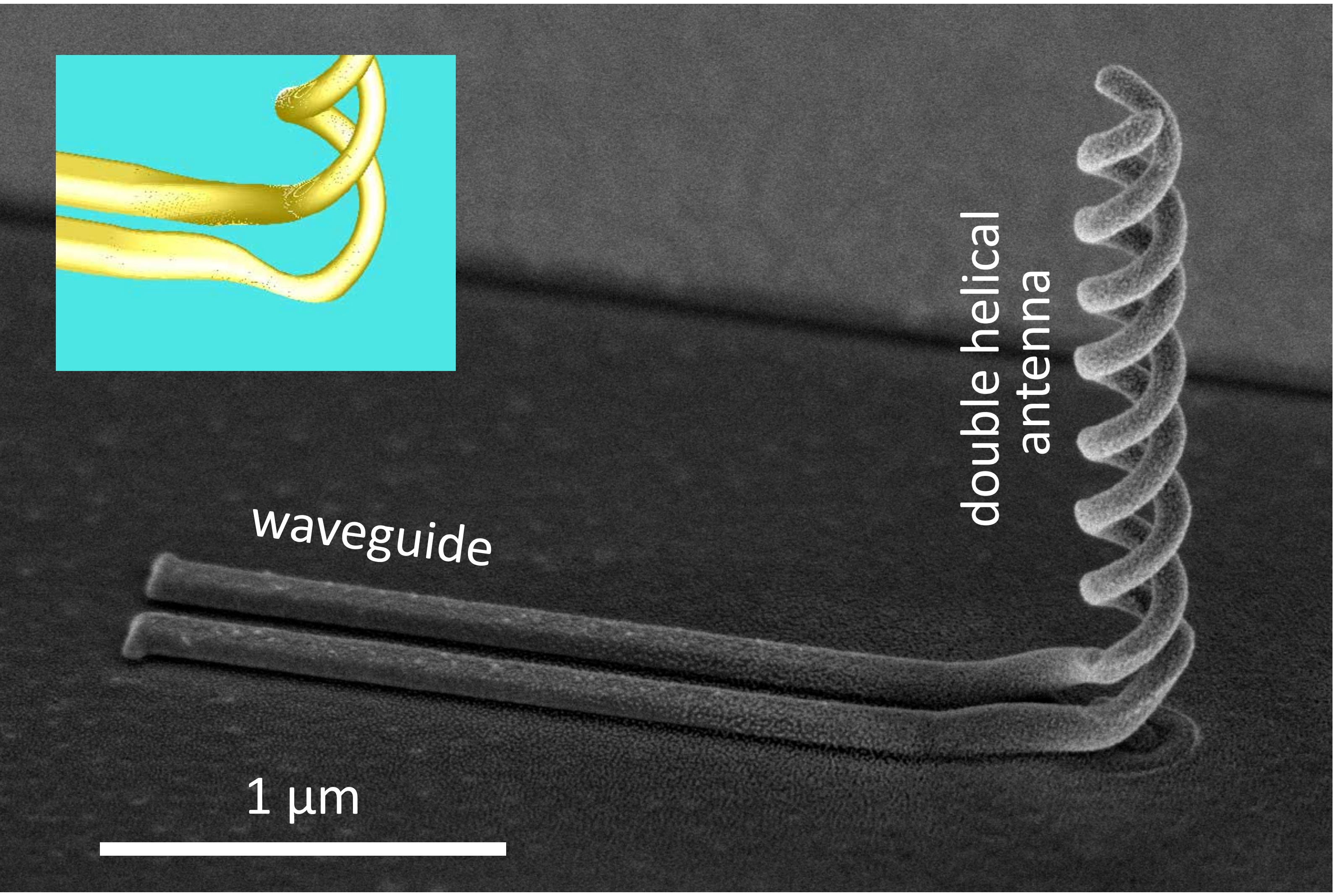


Fig. 1. High-resolution scanning electron microscope image of the fabricated device consisting of the plasmonic waveguide and a double helical antenna. Inset shows an optimized transition region, retrieved from the simulation software.

Machine-learning based optimization and 3D nanoprinting of plasmonic polarization converters for next-generation optical quantum devices

Polarization is a fundamental property of light, directly linked to the spin of its quanta, the photons. Controlling polarization is therefore essential for many photonic quantum information protocols, which rely on the interference of indistinguishable single photons from quantum light sources. While macroscopic polarization control devices exist, integrating this functionality into future quantum devices requires nanoscale solutions to precisely manipulate light at chip level. Metallic nanostructures offer a promising approach, since they are able to support plasmon polaritons. These resonant excitations allow for optical field confinement far below the diffraction limit, providing efficient nanoscale control of light and enhanced radiative decay of quantum emitters.

We have developed a compact on-chip device that converts linearly polarized into circularly polarized light within a footprint smaller than 1 µm^2. The device combines a plasmonic 2-wire waveguide with a double helical antenna. A spline function was used to smoothly connect the transition region, linking the double helix to the waveguides. Its parameters were optimized using a particle swarm optimization algorithm. The device emits highly directional left- or right-handed circularly polarized light with a high degree of polarization purity. Although optimized for a specific wavelength, modeling proves that the polarization converter is also suited for efficient broadband operation, particularly in the near-infrared spectrum. This capability opens up the exciting possibility of using it for nonlinear optics, converting standard telecom far-field radiation into visible light on chip.

To fabricate this miniature device, we employ a direct writing approach with focused beams of electrons and ions. The entire fabrication process takes place within the same vacuum chamber of a standard tool for focused ion beam processing. While focused ions physically remove material through sputtering, the electron beam cleaves gaseous precursor molecules at the focal point, building structures in the manner of a nanoscale 3D printer. We optimized the 3D writing routine based on the implementation of empirical calibration structures. As can be seen from Fig. 1, the resulting device closely matches the original design from the simulations. Currently, we evaluate the performance of the first prototype polarization converters experimentally. With its compact size and ultimate 3D precision, this nanoscale polarization converter could become an essential component in next-generation optical quantum devices.

This work is funded by the German Research Foundation (DFG) within the project 'chiralFEBID' under grant no. HO 5461/3-1. Activities are also supported by the VDI Technologiezentrum GmbH with funds provided by the German Federal Ministry of Education and Research (BMBF) under grant No. 13N14906.

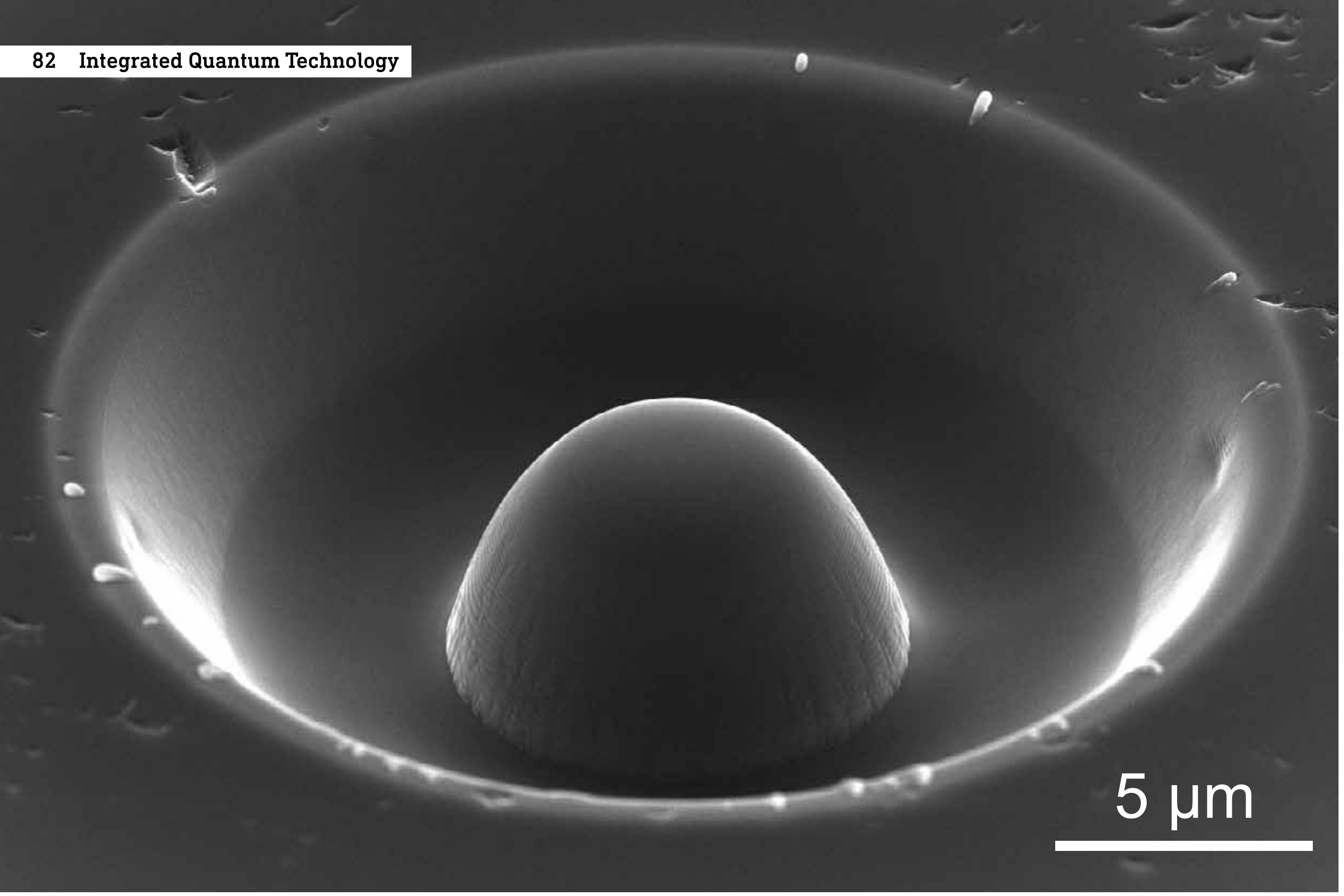


Fig. 1. Scanning electron micrograph of the SIL, milled in diamond with the focused gallium ion beam.

