ANNUAL REPORT
2025 | 2026

Leibniz
Ferdinand
Braun
Institut

Topics inlude:

Shaping the quantum future:
from fundamental research to real-world applications

FBH space strategy:
integrated, reliable, transferable

Strengthening Europe's semiconductor ecosystem
with APECS

Research with impact – key technologies "made in Germany"

Germany's High-Tech Agenda sets a clear direction: research and innovation must strengthen technological sovereignty, economic resilience, and international competitiveness.

The agenda identifies key technologies and strategic research fields that will shape future value creation – from microelectronics and quantum technologies to aerospace, security research, and climate-neutral energy generation. Many of these priorities directly reflect FBH's research profile, which clearly confirms our long-term strategic direction.

With our expertise spanning the entire value chain – from design and chip development to manufacturing and fully integrated prototypes – we develop high-performance photonic, electronic, and quantum technology components for applications in communication, sensing, medicine, aerospace, and future energy systems. As a research partner to both industry and science, we not only drive technological innovation but also provide important scientific and technical impetus to the economy – regionally, nationally, and internationally.

Our work builds on FBH's state-of-the-art cleanroom and laboratory infrastructure. Through initiatives such as the APECS pilot line within the European Chips Act, we contribute to strengthening resilient semiconductor production and advanced heterogeneous integration technologies in Europe together with partners from Research Fab Microelectronics Germany (FMD) and across the EU.

Skilled professionals are essential for technological innovation. Supported by the Federal Ministry of Research, Technology and Space, we are establishing the Microtec Academy as a nationwide education and training network for microelectronics and microsystems technology. Together with partners from industry, research, and education, the academy develops modern qualification pathways – from vocational training to academic education and lifelong learning. Digital learning environments and hands-on training formats will help secure the next generation of specialists for Germany's and Europe's semiconductor industry.

Research, technology, administration, and all science-supporting activities at FBH rely on the dedication of the people behind them. Our sincere thanks therefore go to all employees whose expertise, creativity, and commitment make our achievements possible. We are equally grateful to our customers and long-standing partners for their trust and successful collaboration. Together, we continue to develop technologies that address key societal and industrial challenges.

We also like to thank the State of Berlin and the Federal Government for their continued support, which forms the foundation of our R&D activities.

On the following pages, we invite you to explore the projects, developments, and milestones that shaped the past year at FBH. We hope you enjoy reading and discovering them.

Patrick Scheele & Karin-Irene Eiermann

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Profile & structure

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

Ferdinand-Braun-Institut (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.

In photonics, 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. Applictions range from materials processing, medical technology, and high-precision metrology to optical communication in space.

In quantum technologies, we translate laboratory-scale proof-of-concept experiments into robust, application-ready systems. Developments include quantum photonic components, hybrid micro-integrated modules, compact quantum sensors, diamond nanophotonic devices, and photonic quantum chips for secure communication, high-precision measurements, sensors, and computing platforms.

Advancing device fabrication with FBH's state-of-the-art plasma etching technology.

In high-frequency electronics, we develop high-efficiency multi-functional microwave power amplifiers and millimeter-wave transceivers targeting energy-efficient wireless communications, radar, industrial sensing, and imaging. In addition, the institute specializes in heterogeneously integrated broadband MMICs and high-speed drivers for high-power diode lasers.

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 and Master theses as well as PhDs.

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 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 also p. 38).

More about us and our profile.

How we are organized – FBH's structure

FBH structures its research in labs and departments across four core areas: III-V Technology, III-V Electronics, Photonics, and Integrated Quantum Technology. Within this framework, we collaborate closely with universities through Joint Labs.

An efficient administration underpins all research and development activities. Teams in human resources, finance and controlling, procurement, and IT services provide targeted support. Technical services ensure the reliable operation of laboratories and cleanrooms.

A process-oriented quality management system and the communications unit strengthen and complement FBH's core capabilities. Through the Innovation & Technology Transfer Department, we also drive our technology transfer activities as well as vocational training and further education in high technology.

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 euros.

leibniz-gemeinschaft.de/en

Leibniz Association

How we have developed – facts and figures

Founded 1992

2024

Staff

393 Employees

155 Scientists

47 PhD candiates

29 Student assistants & bachelor / master students

12 Trainees

Key figures

163 Third-party funded projects

105 Peer-reviewed publications

273 Patents

161 Talks (33 of which invited)

Revenue
(in million €)

19.6 Basic funding: State of Berlin & Federal Government (1 dot equals 100,000 €)

20.9 Public third-party funding

4.0 Industrial contracts

2025

Staff

393 Employees

163 Scientists

43 PhD candiates

26 Student assistants & bachelor / master students

10 Trainees

Key figures

131 Third-party funded projects

140 Peer-reviewed publications

295 Patents

180 Talks (29 of which invited)

Revenue
(in million €)

19.6 Basic funding: State of Berlin & Federal Government (1 dot equals 100,000 €)

20.6 Public third-party funding

4.2 Industrial contracts

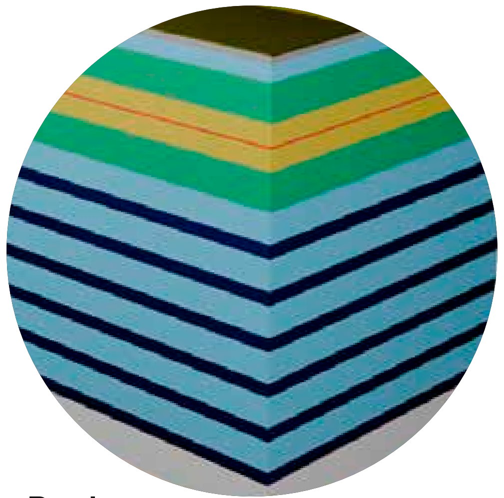
What we offer – advanced technologies & services

We leverage our comprehensive expertise, dedicated staff, and more than 4,000 sqm of state-of-the-art cleanroom and laboratory facilities to cover the full value chain in-house.

Our portfolio covers customized R&D services in the areas of epitaxy and processing, the development of customer-specific chips and modules, and the provision of fully integrated plug-and-play prototypes.

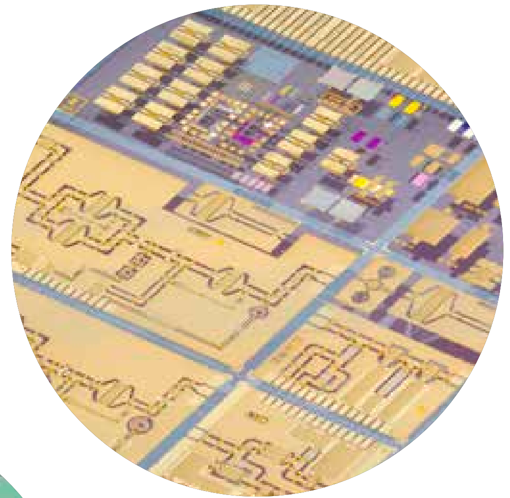
We strengthen these capabilities through strategic partnerships with leading research institutions. In ten Joint Labs, we work closely with universities to advance key technologies. As part of **Research Fab Microelectronics Germany (FMD)**, we collaborate with 14 partners to drive European chiplet innovation. The cross-institutional **APECS pilot line** – Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems – bundles diverse technologies on a single platform and sets new standards in advanced packaging and heterogeneous integration.

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

Your partner across the whole process chain

Ways of cooperating with us:

- Joint research projects
- Industrial contracts
- Small-series production
- Prototypes
- Consulting
- Technology services
- Technology transfer

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

Highlights

Shaping the quantum future: from fundamental research to real-world applications

Quantum technologies (QT) have become an important field of research and development (R&D) worldwide. As more and more applications emerge, economic interest grows. Against this backdrop, our research area Integrated Quantum Technology has expanded significantly in recent years.

A decisive advantage lies in our ability to cover the entire innovation chain in-house. Our activities span material-level fundamental R&D and extend to modules and systems for quantum sensing, communication, and imaging. This breadth places us in a strong position as QT rapidly transitions from laboratory concepts to real-world deployment.

FBH highlights in 2025

1 A major milestone was the founding of **Rydberg Photonics** as a spin-off. This step extends our successful transfer model to the strategically important QT domain. The company builds directly on our long-standing expertise in high-performance, micro-integrated photonic solutions for quantum systems and demonstrates how application-driven research at FBH can be made commercially viable.

2 At the component level, we have developed **micro-optical isolators** for various wavelengths, including 423, 689, 698 and 854 nm. These devices facilitate hybrid micro-integration of laser modules at wavelengths below 770 nm, supporting applications such as strontium atomic clocks (~700 nm) and calcium-ion-based quantum computing systems operating around 400 nm.

Rydberg Photonics

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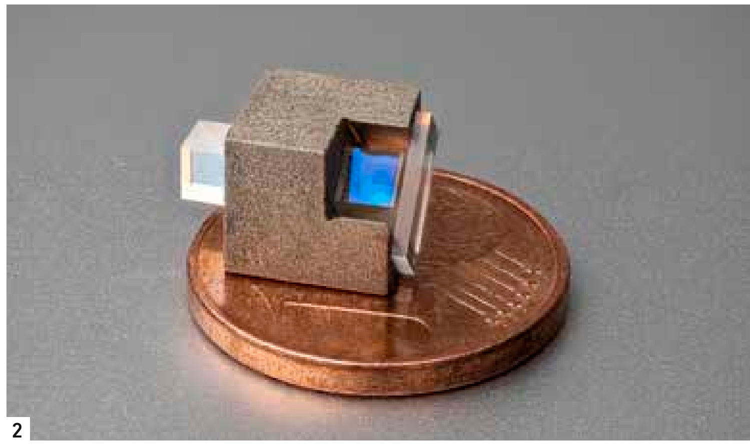

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Miniaturized optical isolator with 30 dB isolation for wavelengths between 400 and 950 nm.

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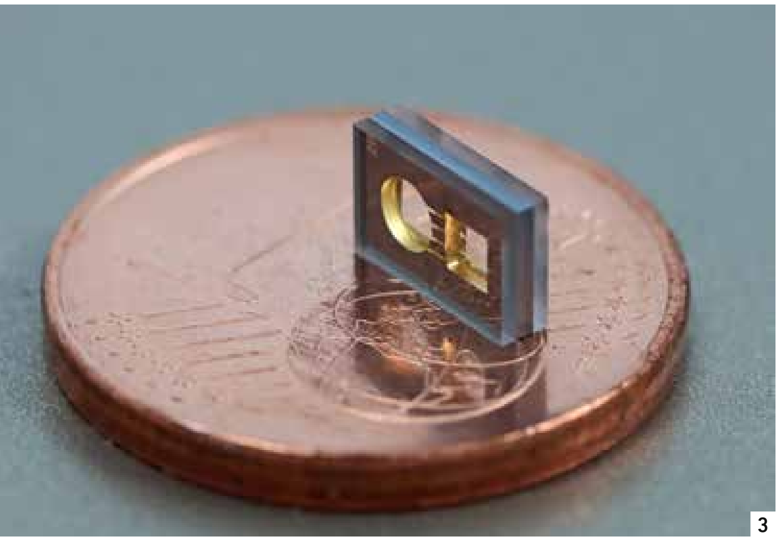
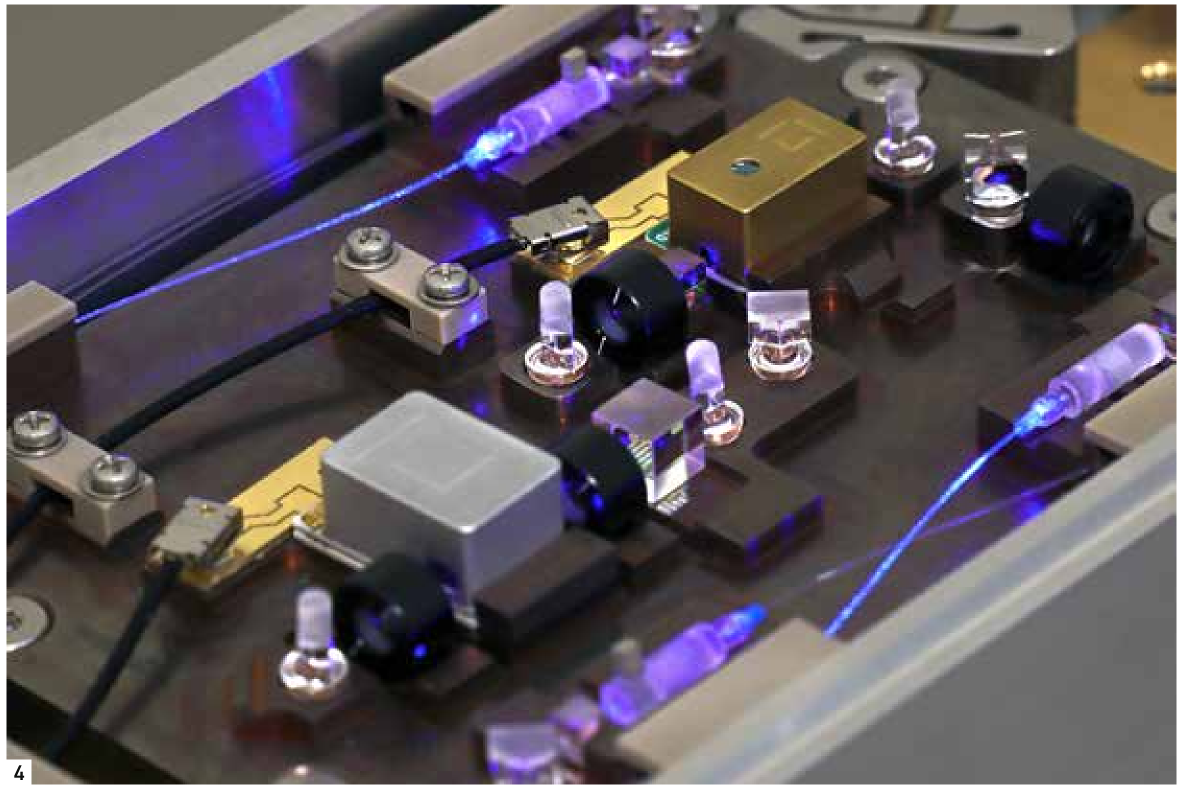


Microfabricated alkali vapor cell.

3 Alkali vapor cells exemplify another successful development with strong and growing demand. As a key component of many integrated atomic devices, their size, weight, reliability, and production cost directly determine both applicability and economic viability. We have developed a fabrication technology for miniaturized vapor cells that addresses the requirements of future mobile quantum applications, including navigation, sensing, and telecommunications.



Detail of a light-control unit for strontium-based optical clocks.

4 For the first time, we realized **light control units** featuring miniature electro- and acousto-optic modulators for quantum sensing and atomic clock applications within the QUASENS project. In combination with our hybrid micro-integrated laser modules, these developments enable us to offer miniaturization of all photonic modules needed for quantum sensing and quantum computing applications.

Fully assembled, very compact Quick^3 payload with dimensions of only 10 x 10 x 15 cm^3, including single-photon source and quantum experiment. The gray box contains the FBH laser unit.

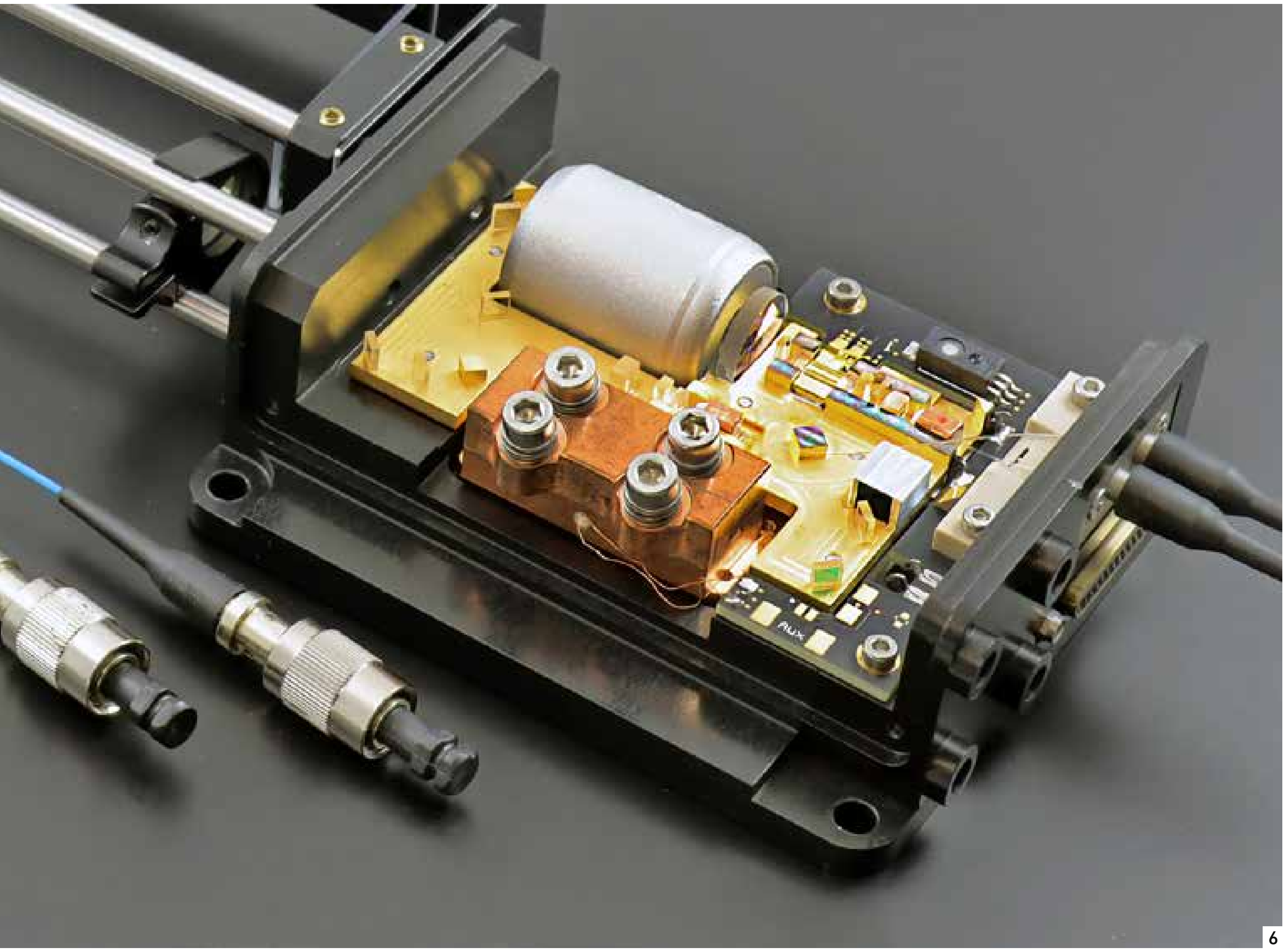
The development of ECDL-MOPA laser modules for space deployment has reached an important milestone. We implemented a **patented isostatic mounting concept** for the micro-optical bench of photonic modules that decouples the bench from mechanical and thermo-mechanical stress exerted onto the housing while maintaining excellent thermal heat dissipation. The design successfully passed random vibration and mechanical shock tests at load levels required for a rideshare launch on a SpaceX Falcon 9.