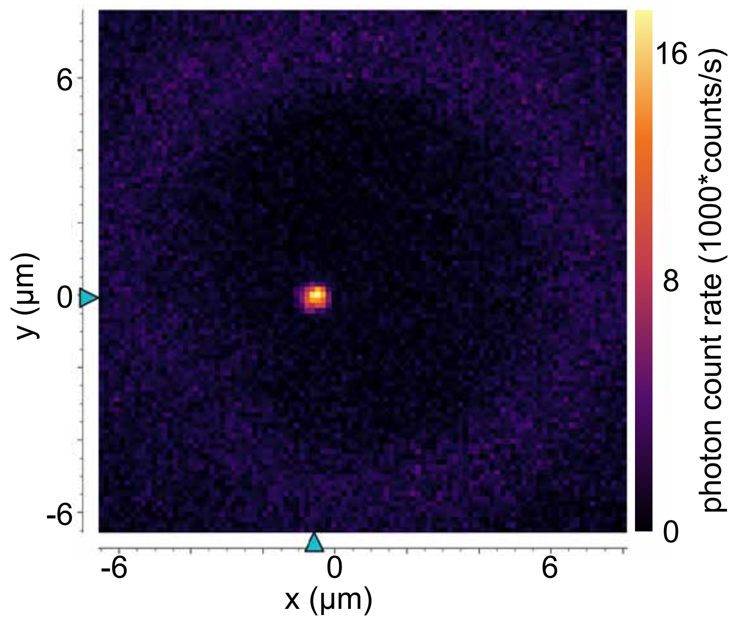


Fig. 2. Confocal microscopy map of the first prototype of SIL with a distinguishable photon emitter.

Solid immersion lenses in diamond for developing quantum networks

In recent years, a deeper understanding of the laws of quantum mechanics has driven the development of new technologies, ushering in a new quantum revolution. Among these breakthroughs, quantum networks promise to provide new methods to establish long-distant entanglement and secure communication. Such infrastructures are envisioned to be formed by a large number of nodes that are interconnected by sharing entangled particles pairs, thus establishing 'quantum links' among them. Key components for such infrastructures are efficient spin-photon interfaces, which are systems that couple stationary qubits (the spin) with their flying counterparts (the photons).

Color centers in diamond are one of the promising platforms for realizing efficient quantum networks. They are, in fact, characterized by individual spins that can be optically addressed and provide long coherence times. In other words, these systems are capable of generating entanglement and storing it for a relatively long time. Furthermore, they are naturally integrated in a solid-state platform, potentially enabling to fabricate devices and produce quantum photonic integrated chips. Owing to these properties, a number of proof-of-concept, lab-scale quantum networks have already been demonstrated by different groups, where entanglement between three nodes has been achieved. This amazing achievement was made possible using solid immersion lenses.

Solid immersion lenses (SILs) are microstructures that significantly increase the light collection efficiency of defect-based quantum emitters in high-refractive-index materials. Their half-spherical shape circumvents total internal reflection, allowing for improved photon extraction. Within our Joint-Labs Photonic Quantum Technologies and Diamond Nanophotonics, operated collaboratively with Humboldt-Universität zu Berlin, we have developed a new fabrication process for producing such devices in diamond at the position of stationary qubits. This was achieved by employing a focused ion beam (FIB) milling technique that uses a very narrow beam of gallium ions to precisely carve the SIL out of the diamond substrate.

Thanks to our optimized approach, the resulting SILs are operational without any further post-treatment, thus speeding up the overall production process compared to similar devices reported in literature. We have characterized the first generation of fabricated SILs with confocal microscopy and detected a 10-fold increased photoluminescence signal from the color centers embedded in them. This confirms the improved photon collection efficiency and demonstrates that our devices can perform equally well in quantum networks as previous devices, while offering the advantage of reduced fabrication complexity.

This work is funded by the Leibniz Collaborative program as part of the 'ENGRAVE' project under grant no. K335/2020 and by the German Federal Ministry of Education and Research (BMBF, project DiNOQuant, No. 13N14921).

III-V Electronics

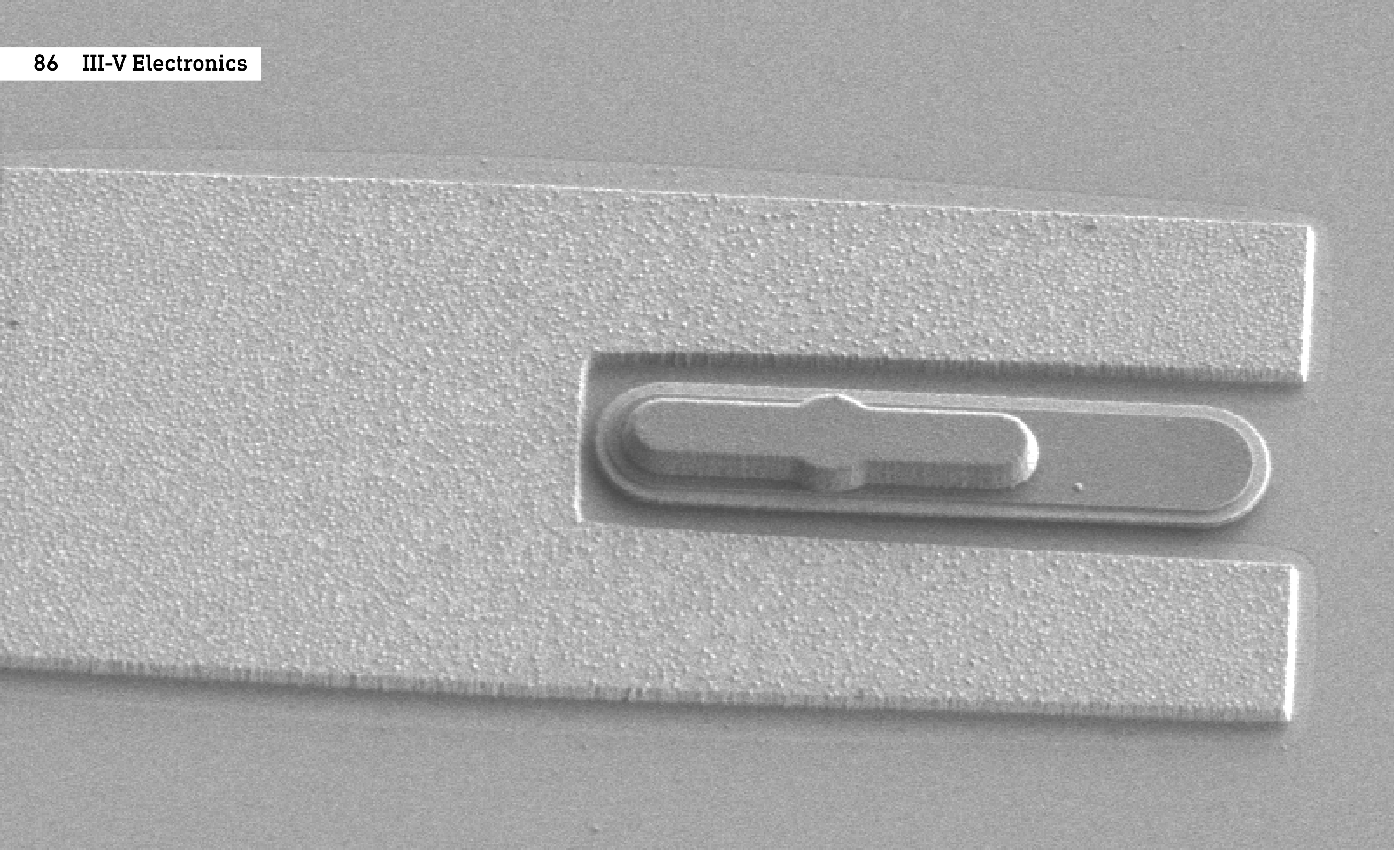


Fig. 1. SEM image of a fully processed transistor in front end of line.

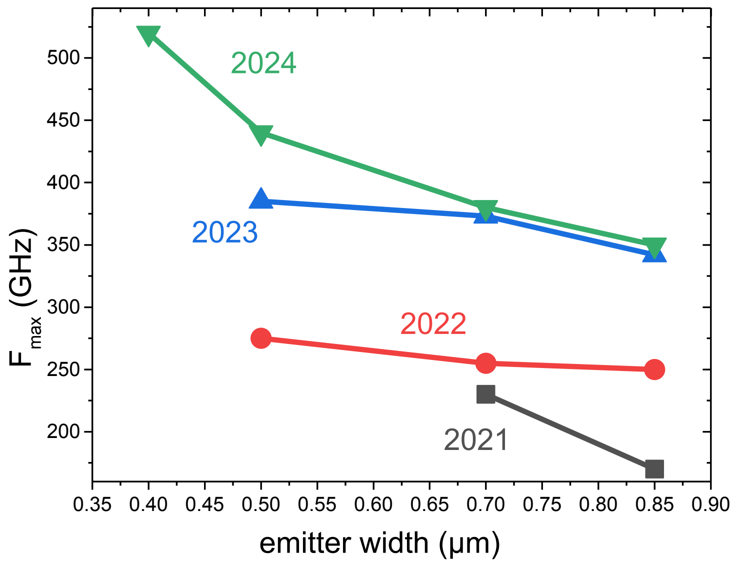


Fig. 2. Evolution of transistor's maximum oscillation frequency throughout different technology generations.

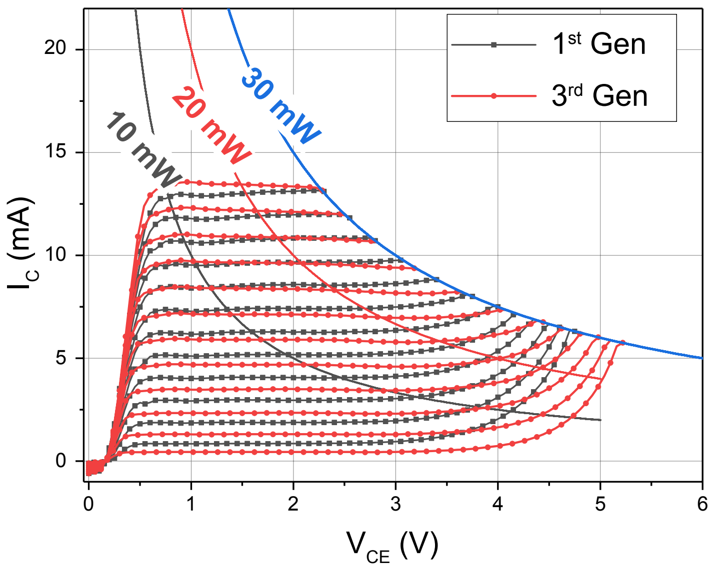


Fig. 3. Safe-operating area measurements for different device generations showing stable operation up to 30 mW.

Key enabling technologies for D-band applications and beyond: InP HBT MMIC and heterointegration approach

The increased demand for high data rates and higher operating frequencies – driven by technological fields like high-speed communication links, sensing applications, data centres, and artificial intelligence – has heightened the need for semiconductor technologies which can meet these challenging requirements.

As highly scaled systems with extremely small form-factor and efficient power consumption become more important, it is clear that the standard Si-based CMOS technologies alone cannot tick all the boxes. III-V-based technologies offer, owing to their material properties, certain performance advantages when compared to Si-CMOS. It is therefore clear that a mature III-V based MMIC technology can open more possibilities to achieve said highly efficient systems in conjunction with the more stable Si-based CMOS technology.

InP-based heterojunction bipolar transistors (HBTs) have recently proven to be a perfect candidate for these challenges. Thanks to their special material properties, such as high carrier mobility and saturation velocities, InP-based HBTs have been able to show maximum oscillation frequencies (f_{max}) above 1 THz with breakdown voltages well above 4 V. This makes them ideal for D-band applications (from 110 to 170 GHz).

We offer our own MMIC process at FBH in a multi-project wafer (MPW) fashion. The process offers designers transistor nodes as small as 400 nm, with f_{max} and breakdown voltages of 500 GHz and 4.5 V, respectively. The process relies on the highly-scalable triple mesa approach with good thermal grounding, allowing for high-density integration of active elements. Additionally, the MMIC stack includes multi-routing metal layers, which enable high design flexibility. A process design kit framework is provided to facilitate design layout and troubleshooting.

Seamless integration of III-V chips with other chips and/or systems poses a technological challenge. Due to different technology-readiness levels, contamination, and yield restrictions, integration has traditionally been performed at package level or with simple proximity using wirebonds.

At FBH, we offer a one-of-a-kind chiplet integration approach. Our flip-chip process allows for direct bonding of InP HBT MMIC chiplets directly onto CMOS and BiCMOS chips with alignment accuracy below 1 µm and RF losses of less than 0.5 dB up to 300 GHz.

The work presented was carried out in the framework of the APECS Pilot Line of the Chips Joint Undertaking, funded by Horizon Europe and Digital Europe Programmes and national funding authorities of Austria, Belgium, Finland, France, Germany, Greece, Portugal, Spain. It has been funded by the German Federal Ministry of Education and Research (BMBF) within the frameworks of Research Fab Microelectronics Germany (FMD).

Publications

[1] M. Rausch, M. Wietstruck, C. Stölmacker, R. Doerner, G. Fischer, A. Thies, S. Knigge, H. Yacoub, W. Heinrich, "Broadband hetero-integration of InP chiplets on SiGe BiCMOS for mm-Wave MMICs up to 325GHz", IEEE MTT-S Int. Microw. Symp. Dig. (2023).

[2] H. Yacoub, C. Mangiavillano, M. Rausch, E. Dischke, W. Heinrich, P. Scheele, "16th German Microwave Conference (GeMiC 2025), ISBN 978-3-9820397-4-9, pp. 366-367 (2025)."

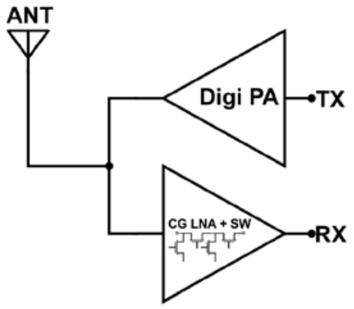


Fig. 1. Block diagram of digital transceiver concept including digital class-E PA (Digi PA) and common-ground LNA (CG LNA) with integrated switch (+SW).

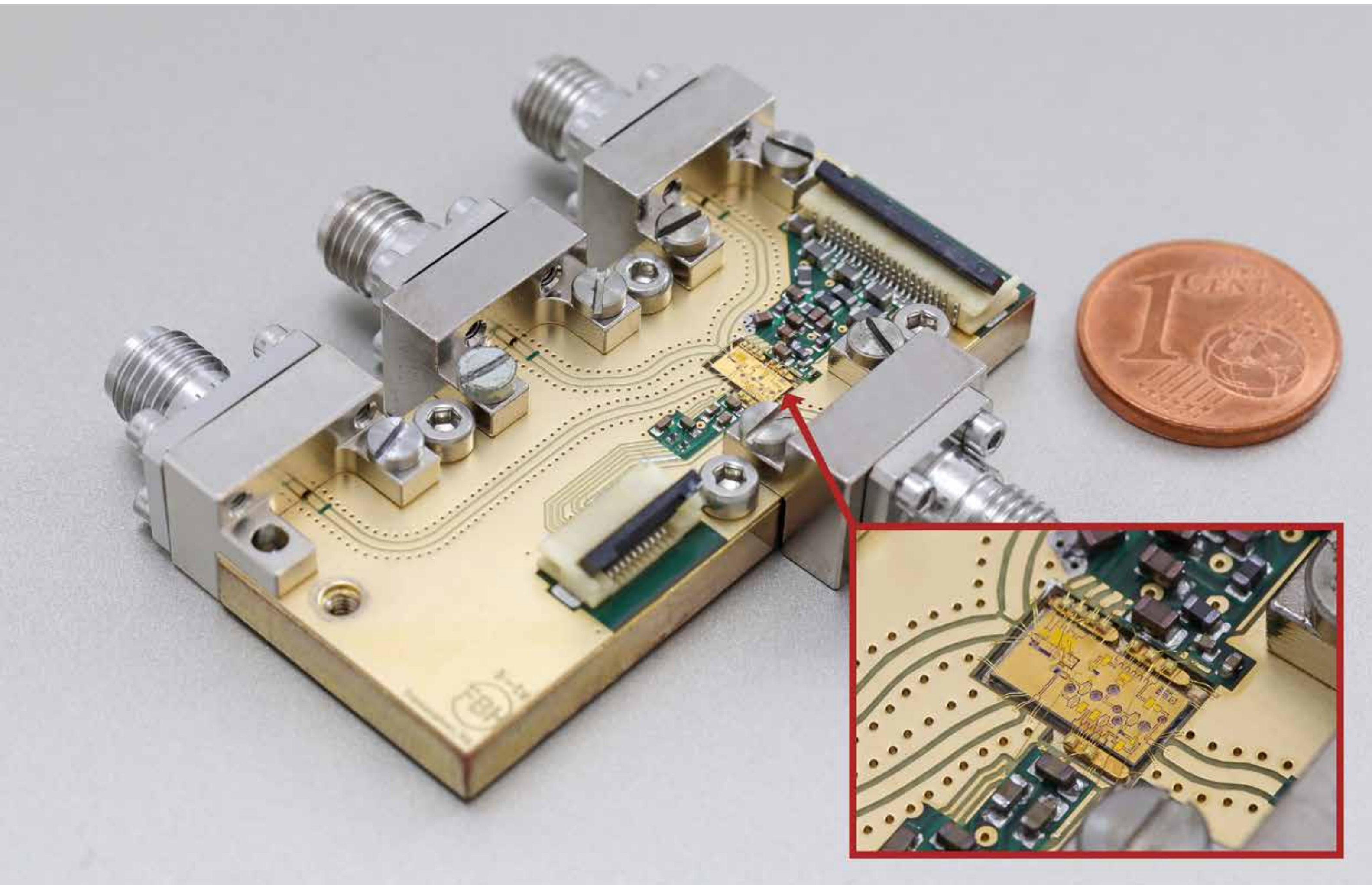


Fig. 2. Realized transceiver module, size: 20 x 50 mm^2.

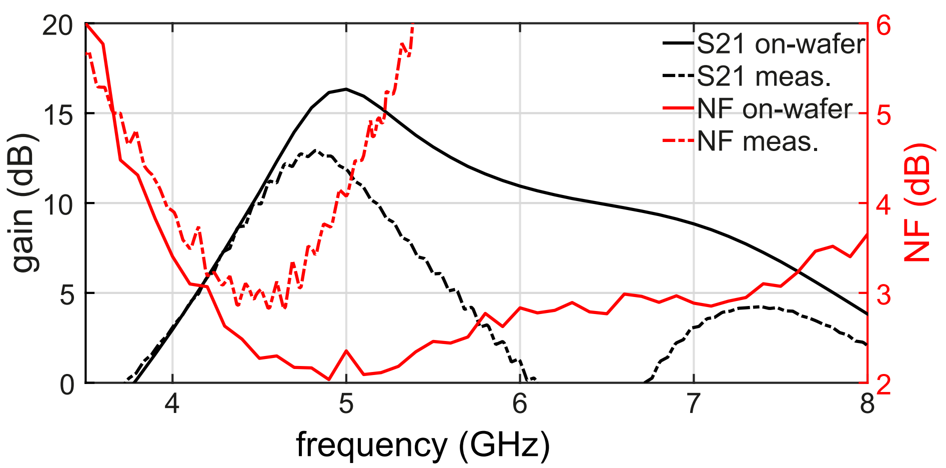


Fig. 3. Gain and noise figure of the LNA measured: on-wafer (solid) and coaxially in-module (dotted).

Digital GaN-based transceiver module for future green 5G networks

The demand for advanced radio frequency (RF) transmit/receive (T/R) front-end modules is growing quickly in fields like space, mobile communications, and radar technology. These essential components, key for next-gen networks, combine wideband capabilities, power efficiency, and low noise to tackle modern tech challenges. Recent innovations have produced compact single-chip half-duplex monolithic microwave integrated circuits (MMICs) transceivers at 5 GHz, integrating a low noise amplifier (LNA), switch, and power amplifier (PA). While these MMICs represent significant progress in miniaturization, the underlying concept remains rather conservative.

Hence, we present an innovative digital transceiver concept that combines an LNA with integrated switching functionality (LNAiS), complemented by a true digital class-E power amplifier (PA) using FBH's GaN technology (Fig. 1). At the antenna port, PA output and LNAiS input are connected in parallel, as a separate switch is not required to isolate the receiver (Rx) and transmitter (Tx) paths. To minimize the mutual detuning of PA and LNA at the antenna port, an optimized common matching is designed.

This concept also marks the first integration of a highly flexible, compact, and efficient digital PA on a TRx chip to date. Due to the digital nature of the PA, the Tx can serve a wide bandwidth from the kHz range to 6 GHz by switching between frequency bands. This is achieved simply by changing the input signal and slightly adjusting the (broadband) output network. One only has to change in Rx mode to another LNA for the respective band. This approach replaces several narrowband conventional analog PA modules, which saves a significant amount of energy and paves the way for a greener ICT.

The LNAiS and digital PA are integrated in a single compact chip (see inset in Fig. 2). The two circuits are connected through the final-stage output inductance of the PA and realized in a hybrid transceiver module (Fig. 2). In Rx mode, the LNA shows a low noise figure of 3 dB (2.17 dB on-wafer) and a good gain of almost 13 dB (14 dB on-wafer) at the targeted frequency of 4.7 GHz (cp. Fig. 3). In Tx mode, the LNAiS provides a high isolation of > 20 dB. The flexible digital class-E PA shows efficiencies of 46 % for 20 MHz LTE (6.5 dB PAPR) and 25 % for OFDM (9 dB PAPR) input signals at 4.7 GHz, respectively.

Furthermore, the PA achieves a maximum P_{out} of 32 dBm at a drain supply voltage of 12 V for 1-tone input with 50 % duty-cycle. Moreover, 37 % of η_{drain} has been achieved at 3.7 GHz with a 6.5 dB 20 MHz LTE signal, proving the flexibility of the digital approach, only limited by the class-E-like output network in this work. In terms of linearity, the values need improvement targeting the practical application. However, the proposed novel digital TRx combines promising performance with high flexibility in the Tx chain and compacter circuitry, since an antenna switch is no longer required. The concept therefore proves to be a true candidate to realize a greener ICT in future 5G networks.