5 We also expanded our activities toward cost-efficient, space-related quantum satellite applications. In 2025, an FBH-built laser system based on the **New Space approach** was successfully launched into space. The Quick^3 nanosatellite mission targets fast and secure quantum-based communication. New Space solutions are breaking new ground and demonstrate how innovative quantum technologies can support next-generation navigation, Earth observation, and time measurement systems – at lower cost.

> A decisive advantage lies in our ability to cover the entire innovation chain in-house.

Our **quantum light modules** use entangled photons to advance and miniaturize systems for mid-infrared (MIR) hyperspectral imaging and quantum OCT sensing. In this approach, one photon interacts with the sample in MIR, while its entangled counterpart transfers the information to a standard silicon-based spectrometer operating in the near-infrared (NIR) spectral range.

Since NIR detection technology is far more cost-efficient and easier to integrate than MIR detection systems, the modules enable sensitive measurements in a compact and robust setup. The team behind these modules combines expertise in laser technology and miniaturization from our Laser Modules Lab with the know-how of our Prototype Engineering Lab, to create customized plug-and-play solutions that integrate individual components into highly complex modules ready for seamless system integration.



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Quantum light source for early cancer diagnostics.

6 We also advanced quantum-enabled photonic technologies with clear application potential. A prominent example are FBH's **quantum light sources** for medicine and life sciences. Using high-power diode lasers emitting at 1170 nm and 720 nm, we generate entangled photon pairs for quantum imaging. The approach relies on "measurement by undetected photons," where mid-infrared light probes tissue while near-infrared photons carry the image information. This method reduces system complexity, shortens measurement times, and enables cost-efficient diagnostics. Within the QEED project, we translated this concept into compact modules and take an important step toward faster early cancer diagnostics.

In 2025, we also submitted a QT-related project proposal that succeeded in the **Leibniz Competition** and has received 1 M€ funding for three years starting March 2026. The TeleQuaM project focuses on chip-integrated quantum memories for the telecom range. We will develop such a memory based on a scalable photonic platform incorporating a thin film of silicon carbide. This way, we aim to advance quantum functionalities such as quantum communication toward integration into everyday devices.

These examples illustrate how we combine scientific excellence with a strong focus on applications. As quantum technologies gain relevance for technological competitiveness and economic value creation, FBH is well positioned to actively shape this rapidly evolving field.

Joint Labs: successfully connecting fundamental research and application

7 Collaboration remains core to our strategy. We work closely with industrial partners as well as with leading research institutions, thus bridging the gap between fundamental research and application. In 2025, we established the Joint Lab Nonlinear Quantum Optics together with Sven Ramelow. This new lab complements the four existing Joint Labs with Humboldt-Universität zu Berlin (HU Berlin). By pooling expertise and infrastructure, the initiative further accelerates interdisciplinary research and technology development, targeting new QT applications in environmental analysis, medicine, and information processing.

The appointment of Markus Krutzik, Head of our Joint Lab Integrated Quantum Sensors, to a professorship at HU Berlin additionally strengthens our position in quantum sensing and atom-based technologies.

The outcome within our Joint Labs has also received strong recognition. The QPIS project, led by Tim Schröder, Head of our Joint Lab Diamond Nanophotonics, secured the BMFTR Grand Challenge for Quantum Communication. In addition, Marco Stucki won the Berlin University Alliance Ideas Competition for innovative concepts at the interface of science and application. These achievements highlight both the scientific excellence of our Joint Labs and their relevance for society and future technologies.

7

Two of FBH's five Joint Lab heads in quantum technology: Markus Krutzik (left) and Sven Ramelow (right).

FBH space strategy: integrated, reliable, transferable

FBH pursues a coherent space strategy that combines scientific excellence with technology readiness and clear pathways to application and transfer. We develop electronic, photonic, and quantum technologies that meet the demanding requirements of space missions while remaining scalable and transferable to other domains.

8

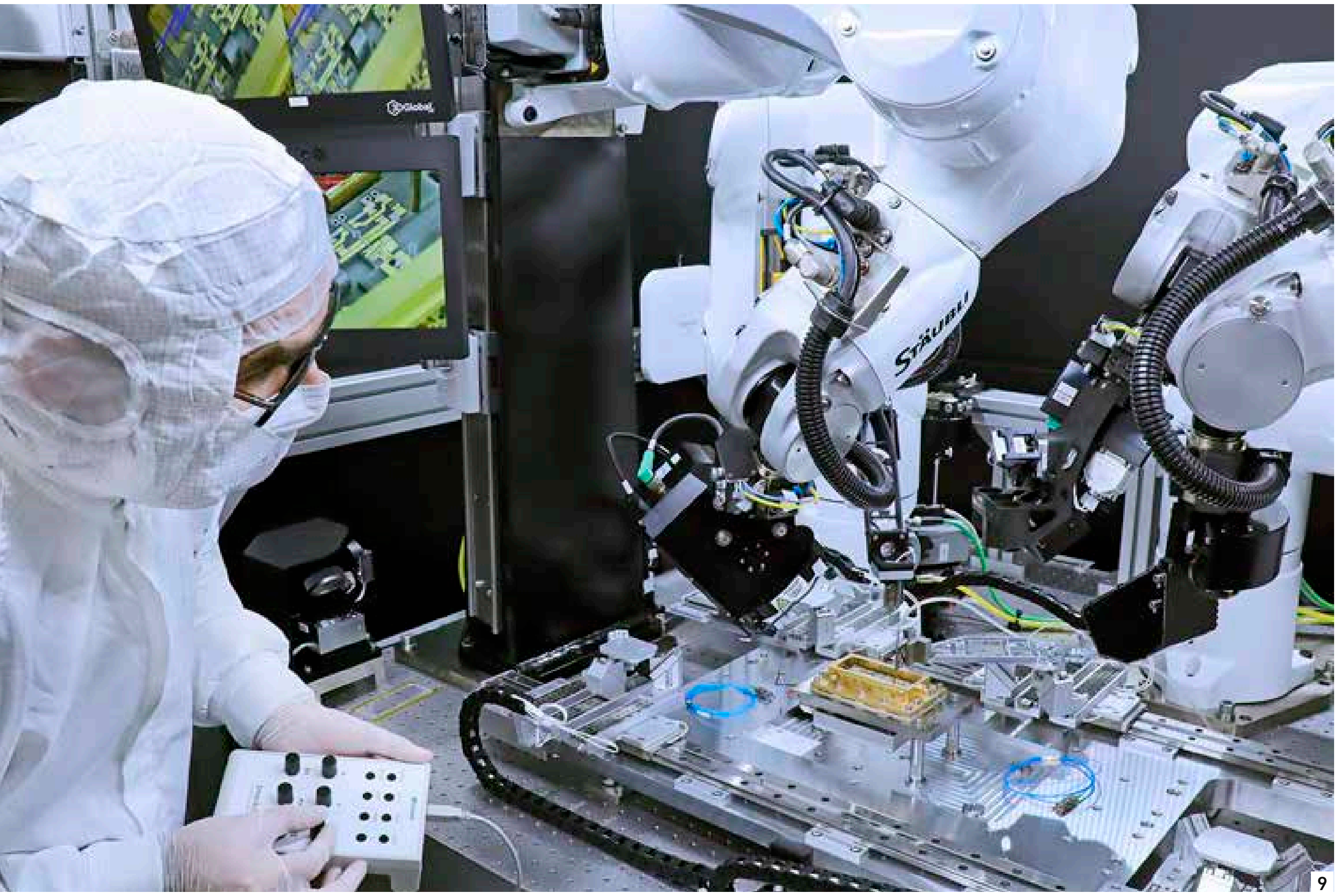
461 nm light-control unit for strontium-based optical clocks, targeting space applications.