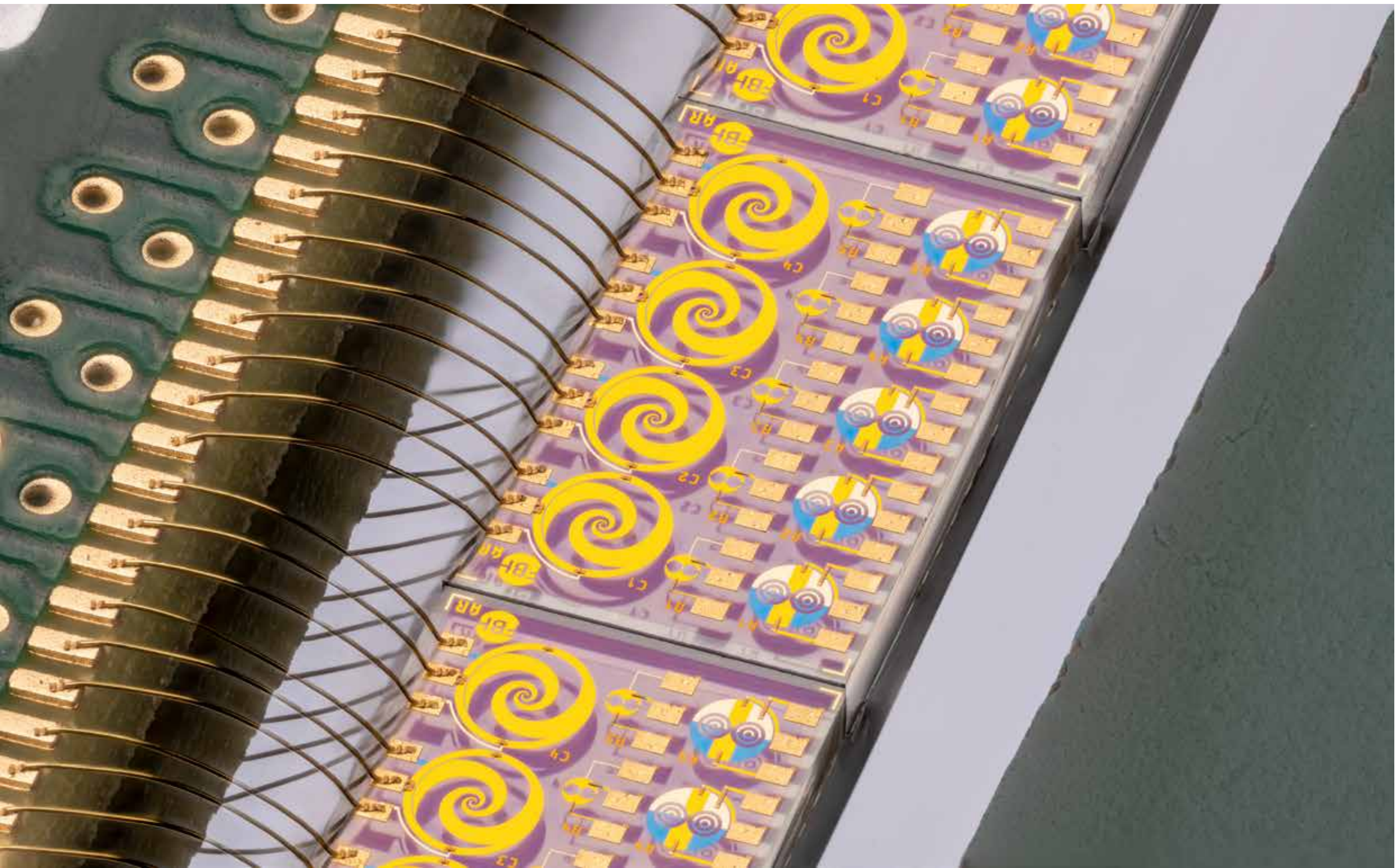
This work was funded by the Deutsche Forschungsgemeinschaft (DFG) under grant no. WE6288/3-1, RU1203/17-1. Further, it was partly funded by the German Federal Ministry of Education and Research (BMBF) within the Research Fab Microelectronics Germany (FMD) framework under ref. 16FMD02, as well as within the project Green ICT @ FMD under ref. 16ME0505.

Publication

M. Krishnaji Rao, A. Wentzel, T. Hoffmann, L. Schellhase, S. A. Chevtchenko, M. Rudolph, "Digital GaN-based Transceiver Module for Future Green 5G Networks", Proc. of 54th European Microwave Conference (2024).

Fig. 1. The terahertz line scanner captures a structured wafer in real time.

Fig. 2. Close-up of a chip with four THz detectors from the THz detector array.



World's first terahertz line scanner for real-time systems implemented

We have developed a terahertz line scanner that, for the first time, is entirely based on monolithically integrated THz detectors. This technology enables efficient and cost-effective realization of longer scan lines in industrial environments.

Terahertz radiation (THz) penetrates materials such as plastics, polymers, ceramics, and organic tissue. This makes it ideal for non-destructive material testing and the identification of hidden objects – for example, in the detection of material defects. The new terahertz line scanner was specifically designed for industrial applications and is characterized by high scalability, fast throughput, and outstanding image resolution. The technology demonstrator consists of a high-power THz source and an innovative detector head that scans objects on a conveyor belt. The captured image is displayed on a monitor in real time.

The detector head contains a 6 cm long detector array, composed of 20 individual chips, each with four THz detectors. In total, 80 detectors operate with a spacing of just 640 µm, achieving high image resolution. Depending on the chosen THz source, the detectors can be used in a frequency range from 100 GHz to 1.5 THz. The conveyor belt speed is variably adjustable, reaching up to 1.5 meters per second.

Each THz detector signal is amplified and digitized with a resolution of 16 bits. The maximum readout speed is 15,000 lines per second – an unprecedented measurement speed. Measurements at 300 GHz with a sampling rate of 10,000 lines per second demonstrate that a complete image can be captured in less than one second at a conveyor speed of 0.25 meters per second. A signal-to-noise ratio of 30 dB is achieved in the process.

This terahertz line scanner is the first real-time imaging system in the THz spectral range to achieve such sensitivity and a readout speed of up to 15,000 lines per second. The monolithic integration of the detectors enables scalability effects, paving the way for a cost-efficient solution in industrial applications. In the future, the use of InP-based THz detectors is expected to further improve the signal-to-noise ratio. This opens up new possibilities for high-resolution, fast, and reliable terahertz imaging in industrial applications.

Publication

A. Rämer, E. Negri, H. Yacoub, J. Theumer, J. Wartena, V. Krozer, W. Heinrich, "A Monolithically Integrated InP HBT-based THz Detector", Proc. of 54th European Microwave Conference (2024).

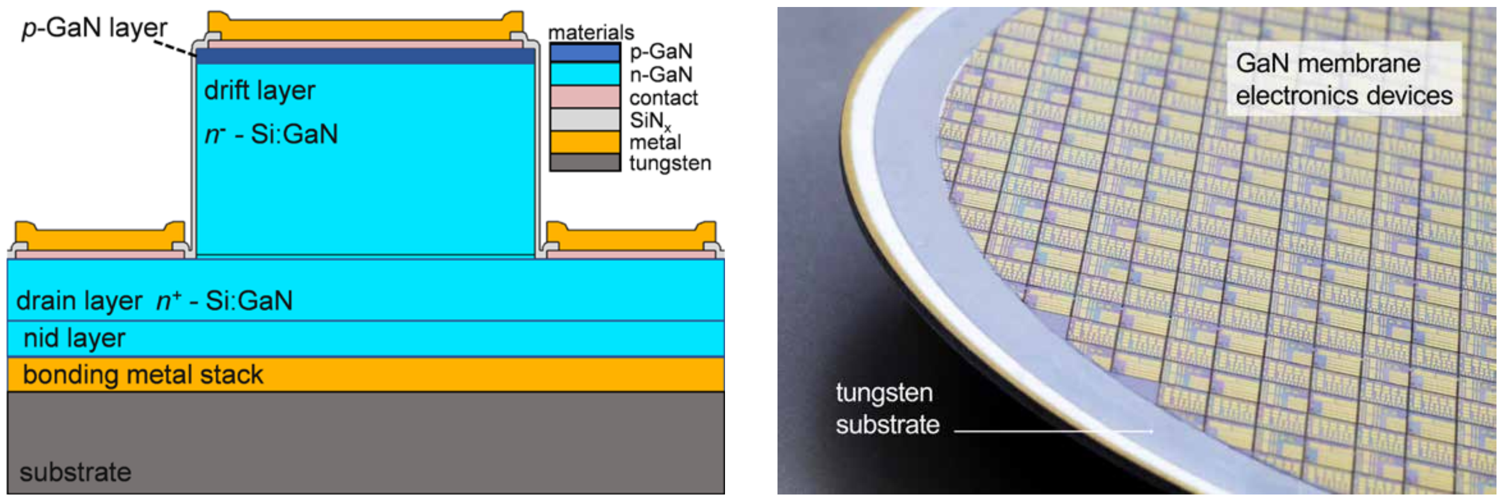


Fig. 1a) GaN membrane on tungsten vertical *pn*-diode schematic cross-section. b) Finished GaN on tungsten 4-inch wafer.