8 Our strategic focus is on the development of robust III-V semiconductor components, photonic modules, and integrated quantum systems for sensing, communication, navigation, and earth and space observation, with a strong emphasis on LiDAR, secure optical links, quantum sensors, and optical clocks. We advance solutions from discrete III-V semiconductor devices toward hybrid-integrated modules and full systems, enabling high performance under constraints of size, weight, power, and cost (SWaP-C).

> We develop electronic, photonic, and quantum technologies that meet the demanding requirements of space missions.

That is pretty much what our recently opened cleanroom looked like before. Today, the new infrastructure meets the demanding requirements of **module development for space and quantum technology applications**. A team from our Joint Lab Quantum Photonic Components transformed the empty lab space into a highly functional laboratory for hybrid micro-integration and the production of compact, robust, and reliable photonic modules.

The facilities include specialized workstations for characterization and ultra-precise assembly as well as a collaborative robotic integration platform that supports and accelerates the assembly of complex modules with nanometer precision. Much of the planning and implementation was carried out in-house and only made possible through the team's exceptional dedication and many extra hours of work. The project required careful design of the laboratory infrastructure, including ventilation and supply systems, and close collaboration with construction specialists.



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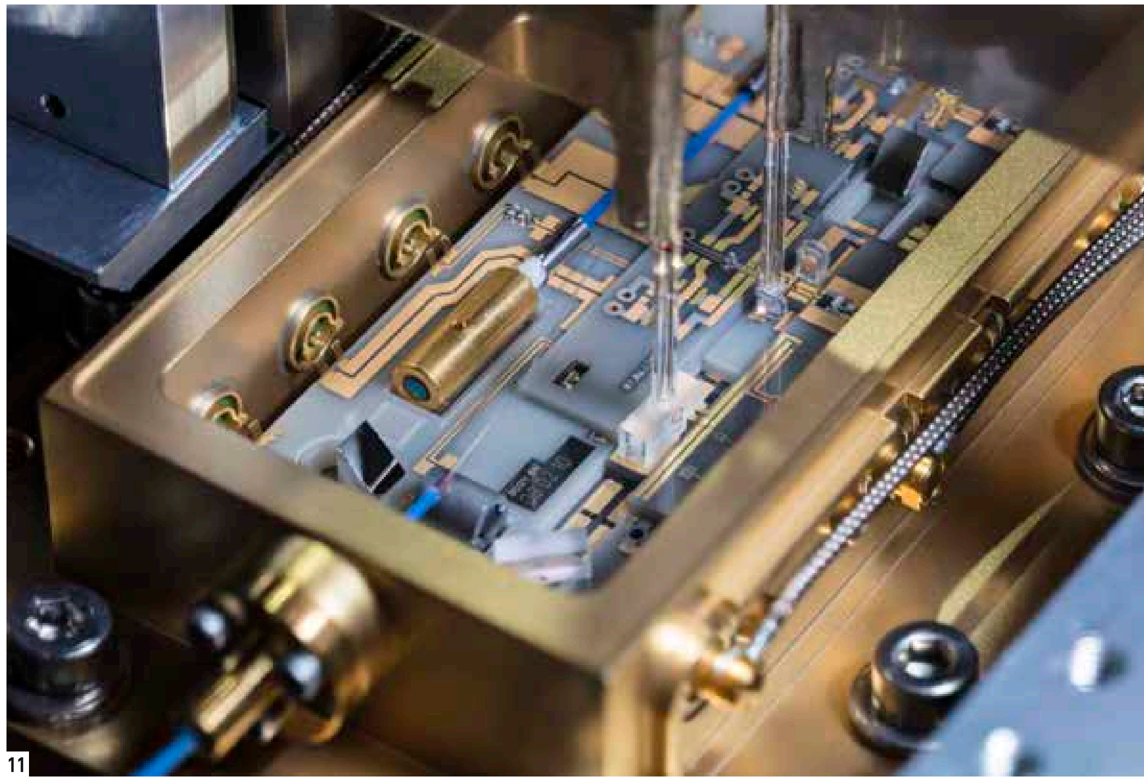
Speeding up processes: robotic setup for ultra-precise micro-integration of photonic modules for challenging space environments.

9 A distinguishing element of our space activities is the **systematic integration of product assurance** (PA) and space standards into research and development. To this end, we offer the integration of critical flight hardware in an ISO5 cleanroom environment. In addition, we maintain a dedicated PA expertise at FBH, based on the European Cooperation for Space Standardization (ECSS) requirements, to ensure reproducibility, reliability, and qualification readiness. This capability forms the basis for cooperation with national and international space agencies and industrial partners. We actually take it one step further and offer research groups, SMEs, and start-ups access to proven space-capable technologies as a technology incubator.

10 3D-printed, space-ready components are gaining importance in space applications. At FBH, we provide the required infrastructure and have successfully demonstrated additively manufactured components for space use, including frequency references and optically pumped magnetometers. These technologies open new design freedoms and enable a high level of functional integration, while significantly reducing mass and assembly complexity. Additive manufacturing thus supports rapid prototyping, mission-specific customization, and the realization of compact, high-performance space systems.

11 Looking forward, our strategy emphasizes **miniaturization and integration** through photonic integrated circuits and heterogeneous integration, including novel material platforms. By building on established heritage and addressing both high technology-readiness-level (TRL) applications and fundamental quantum research, we aim to deliver reliable, high-impact technologies for space missions and beyond.



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Space-compatible high-precision microintegration technology at FBH.

10

Miniaturized optical frequency reference module with rubidium vapor cell, enabled by additively manufactured technical ceramics.

Strengthening Europe's semiconductor ecosystem with APECS

For more than a year now, FBH has been contributing its expertise in III-V electronics and photonics to the APECS pilot line (Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems). Established under the EU Chips Act, APECS forms a pan-European infrastructure aiming to accelerate the industrial transfer of advanced packaging, chiplet, and heterogeneous integration technologies.

The pilot line provides access to design, pilot manufacturing, and system-level integration for industry, SMEs, start-ups, and research organizations, thereby reinforcing resilient and secure European semiconductor value chains. By anchoring key competencies in advanced integration within Europe, APECS directly supports the goal of technological sovereignty and reduces dependencies on non-European technologies.

Heterogeneous integration at FBH: combining the best of two technology worlds

Heterogeneous integration forms a central pillar of FBH's research and technology development within the APECS pilot line. We contribute key processes that combine the strengths of group-III-V compound semiconductors with mature silicon platforms, targeting scalable, high-performance solutions for next-generation electronic and photonic systems. The activities address two areas: heterogeneous integration of indium phosphide (InP) on BiCMOS for high-frequency electronics and gallium arsenide (GaAs) laser chiplets on silicon nitride carriers using micro-transfer printing.

> *We contribute key processes that combine the strengths of group-III-V compound semiconductors with mature silicon platforms.*

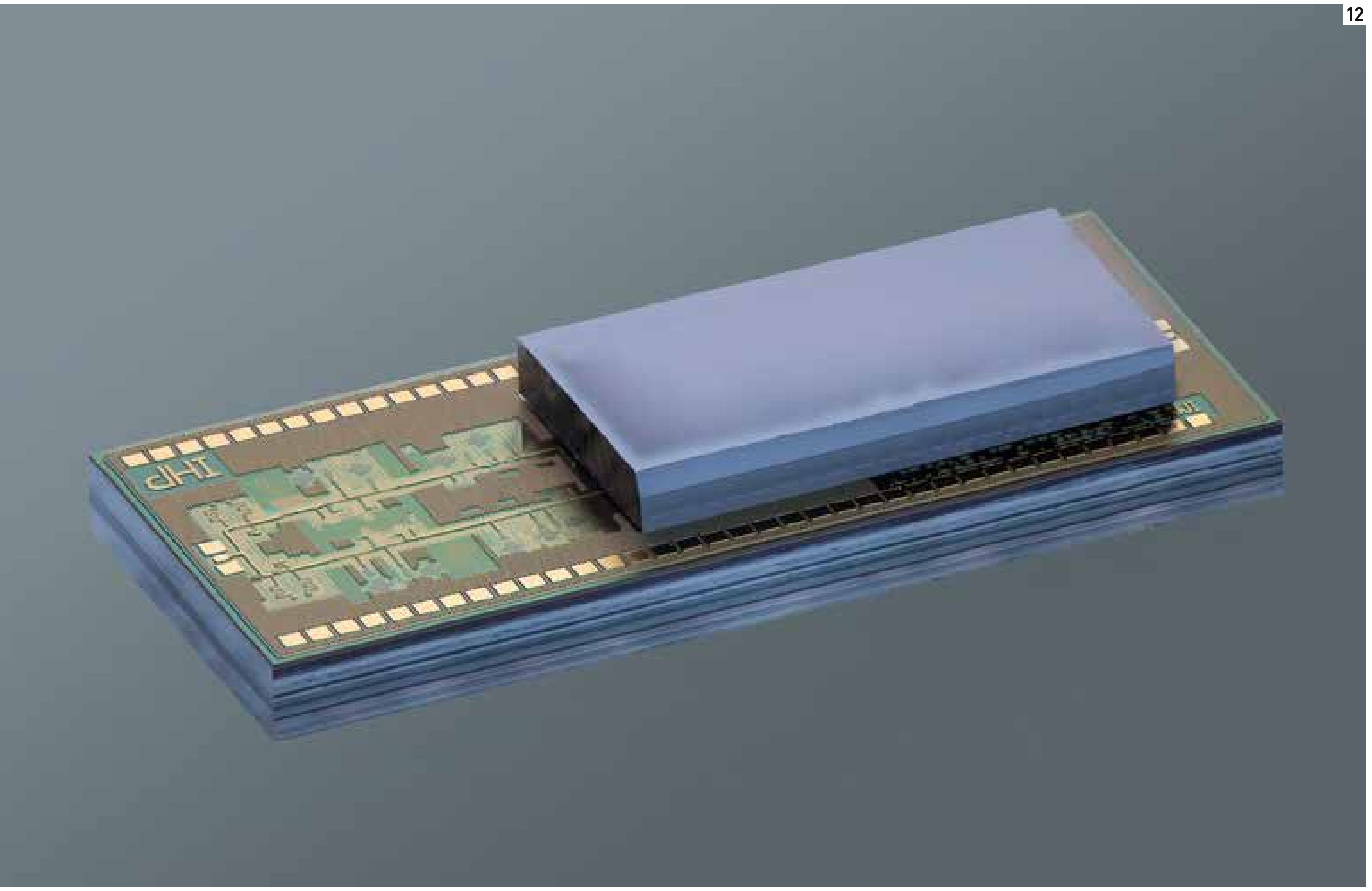
Everyone here is pulling in the same direction: The **APECS pilot line** strengthens Europe's semiconductor ecosystem through advanced packaging and heterogeneous integration, helping to increase technological sovereignty and resilient supply chains in Europe. We contribute key expertise in heterogeneous integration: bipolar InP chiplets for high-frequency applications and GaAs laser chiplets to be incorporated into photonic integrated circuits.