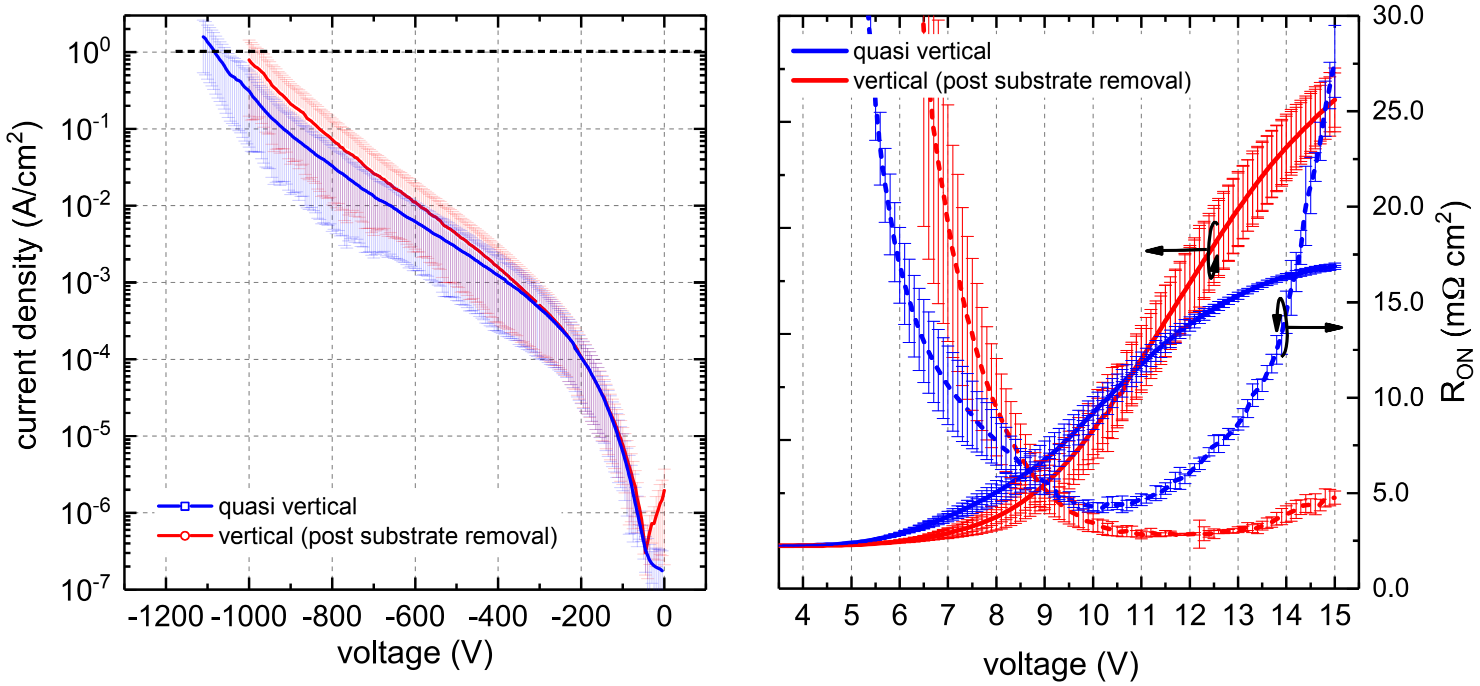


Fig. 2a) Wafer level *pn*-diodes reverse bias characteristic after front side process (quasi-vertical) and on tungsten substrate after backside process (fully vertical). b) GaN *pn*-diodes on-state characteristic on sapphire (quasi-vertical) and on tungsten substrate (fully vertical).

High-voltage vertical GaN membrane *pn*-diodes on tungsten substrates via substrate transfer

Vertical GaN-based power switching devices, including diodes and transistors, present significant advantages over lateral heterostructure-based counterparts. A key benefit is their reduced die size, which directly lowers the specific on-state resistance ($R_{DS\_on} \times A$). This parameter can improve by an order of magnitude, achieving values as low as 1.0 mΩ cm², making these devices well-suited for high-efficiency, compact power electronics applications.

The targeted blocking capability larger than 1 kV demands GaN drift layers thicker than 10 µm with low residual background doping. However, growing such thick GaN epi layers is especially challenging on foreign substrates. The interface lattice mismatch and thermal coefficient differences generate a series of undesirable effects, such as increased threading dislocations density, higher leakage current, mechanical strain, and fragility. Thick (> 10 µm) GaN drift layers on 4-inch sapphire substrates thus lead to significant wafer bow. In our previous work, we demonstrated that sapphire substrate laser stealth scribing can sufficiently reduce wafer bow, enabling wafer processing on common semiconductor processing tools.

This letter reports on the removal of the electrically and thermally insulating sapphire substrate and the subsequent bonding of GaN membranes to a conductive substrate on 4-inch wafer scale. This process enables true vertical conduction in GaN layers originally grown on sapphire.

To achieve this, the wafers are temporarily top-side bonded to a second double-side-polished sapphire carrier wafer. The original substrate is then removed with a laser lift-off (LLO) process with an ultrashort pulsed laser.

We demonstrate the fabrication of fully operational vertical GaN devices utilizing GaN thin membranes grown on sapphire substrates, subsequently transferred onto tungsten substrates. The membrane transfer process significantly enhances forward diode conductivity, reducing the on-state resistance from 3.39 mΩ·cm² to 1.71 mΩ·cm². While there is a slight reduction in blocking strength, the devices maintain a high blocking voltage exceeding 1000 V. The high process yield and straightforward membrane transfer technique underscore the potential cost-effectiveness of GaN for vertical high-power applications. This approach leverages inexpensive sapphire substrates, substantially lowering the costs typically associated with GaN substrates.

This work was partly supported by ECSEL JU through the European Union's Horizon 2020 Research and Innovation Program and Germany, France, Belgium, Austria, Sweden, Spain, and Italy, under Grant 101007229.

Publications

[1] E. Brusaterra, E. Bahat Treidel, L. Deriks, S. Danylyuk, E. Brandl, J. Bravin, M. Pawlak, A. Külberg, M. Schiersch, A. Thies, O. Hilt, "Vertical GaN-on-Tungsten High Voltage -Diodes from Sapphire-grown GaN Membranes", IEEE Elec. Devi. Lett. (2025).

[2] E. Bahat Treidel, E. Brusaterra, F. Brunner, O. Hilt, "Vertical GaN Power Switching Devices on Native and Foreign Substrates", 12th International Workshop on Nitride Semiconductors (invited) (2024).

[3] E. Brusaterra, E. Bahat Treidel, A. Külberg, F. Brunner, M. Wolf, O. Hilt, "Wafer Bow Tuning with Stealth Laser Patterning for Vertical High Voltage Devices with Thick GaN Epitaxy on Sapphire Substrates", in Proc. of CS MANTECH (2024).

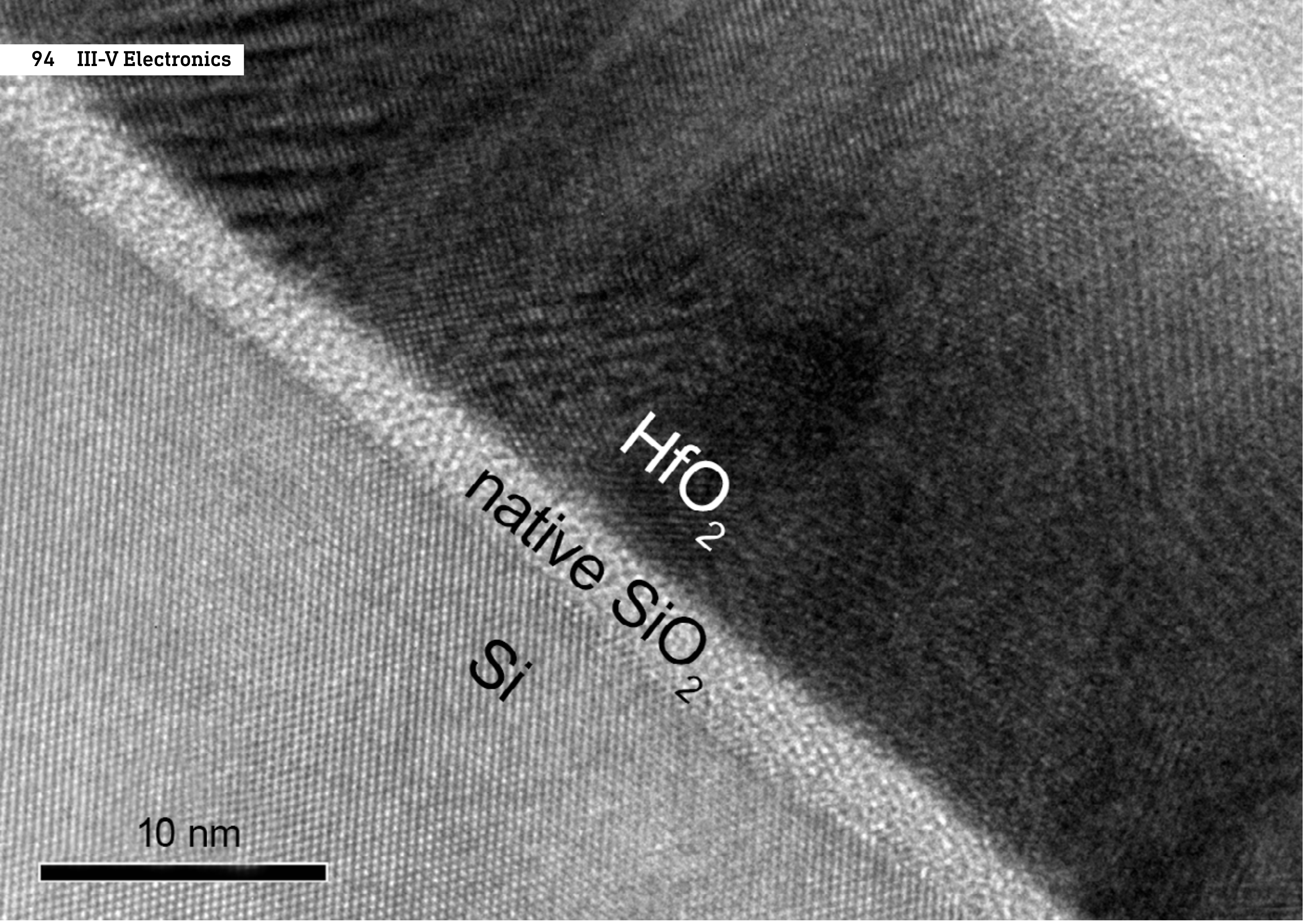


Fig. 1. Cross-sectional transmission electron micrograph of a polycrystalline PEALD HfO_2 layer on Si wafer.

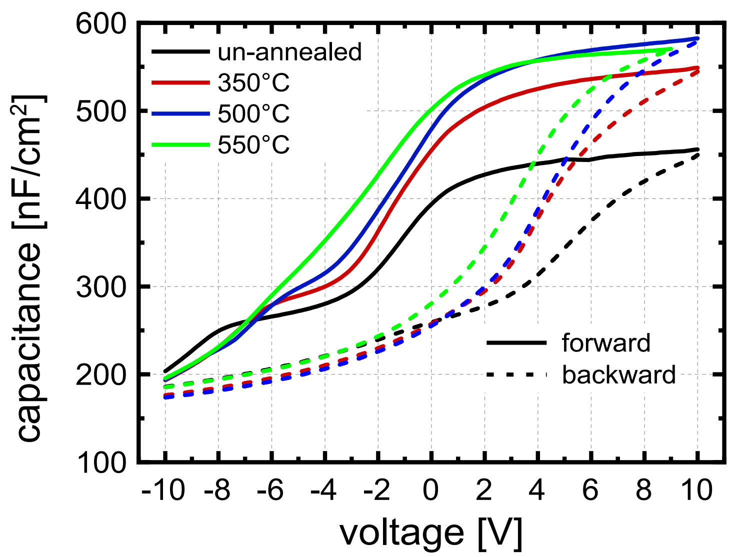


Fig. 2. Capacitance – voltage characteristics of un-annealed and annealed HfO_2-based GaN MOS capacitors in forward (solid) and reverse (dashed) bias.