This work helps transfer novel chiplet technologies into application-oriented research and supports secure, resilient semiconductor value chains. At FBH, this endeavor relies on many different areas of expertise: researchers and technical staff from electronics, photonics, and process technology, specialists in mounting and assembly, as well as colleagues from administration and project management who help coordinate the activities within this European initiative.

Electronics heterogeneous integration: joining indium phosphide with Si-BiCMOS and CMOS

12 In electronics, we develop heterogeneous integration strategies that overcome the intrinsic performance limits of silicon technologies at mm-wave and sub-THz frequencies. InP bipolar chiplets deliver substantially higher output power and power-added efficiency than SiGe-BiCMOS or CMOS, particularly above 100 GHz. Within APECS, we combine these InP chiplets with SiGe-BiCMOS and CMOS platforms to realize heterogeneously integrated transmitter and front-end concepts. This approach unites the superior high-frequency performance of III-V devices with the high level of functional integration offered by silicon technologies. A micro-bump-based interconnection approach, fabricated with backend-of-line lithography, minimizes RF losses and parasitics up to D-band and beyond. The result is a compact and scalable architecture that supports energy-efficient wireless systems and opens a viable path toward future 6G applications.

> *We offer industry direct access to state-of-the-art infrastructure, deep technological expertise, and scalable processes.*



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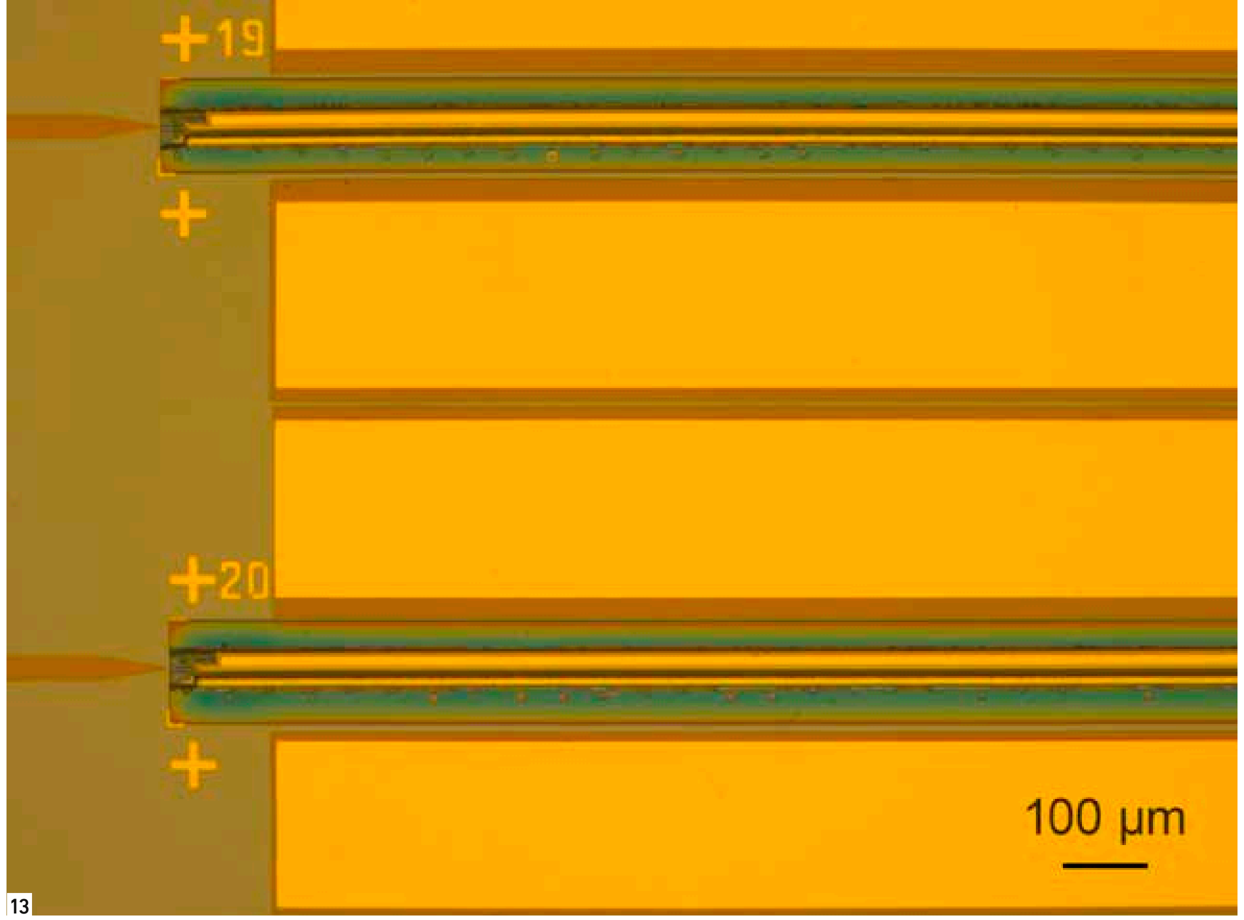
Heterogeneously integrated InP power amplifier and switch on SiGe-BiCMOS transceiver.



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Laser chiplets printed in the recess of a SiN platform.

Photonic heterogeneous integration: gallium arsenide laser chiplets on silicon nitride

13 In photonics, we pursue heterogeneous integration routes that go well beyond conventional hybrid assembly. We develop thin GaAs laser diode chiplets and integrate them onto silicon nitride (SiN) carriers using micro-transfer printing. SiN provides an excellent passive photonic platform: It is CMOS-compatible, offers a wide transparency window, and has low optical losses.

We have demonstrated transferable GaAs chiplets covering wavelengths from the red to the near infrared. Both evanescent and butt-coupling are explored as integration concepts, with the latter allowing for efficient optical coupling while maintaining flexibility in wavelength selection. Our objective is to develop multi-wavelength, application-specific photonic integrated circuits (PICs) and thereby respond to the growing demand for scalable photonic integration in sensing, precision metrology, and emerging quantum technologies.

14

14 To find out more, simply click on our latest frequent issue dedicated to heterogeneous integration.

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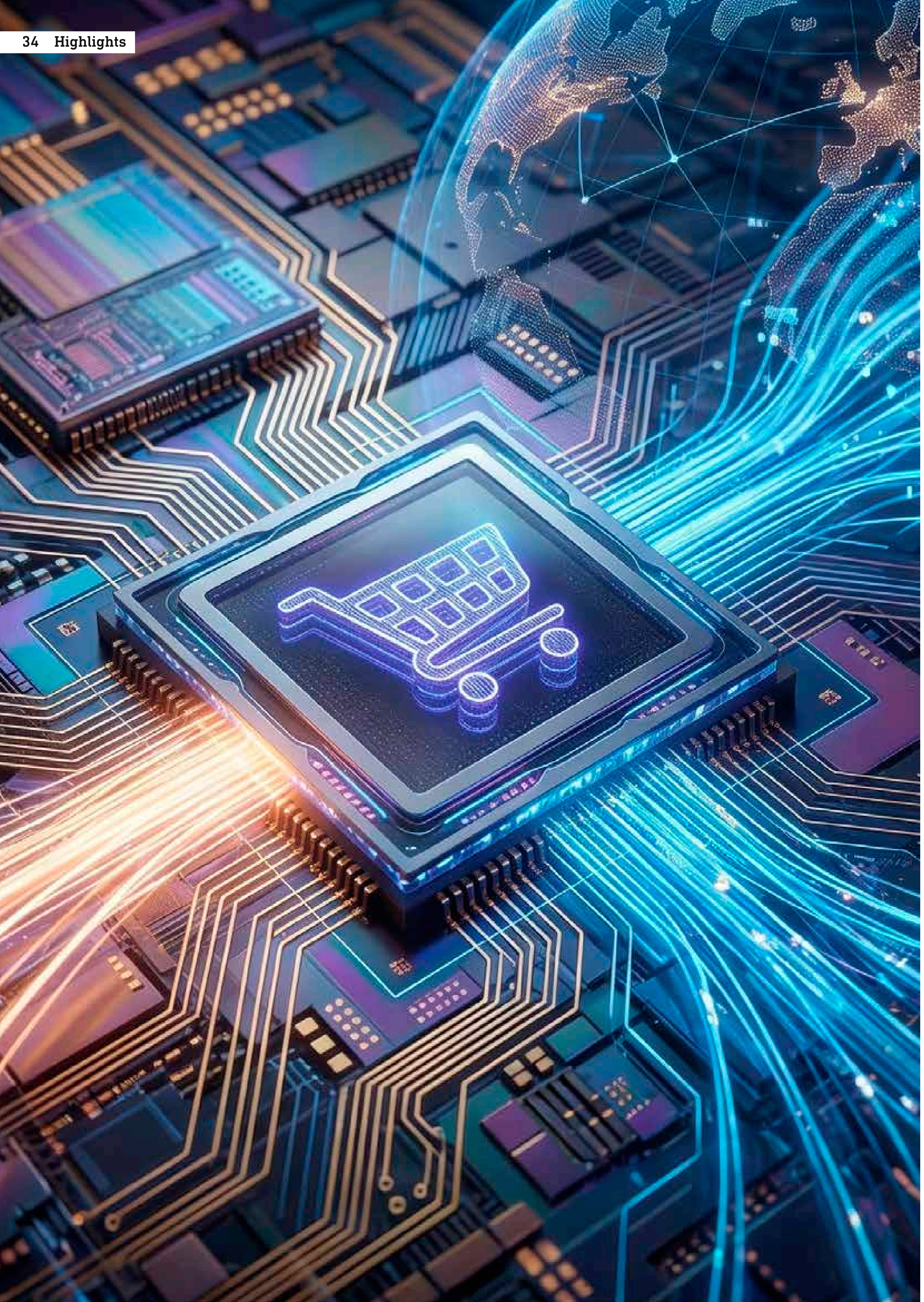


Technology transfer at FBH: an integrated strategy for sustainable impact

FBH continues to demonstrate how excellent research translates into economic and societal impact. As an applied research institute, we have made technology transfer a strategic pillar of our mission. Close cooperation with industrial partners – ranging from global technology leaders to innovative start-ups – and numerous FBH spin-offs ensure that scientific results rapidly find their way into real-world applications.

We maintain numerous long-term partnerships with companies in the fields of photonics, quantum technologies, and high-frequency electronics. These collaborations cover the entire innovation chain, from joint research projects and system development pilot production to pilot product and licensing. Embedded in national and European innovation networks, especially Research Fab Microelectronics Germany (FMD) and the APECS pilot line, FBH offers industry direct access to state-of-the-art infrastructure, deep technological expertise, and scalable processes.

A particularly visible indicator of successful technology transfer is the institute's strong track record in spin-offs. Since its founding, FBH has given rise to twelve technology-based start-ups. The latest spin-off Rydberg Photonics, founded in 2025, further underlines our role as a high-tech incubator, transforming FBH-developed technologies into market-ready products.

FBH's newly established Innovation & Technology Transfer Department

15 To further streamline and strengthen these activities, FBH established the new Innovation & Technology Transfer Department in 2025, headed by Doreen Friedrich. The department bundles existing competencies and provides a structured framework for all transfer-related processes. Its activities rest on five pillars:

- research management to support third-party funded projects and increase external funding
- business development to open new markets and build long-term industrial partnerships
- industrial partner management, including systematic and efficient industrial order management
- support for spin-offs, including market analysis and business plan development
- education management to foster young talent and strengthen regional and national skills development.

Our **newly established Innovation & Technology Transfer Department** brings together expertise from research management, business development, industrial project coordination, education management, and support for spin-offs. Acting as an interface between science, industry, and education, the team creates structured pathways for transferring research results into practical applications and long-term industrial partnerships.

Activities include coordinating externally funded projects, strengthening technology transfer and industrial collaboration, commercializing innovative ideas, and contributing to the development of the next generation of highly skilled technology professionals and technicians. By connecting knowledge and experience from different areas, the department helps translate cutting-edge research into market-oriented products and services while contributing to the APECS pilot line and strengthening technological sovereignty in Europe.

Microtec Academy: skills for Europe's high-tech future

With the new Innovation & Technology Transfer Department, FBH sends a clear signal: Technology transfer is not an add-on, but an integral part of our institutional strategy. By systematically linking research excellence, industrial cooperation and entrepreneurship, FBH reinforces its position as a key driver of innovation – and as a reliable partner for industry in shaping future technologies.

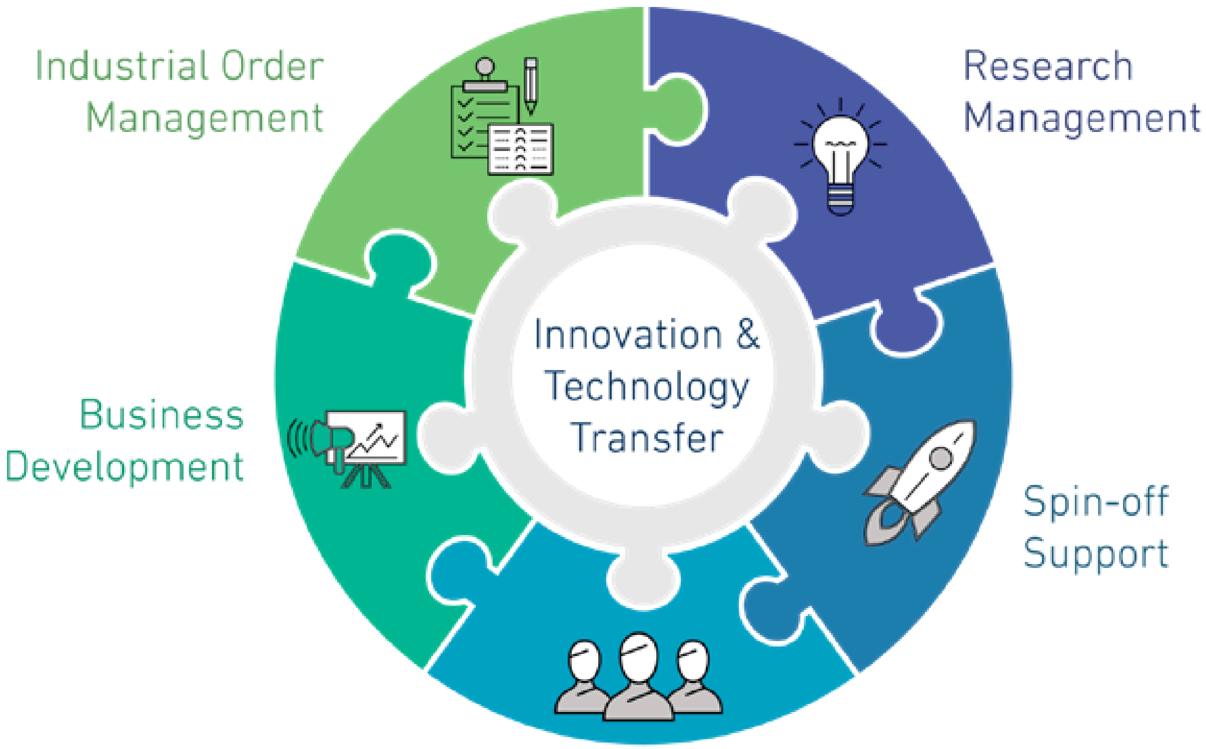
> *Microtec Academy covers the full spectrum of skills development within one coherent framework, from career orientation and training to doctoral pathways.*

16 Microelectronics and microsystems technology drive innovation in energy, mobility, health, and digital infrastructure. Germany's ability to compete in these fields depends not only on technological infrastructure but also on skilled people at scale. This challenge is the starting point of Microtec Academy, which we are developing as a BMFTR-funded national education academy.

The Academy covers the full spectrum of skills development within one coherent framework, from career orientation and training to doctoral pathways. We connect companies, research institutions, and education partners, pool expertise and infrastructure, and transfer knowledge rapidly into practice. As a nationwide network, the Academy links regional clusters and serves learners and companies across Germany.

16

Hands-on learning at Microtec Academy: Apprentices gain practical skills in micro- and nanosystems technologies training for careers in advanced high-tech manufacturing.