Enabling atomic-scale dielectrics for future devices

Emerging technologies demand precise control over film thickness and material properties. To address these requirements for future device landscapes, we provide a platform for obtaining conformal dielectric layers with atomic-scale precision and control.

Atomic Layer Deposition (ALD) has emerged as a promising method to precisely develop high-quality nano- and atomic-scale thin films of various materials. We have developed ALD processes for two technologically relevant oxides: Al_2O_3 and HfO_2. Beyond the conventional thermal ALD process, we utilize Plasma Enhanced ALD (PEALD) to grow dielectric layers at temperatures as low as 100° C, making it feasible for temperature-sensitive substrates. PEALD offers greater flexibility in terms of process development, and the remote plasma configuration of our tool ensures that substrates remain undamaged by plasma exposure.

We have successfully grown Al_2O_3 layers using trimethyl aluminum (TMA) and H_2O by thermal ALD, and O_2 plasma as the oxidizing agent in the PEALD variant. This resulted in a growth of about 1.2 Å per cycle, a refractive index of approximately 1.65 in the visible spectral range, and thickness non-uniformity within 1-2 % on a 100 mm wafer scale. The produced Al_2O_3 layers are amorphous, smooth, and stoichiometric, transitioning to polycrystalline upon annealing above 600 °C.

For developing PEALD HfO_2 layers, we employed tetrakis(dimethylamido)hafnium (TDMAH) and O_2 plasma as precursors. We achieved a growth of about 1.8 Å per cycle, a refractive index of approximately 2.02 in the visible spectral range, and thickness non-uniformity below 2 % on a 100 mm wafer scale. The HfO_2 layers undergo an amorphous-to-polycrystalline phase transition at a deposition temperature of around 200-250 °C. Fig. 1 depicts a cross-sectional transmission electron micrograph of a polycrystalline PEALD HfO_2 film grown on Si wafer, showing sharp and chemically distinct interfaces.

By optimizing process parameters, we have enabled films with a high refractive index, high density, high dielectric constant, good stoichiometry, low roughness, and minimal impurities – key properties for device applications. Such PEALD HfO_2 layers are implemented as gate dielectrics in GaN-based metal-oxide-semiconductor (MOS) capacitors. Further investigations were carried out to observe the evolution of electrical properties under high-temperature annealing conditions. Exemplarily, Fig. 2 illustrates capacitance – voltage characteristics (at 1 MHz and 0.1 V AC signal frequency and amplitude) of un-annealed and annealed MOS capacitors in forward and reverse bias.

Building on this work, we have also fabricated Al_2O_3/HfO_2 nanolaminates for tailoring various functionalities, including refractive index, bandgap, dielectric constant, and breakdown strength. For instance, Al_2O_3/HfO_2 nanolaminate gate material-based metal-oxide-semiconductor field effect transistors (MOSFET) have demonstrated three times higher forward current and five times higher gate breakdown strength compared to pure Al_2O_3-based multilayers.

Our recent progress demonstrates a potential route to develop atomically controlled oxides such as Al_2O_3, HfO_2, and their nanolaminates with varying individual thicknesses and compositions. We are now addressing new challenges in terms of ALD process development for other oxides and nitrides and their novel applications in device technologies.

This research was funded by the YESvGaN project funded from the ECSEL Joint Undertaking (JU) under grant agreement No 101007229. The JU receives support from the European Union's Horizon 2020 research and innovation program and Germany, France, Belgium, Austria, Sweden, Spain, and Italy.

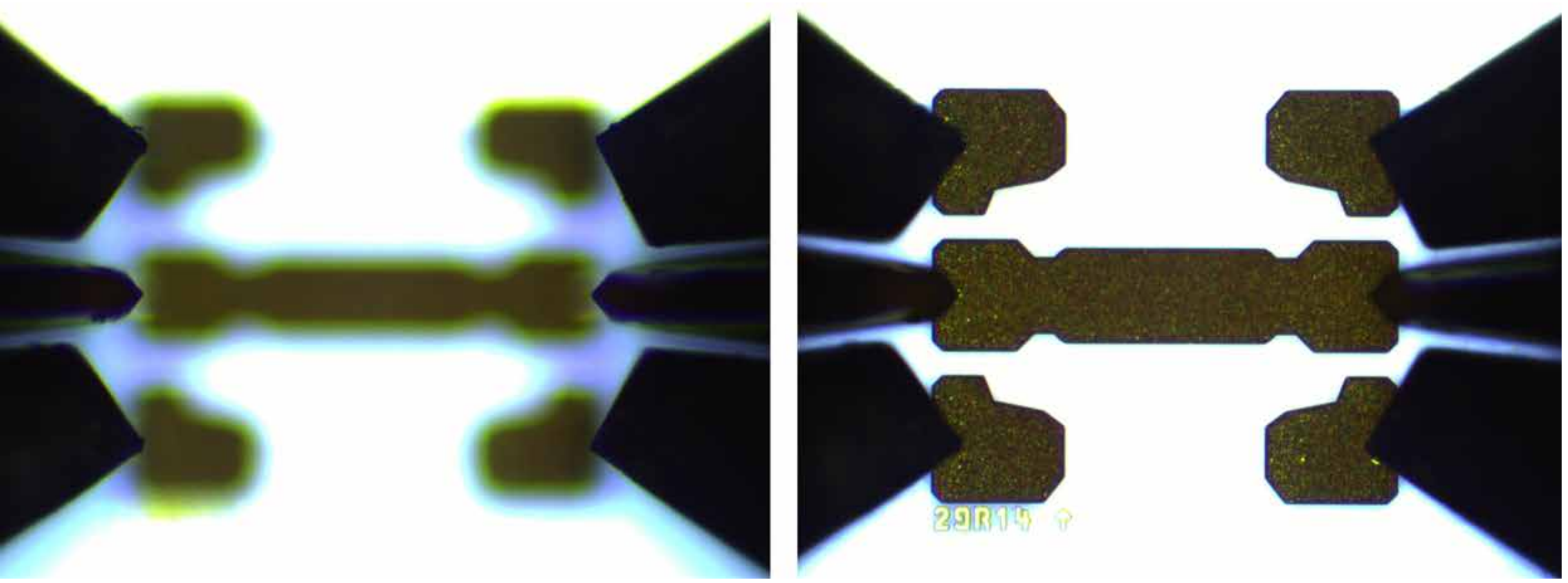


Fig. 1. Device Under Test (DUT) with the probe positions before touchdown (l.) and after the correct skating is achieved (r.).

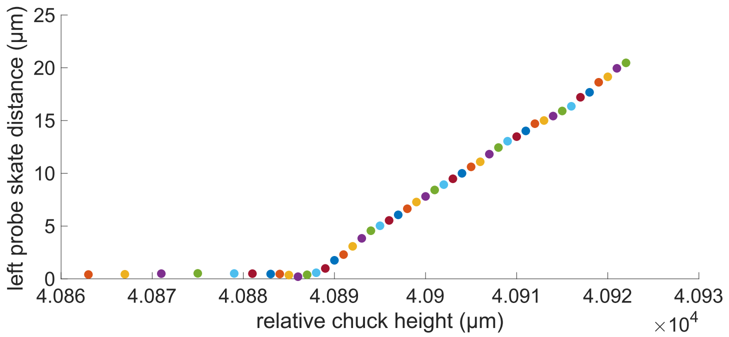
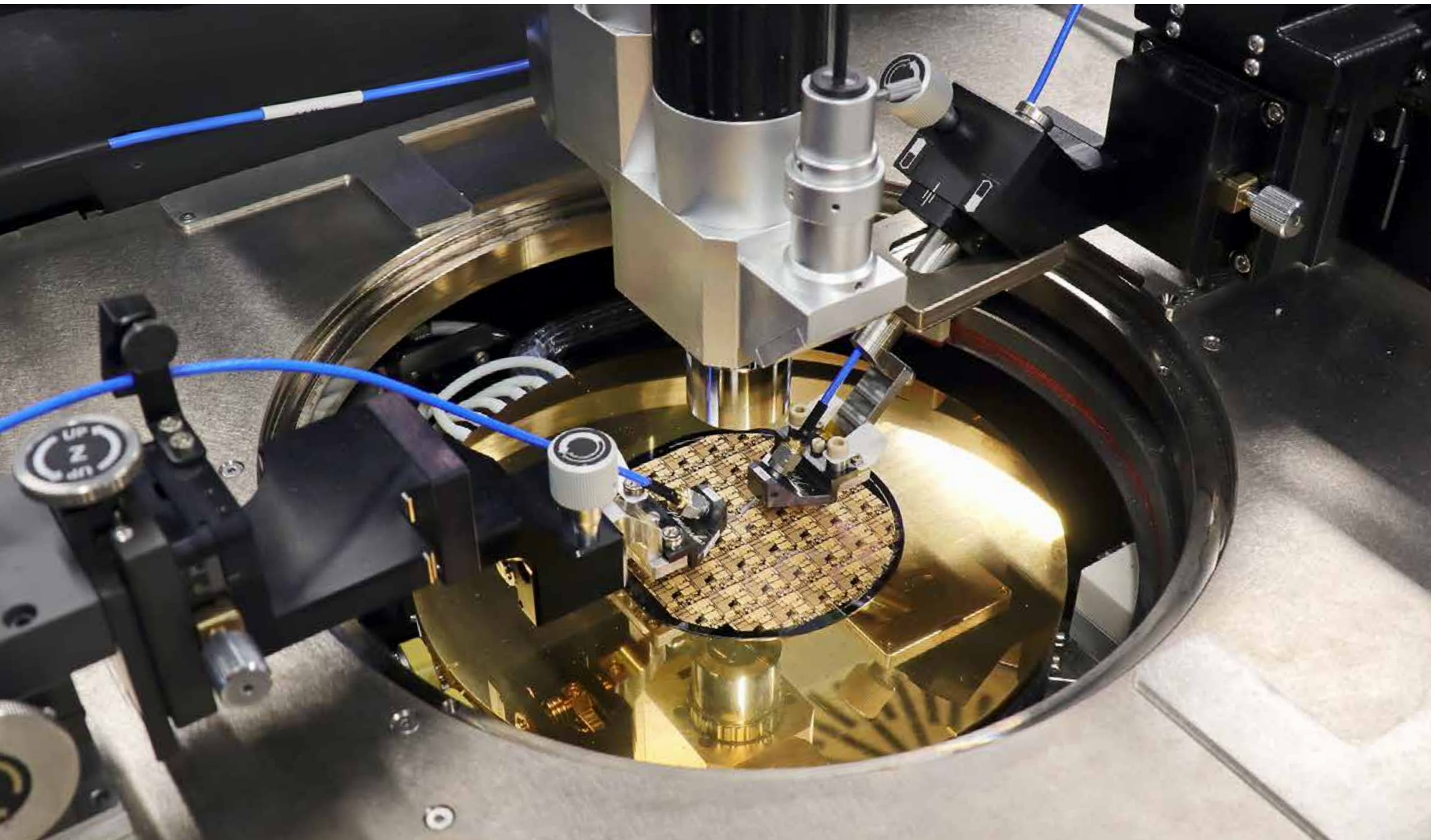


Fig. 2. Profile of the skating observed throughout the measurement process.

Fig. 3. Measuring setup, containing the automatic probe-station and the probes, with their respective manipulator, in contact with a wafer.



Advancing RF power transistor testing: precision automation with machine learning

Efficient and reliable communication systems depend on the precise analysis and optimization of high-frequency power amplifiers. These critical components are essential for advancing innovations that improve energy efficiency while maintaining the high signal quality demanded by modern applications. In today's rapidly evolving mobile and satellite communication landscape, precise RF measurement techniques are essential to meet demanding performance requirements.

Against this backdrop, the Matador project is a pioneering collaboration between FBH and Technische Universität Berlin. Financed as a high-risk, high-gain initiative as one of the winners of the Leibniz Competition in 2023, the project aims to push the boundaries of RF power transistors characterization and optimization.

In its first year, we have developed an improved on-wafer probe contacting and distance correction method that achieves probing accuracy and repeatability below 2 µm. This optically based method technique tracks probe-skating – the probe movement on the wafer after contact – in real time and terminates it when the proper skating distance is reached. The method uses the built-in microscope of the probe system and a programmable manipulator that holds one of the two probes to automatically adjust and regulate the probing of the transistors in all positions of the wafer. Thereby, irregularities on the wafer such as wafer bow can be compensated and each device properly contacted, diminishing considerably the error contribution from the probing for RF measurements up to 50 GHz.

Building on this success, we are now extending the system with an optical machine learning (ML) based detection method. This identifies the transistors and self corrects the X and Y position of the wafer so that the probing is always done correctly with respect to the probing pads. Moreover, the method enables optical recognition of various device properties, including whether it has already been probed, its type, and potential optical damages.

This work was funded through the Leibniz Competition project MATADOR "MAchine learning for Test Automation and Design-Optimization of RF power transistors", K572/2023. The measurement system was funded by the German Federal Ministry of Education and Research (BMBF) through Research Fab Microelectronics Germany (FMD), project 16FMD02.

Publications

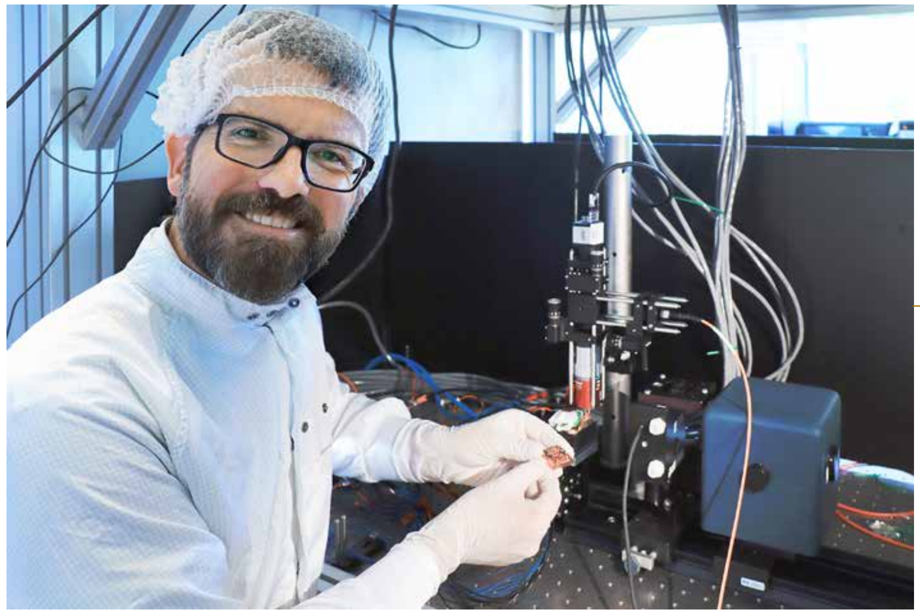
[1] D. Vitali, A. Chillico, W. Samek, O. Bengtsson, "Improved On-Wafer Probing of High-Frequency Components Based on Optical Recognition of the Probe Positions", IEEE Trans. Microwave Theory Tech. (2025).

[2] A. Chillico, D. Vitali, W. Samek, O. Bengtsson, "Automated On-Wafer Radio-Frequency Transistor Characterization with Adaptive Probing and Features Extraction with Uncertainties", International Workshop on Integrated Nonlinear Microwave and Millimetre-Wave Circuits (INMMIC), (2025).

Annex


Thomas Flisgen has been Professor of Electromagnetic Field Theory at BTU since the winter semester of 2024/25.


Tim Schröder, Professor for Integrated Quantum Photonics and head of the Joint Lab Diamond Nanophotonics.


Paul Crump assumed a visiting professorship at the University of Glasgow in August 2024.

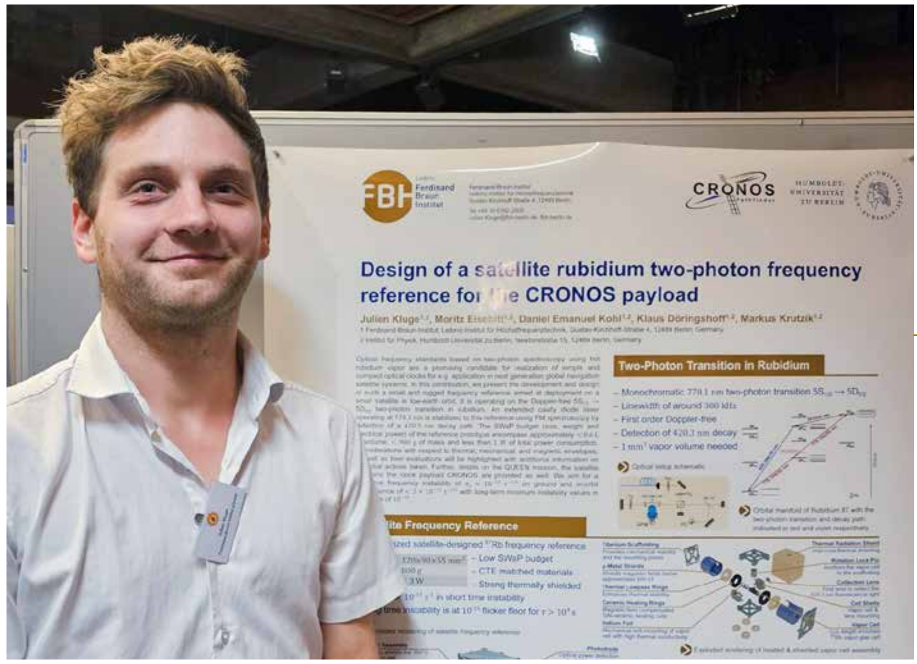
Scientific excellence – personnel and awards

In 2024 / 2025, we once again delivered excellent research results. Numerous FBH employees were recognized with awards and prestigious research grants and were appointed to professorships. Additionally, many FBH publications were again featured among the Editor's Picks of renowned journals.

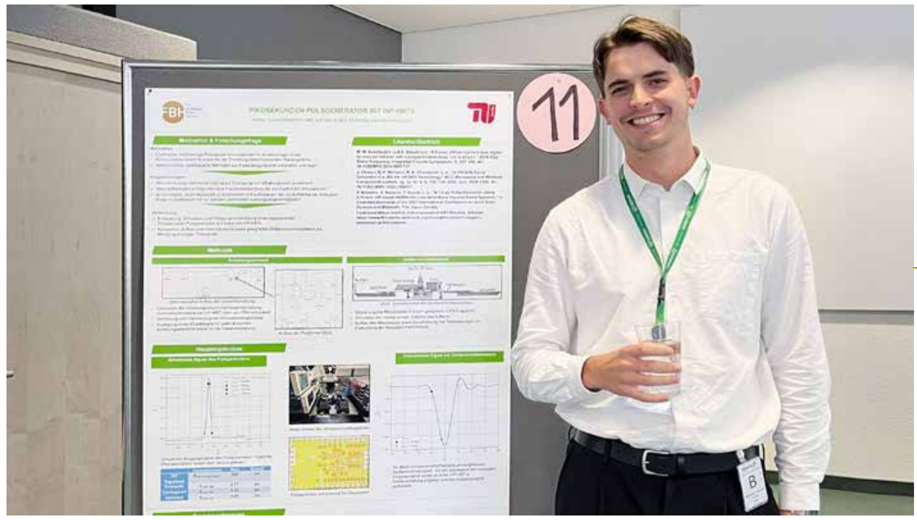
Thomas Flisgen appointed Professor of Electromagnetic Field Theory. Thomas Flisgen has been appointed Professor of Electromagnetic Field Theory at the Brandenburg University of Technology Cottbus-Senftenberg (BTU) starting in the winter semester of 2024 / 25. In this role, he will drive research and teaching in the field of electromagnetic field computation and further strengthen the strategic partnership between BTU and FBH.

ERC Consolidator Grant for Tim Schröder. Tim Schröder has been awarded a Consolidator Grant from the European Research Council (ERC) for his research in the field of quantum physics and quantum technology. The funding for the research project "Multidimensional Hyperentangled Photon Graph States" amounts to around 2.5 million euros over five years. The ERC grants are among the most prestigious awards in European research funding and are awarded for outstanding scientific achievements.

Newly established visiting professorship of Paul Crump. FBH and the University of Glasgow are deepening their cooperation, focusing on ultra-high-power photonic applications. As part of this, Paul Crump assumed a visiting professorship in Scotland in August 2024. He is working closely with Stephen Sweeney's group at the James Watt School of Engineering to further strengthen the partnership between two of the world's leading institutes in photonics.



Julien Kluge at the Hot Atomic Vapor Workshop.



Awarded for his Master's thesis: Sebastian Ahrens.

WOCSDICE-EXMATEC 2024 Best Student Paper Award for Petros Beleniotis. Petros Beleniotis received the Best Student Paper Award at the WOCSDICE-EXMATEC 2024 conference in Heraklion, Crete, Greece for his paper "A Computational Modeling Method for Performance Optimization of GaN HEMT".