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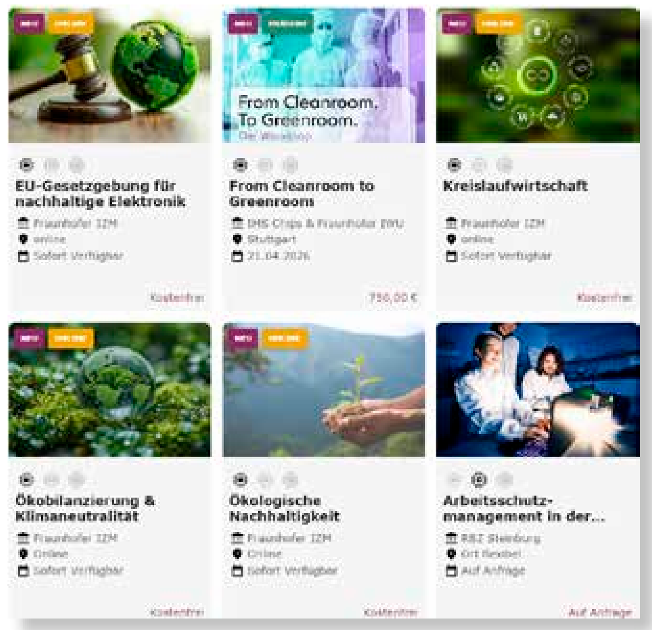
Strong momentum in 2025

In 2025, Microtec Academy reached key milestones. Around 55 qualification formats attracted roughly 1,400 participants, covering both technical depth and cross-cutting topics such as sustainability and management. We also initiated the double master's program Master of Engineering/Master Professional "Engineering and Management in Micro and Nanotechnologies", which strengthens permeability between academic and vocational education and opens flexible career paths across qualification levels.

17 At the same time, we launched a new course booking platform on **microtec-academy.de**, which marks the first step toward a full learning management system later this year. The platform offers central access to all offers and supports participants, trainers, and partners. In addition, the first systematic survey of qualification needs, with 114 respondents from industry and research, provides a solid basis for further program development and helps us focus on high-impact topics.



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Microtec Academy's online platform provides easy access to training and qualification programs, supporting learners at every stage of their high-tech career.

18

Students practicing soldering in a workshop designed to spark interest in a microelectronics career.

Reaching the next generation

18 Skills development starts early. In 2025, we organized 17 company visits and workshops for around 450 schoolchildren and reached another 2,500 young people at career fairs. These activities gave hands-on insights into cleanrooms, laboratories, and high-tech production environments.

19

19 We complemented these efforts with the launch of **be.hightech**, a digital platform for career and study orientation. Interactive content, virtual reality elements, and clear career pathways make complex technologies accessible.

> The German High-Tech Agenda and the national Microelectronics Strategy now prominently feature Microtec Academy.

20

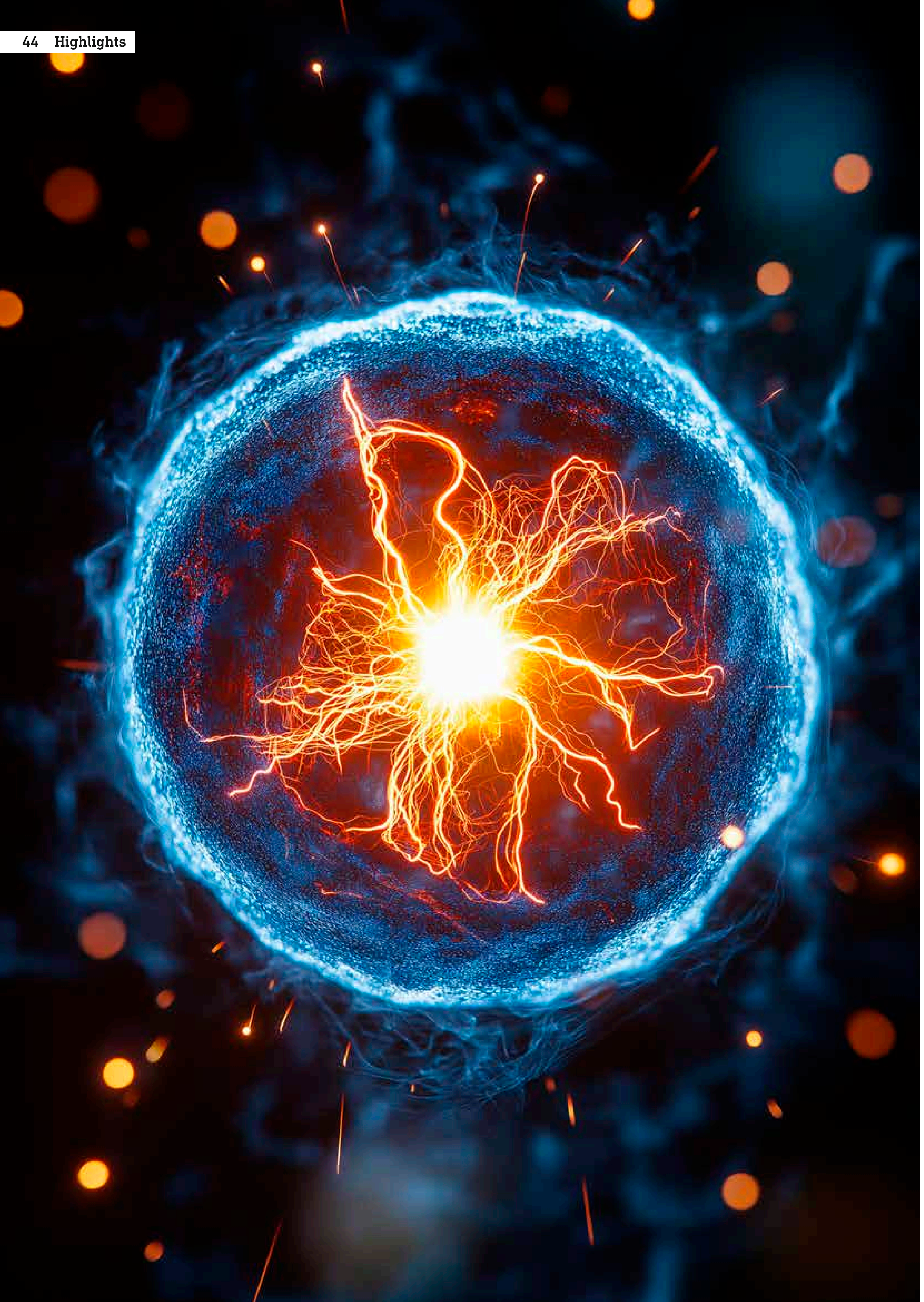
Microtec Academy Forum – FBH educational management presenting workshop results to participants.

Growing visibility: expanded networks and an effective Microtec Academy Forum

20 In 2025, we intensified dialogue with key stakeholders, expanded our cooperation network, and significantly raised our national profile. The German High-Tech Agenda and the national Microelectronics Strategy now prominently feature Microtec Academy. We carried this momentum into March 2026 by hosting the Microtec Academy Forum in Dortmund. Around 140 participants from politics, research, industry, education, and social partners came together to address current trends and develop concrete solutions to secure skilled personnel. Keynotes, workshops, panel discussions, and targeted networking drove the exchange and set clear impulses for the next phase.

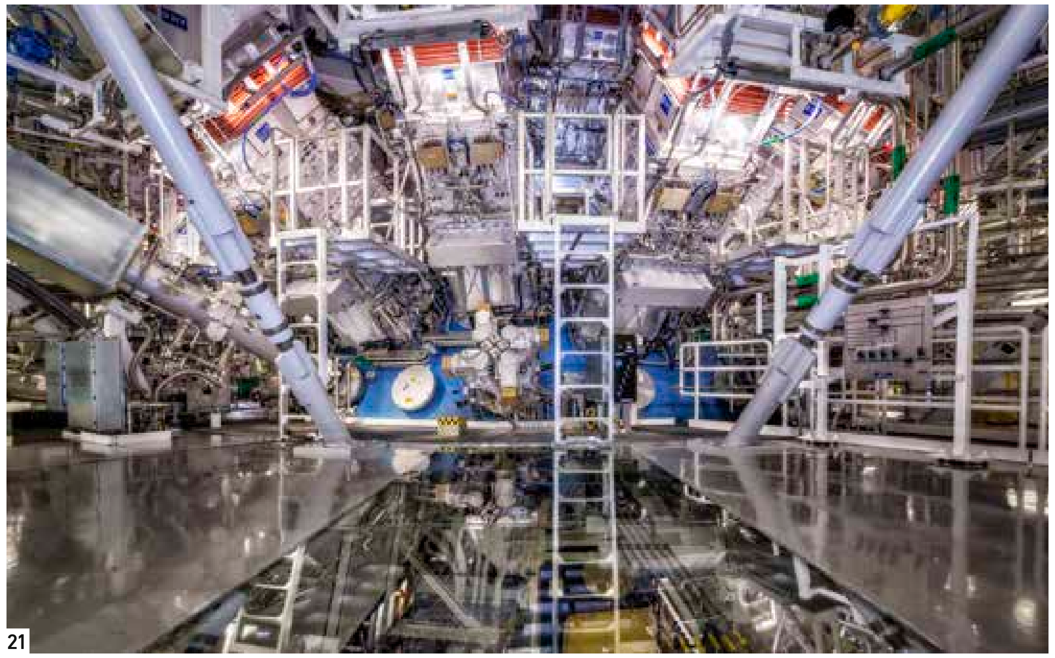
Procurement at FBH covers far more than purchasing materials and equipment. The interdisciplinary team coordinates procurement processes for research projects and technical infrastructure, works closely with internal stakeholders, and manages collaboration with international suppliers. Team members ensure reliable ordering and delivery processes, handle incoming and outgoing goods, oversee customs procedures, and support compliance with export control regulations for sensitive technologies.