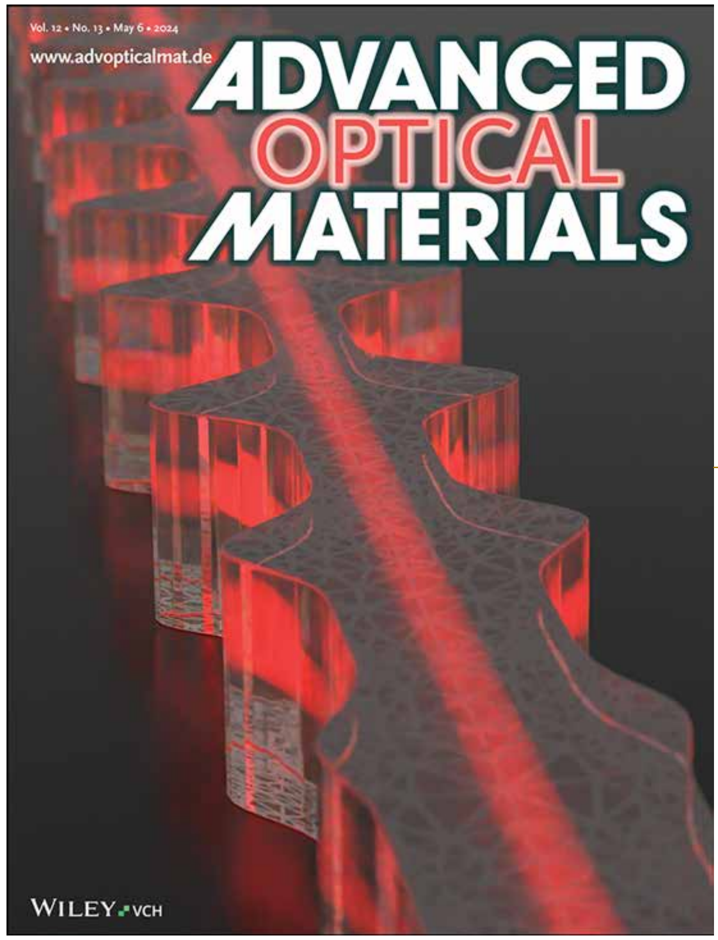
ESLW Best Student Talk Award for Nor Ammouri. Nor Ammouri was honored with the Best Student Talk Award for her presentation "364 W high pulse power laser with multiple epitaxially stacked active regions for LiDAR applications" at the European Semiconductor Laser Workshop 2024 (ESLW) in Kassel.

Thomas Tenzler receives ESLW Best Student Poster Award. Thomas Tenzler received the Best Student Poster Award at the European Semiconductor Laser Workshop 2024 (ESLW) in Kassel. He presented simulation results of a Bragg reflection waveguide laser from the VOMBAT project.

Hot Atomic Vapor Workshop Poster Price for Julien Kluge. Julien Kluge was awarded the Poster Price at the Hot Atomic Vapor Workshop 2024 in Stuttgart. He presented a design of a satellite rubidium two-photon frequency reference for the CRONOS payload.

Third Place ARGUS Science Award for Sebastian Ahrens. Sebastian Ahrens was awarded third place in the ARGUS Science Award for his master thesis entitled "Picosecond Pulse Generator with InP-HBT Circuit Design and Development of a Time-Domain Measurement Setup."

One half of the winning team: Sascha Neinert with the jury prize won by him and Kirti Vardhan.



The Sawfish design by Julian M. Bopp et al.
on the cover of „Advanced Optical Materials".

MyoQuant awarded jury prize at the Berlin Quantum Pioneer Days. Sascha Neinert and Kirti Vardhan were awarded the jury prize of the Berlin Quantum Pioneer incubation program for their research work carried out in the MyoQuant project.

Joint paper on the cover of "Advanced Optical Materials". The publication "'Sawfish' Photonic Crystal Cavity for Near-Unity Emitter-to-Fiber Interfacing in Quantum Network Applications" by Julian M. Bopp et al. and further authors from FBH, Zuse Institute Berlin and Humboldt-Universität zu Berlin made the cover of "Advanced Optical Materials" Volume 12, Issue 13.

Publication selected as Editor's Pick in APL Photonics. The publication "GaAs-based photonic integrated circuit platform enabling monolithic ring-resonator-coupled lasers" by Jan-Philipp Koester et al. has been published in APL Photonics and selected as an Editor's Pick.

Publication in Optics Express selected as Editor's Pick. "Micro-integrated crossed-beam optical dipole trap system with long-term alignment stability for mobile atomic quantum technologies" by Marc Christ et al. has been selected as an Editor's Pick in the current issue of Optics Express.

Events – conferences, workshops, and trade fairs

Last year, FBH was again represented at numerous international trade fairs and conferences. We were able to exchange ideas with the professional community, present current results, and showcase the range of services our institute offers.

Selected event highlights on international stages

At this year's **DPG Spring Meetings** in Berlin and Freiburg, we presented our latest research in photonics, quantum sensing, and AlGaN and InGaN technology through numerous talks.

At the **CLEO Conference** in Charlotte, North Carolina (USA), we showcased innovations in laser and quantum technologies to the expert community.

Our contributions to the **12th International Workshop on Nitride Semiconductors** in Taipei (Taiwan) focused on advancements in group-III nitride materials, nanostructures, and devices.

We presented our optical, optoelectronic, and photonic components for space applications at the **International Conference on Space Optics** in Antibes Juan-les-Pins (France).

At the **IEEE Photonics Conference** 2024 in Rome (Italy), our scientists delivered several invited talks and participated in various committees.

We contributed numerous (keynote) talks and served on the organizing and program committees at the 2024 **European Semiconductor Laser Workshop** in Kassel.

At the **International Microwave Symposium (IMS)** in Washington, DC (USA), we shared our expertise in InP-HBT technology for 5G applications.

Our GaAs-based VCSEL structures took center stage at the **21st International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE XXI)** in Las Vegas (USA).

We also participated in regional scientific discussions at the **iCampµs Cottbus Conference (iCCC2024)** and the **Adlershof Research Forum** in Berlin, where our scientific managing director Patrick Scheele delivered a talk.

Photonics West in San Francisco (USA), the largest international photonics event, marked the beginning of our 2025 event calendar. We showcased our entire diode laser portfolio – from design and chip development to modules and prototypes. In addition to advanced semiconductor-based light sources, we presented novel quantum light modules and the powerful direct-diode laser system "Samba," accompanied by 18 scientific talks at the conference sessions.

Find out where else to meet us.

The Long Night of Science once again attracted numerous visitors.

Full house and eager attention at Mädchen-Technik-Kongress.

A week full of workshops: the first Green ICT Camp at FBH.

Research for everyone

On June 22, 2024, it was that time again: During the **Long Night of Science,** science enthusiasts explored the world of microchips, rice-grain-sized diode lasers, and microelectronic devices at our institute. Both children and adults took part in hands-on experiments and toured our cleanroom and specialized labs.

In 2024, we continued our commitment to encouraging more girls and young women to pursue STEM studies or vocational training. At the **Mädchen-Technik-Kongress,** organized by the FBH-based ANH Berlin network, 158 students explored roles as researchers, programmers, or lab technicians. Many also took advantage of Girls'Day and the **Ausbildungs-Allianz-Adlershof** to learn about career opportunities in high-tech fields. Additionally, we participated for the first time in the Berlin-based **EnterTechnik** initiative, offering participants insights into epitaxy, process technology, precision mechanics, and IT through a voluntary technical year.

In September 2024, we hosted the first **Green ICT Camp,** coordinated by the Research Fab Microelectronics Germany (FMD). Fifty students learned about cutting-edge mobile communication technologies, explored their environmental impacts, and gained insights into assessing these effects through life cycle analysis. (see page 31)

Anastasia Schröder standing in front of her working place, FBH's cleanroom.

We also participated in other training and internship fairs, such as **Kick & Work, Stuzubi Berlin,** and **Vocatium.**

In September 2024, the Leibniz Association's **Book a Scientist** format offered exciting insights into current research topics. **Tim Schröder** answered questions on "Technology with a glamour factor – what diamonds have to do with quantum technologies."

In the podcast series **Weiß der Adler** by FluxFM, Danilo Höpfner explores the science and media hub of Adlershof. In March 2024, **Markus Krutzik** provided insights into the world of quantum research. In September, our trainee **Anastasia Schröder** shared what she enjoys about her work as a microtechnologist.

How to get in touch

Ferdinand-Braun-Institut gGmbH,
Leibniz-Institut für Höchstfrequenztechnik
Gustav-Kirchhoff-Str. 4
12489 Berlin, Germany

Phone +49 30 6392-2600
Fax +49 30 6392-2602
Email fbh@fbh-berlin.de
Web www.fbh-berlin.de

Scientific Managing Director
Prof. Dr.-Ing. Patrick Scheele
Phone +49 30 6392-2601
patrick.scheele@fbh-berlin.de

Administrative Managing Director
Dr. Karin-Irene Eiermann
Phone +49 30 6392-58003
irene.eiermann@fbh-berlin.de

Assistant to the Management / Science Management
Doreen Friedrich, M.Sc., Dipl.-Ing. (FH)
Phone +49 30 6392-3391
doreen.friedrich@fbh-berlin.de

Assistant to the Administrative Managing Director
Dr. Sabine Spohner
Phone +49 30 6392-58005
sabine.spohner@fbh-berlin.de

Head of HR / People Department
Janine Falkenberg, LL. M. (FH)
Phone +49 30 6392-58217
Janine.falkenberg@fbh-berlin.de

Head of Communications
Petra Immerz, M.A.
Phone +49 30 6392-2626
petra.immerz@fbh-berlin.de

Central contact for research areas

Photonics
Prof. Dr.-Ing. Patrick Scheele
Phone +49 30 6392-2601
patrick.scheele@fbh-berlin.de

III-V Electronics
Prof. Dr.-Ing. Wolfgang Heinrich
Phone +49 30 6392-2620
wolfgang.heinrich@fbh-berlin.de

Integrated Quantum Technology
Dr. rer. nat. Andreas Wicht
Phone +49 30 6392-3958
andreas.wicht@fbh-berlin.de

III-V Technology
Prof. Dr. rer. nat. Markus Weyers
Phone +49 30 6392-2670
markus.weyers@fbh-berlin.de

Ferdinand-Braun-Institut gGmbH,

Leibniz-Institut für Höchstfrequenztechnik

Gustav-Kirchhoff-Str. 4

12489 Berlin, Germany

Phone +49 30 6392-2600

Fax +49 30 6392-2602

Email fbh@fbh-berlin.de

Web www.fbh-berlin.de

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Editors

Petra Immerz, Aiko Onken

Contributing authors (research)

Eldad Bahat Treidel, Olof Bengtsson, Gunnar Blume, Enrico Brusaterra, Alessandro Chillico, Paul Crump, Jonas Hamperl, Oliver Hilt, Katja Höflich, Jan-Philipp Koester, Megha Krishnaji Rao, Reza Mahani, Martin Maiwald, Igor Nechepurenko, Sascha Neinert, Ina Ostermay, Katrin Paschke, Pallabi Paul, Tommaso Pregnolato, Adam Rämer, Jens Raß, Jan Ruschel, Tim Schröder, Kornelius Tetzner, Aleksei Tsarapkin, Domenico Vitali, Andreas Wentzel, Hans Wenzel, Hady Yacoub

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