As FBH cooperates with partners and suppliers around the world, these tasks require strong organizational skills, close coordination with research groups, and careful management of international regulations and cross-border logistics. Overall, the team contributes to ensuring efficient and dependable research and development processes across the institute.



Laser fusion: enabling inertial fusion energy with high-power diode lasers

Laser-driven inertial fusion energy (IFE) has progressed from scientific validation in a lab toward an emerging technology field with growing international attention. Investments and public funding target scalable, efficient laser drivers that can meet the demanding requirements of future fusion power plants. We develop and deliver key enabling technologies and actively shape the global laser fusion agenda.



21

Current National Ignition Facility target chamber, where the first laser-induced fusion was demonstrated.

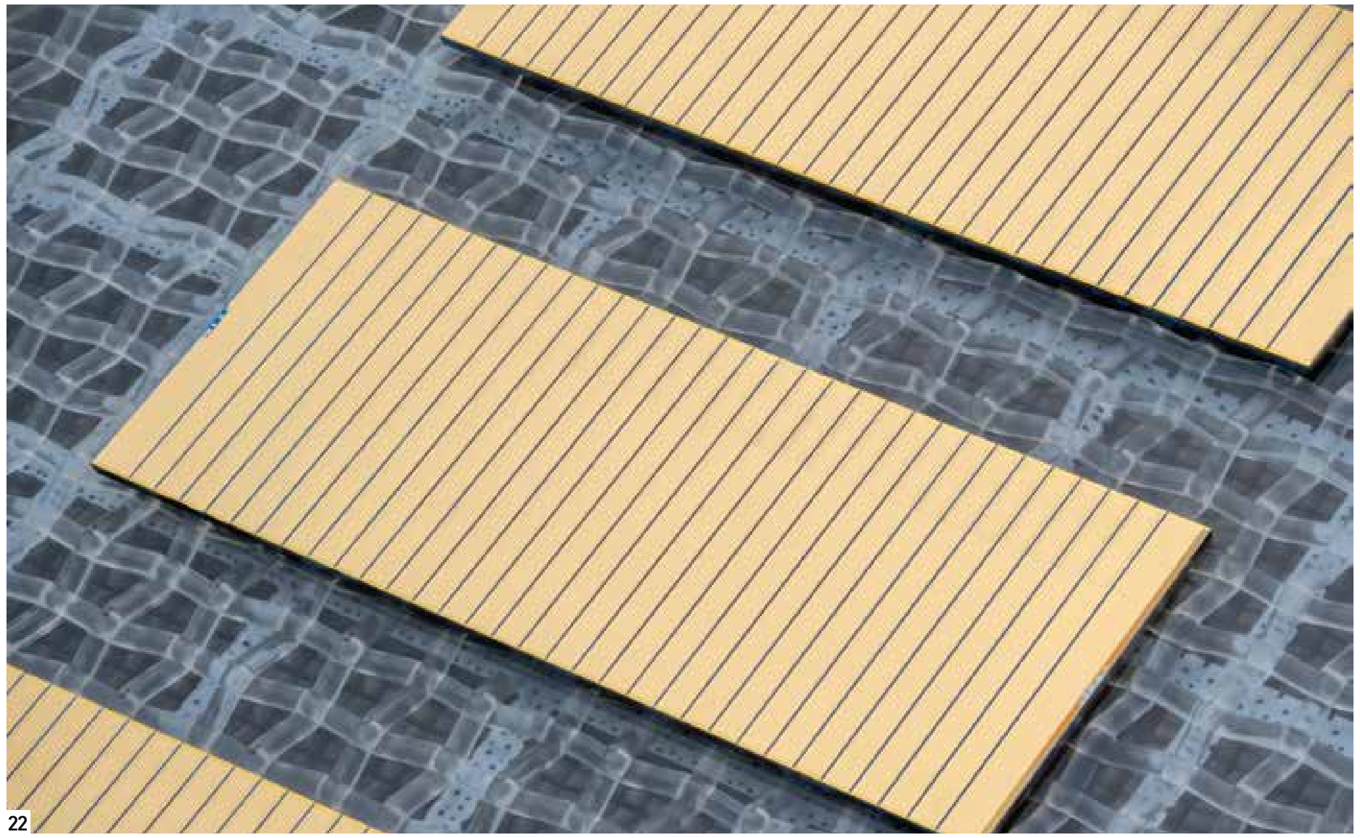
21 High-power diode lasers form the technological backbone of laser fusion drivers. Very large numbers of highly efficient devices are required at the lowest possible purchase (investment) and operating (replacement) costs in €/W. To address this challenge, diode research efforts focus on performance and yield scaling. The devices must combine extreme optical output with high electrical efficiency, spectral stability, and exceptional lifetime – often under 24/7 continuous, high-repetition-rate operation. We address these requirements at device as well as at module level and translate advances into application-ready systems.

FBH 2025 highlights: technological progress and international visibility

22 A major milestone lies in reliability. We demonstrated improvements to our high-volume-capable "air-cleave" passivation approach, which enables failure-free operation to greater than 2 gigashot at 40 W per 200 µm emitter. Such a power level would allow 1-cm bars to operate reliably at powers up to 1.5 kW. This result marks a decisive step toward the lifetimes required for fusion drivers operating at industrial duty cycles. High reliability directly reduces operational risk and is essential for lowering the cost in future IFE facilities.

We also advanced the power-handling capability of our wavelength-stabilized high-power sources, confirmed with the first demonstration of DBR-stabilized diode laser bars emitting 900 W QCW output power at 885 nm. Distributed Bragg reflector (DBR) integration ensures narrow linewidths and spectral stability at high power, eliminating the currently high yield-loss due to diode laser pumps not properly matching the absorption wavelength of the solid-state amplifiers. These characteristics lower costs and further enable more efficient and simpler pumping schemes. They therefore establish a clear pathway toward diode-pumped, high-efficiency fusion laser systems.

Alongside technological progress, we maintain strong international visibility. We shared our results and perspectives through invited talks and tutorials at IEEE Photonics Conference 2025, Compound Semiconductor Week 2026, and Photonics West 2026, highlighting diode lasers as a strategic driver technology for IFE. We also co-chair the international diode laser working group within the STARFIRE hub together with Lawrence Livermore National Laboratory. Our strong participation in this emerging community underscores both technological leadership and commitment to collaboration.



22

Distributed Bragg reflector (DBR) integration ensures narrow linewidths and spectral stability at high power, eliminating the currently high yield-loss due to diode laser pumps not properly matching the absorption wavelength of the solid-state amplifiers.

23

Direct diode laser system for materials processing optimized for aluminum. This system delivers 1 kW continuous-wave optical output, with high power, high brightness diode lasers at its core, emitting at 780 nm.

High-power diode lasers, an enabling technology across industrial applications

23/24 Our diode laser technology does not serve fusion alone. FBH's high-power platforms enable a broad range of industrial applications, from materials processing to additive manufacturing. A prominent example is SAMBA, our direct diode laser system, which has been successfully demonstrating laser welding at our industrial partner's site. It builds on the same advances in brightness, efficiency, and reliability as our IFE efforts. Such applications benefit directly from each other, with industrial operation providing valuable feedback for fusion-oriented designs.

24

Welding tests on steel using the 780 nm diode laser process head, resulting in a 10-layer wall structure (height: 8.5 mm) with a uniform bead geometry.

Certified energy management

FBH continues to strengthen its commitment to sustainability through a certified energy management system in accordance with ISO 50001:2018. We systematically improve energy efficiency, conserve resources, and integrate sustainable standards into our research infrastructure and operations.

25

25 An interdisciplinary energy team coordinates data collection, evaluates efficiency measures, and ensures that energy considerations are embedded in the planning of new facilities, processes, and systems.

Operating 4,000 square meters of cleanroom and laboratory space requires substantial energy, particularly for cleanrooms, ventilation, cooling, heating, and lighting, which account for around 92 % of total consumption. Detailed monitoring and analysis enable us to identify and implement targeted energy-saving measures wherever they are technically feasible, organizationally effective, and economically viable.

Special moments, visits, and international networking

Throughout 2025, our institute attracted considerable interest from policy makers, funding bodies, international partners, and young talents alike. These exchanges reflect our active engagement in dialogue across politics, industry, academia, and the next generation of scientists.

26

Henna Virkkunen (middle) during her lab tour at FBH.

27

Eric Fribourg-Blanc (3rd from left) and the APECS team at FBH.

26 In June 2025, we had the honor to welcome **Henna Virkkunen, Executive Vice-President of the European Commission** and responsible for Tech Sovereignty, Security, and Democracy with her team. We had inspiring discussions around the transformative potential of quantum sensor technology – from groundbreaking applications to the challenges we face in funding, scaling, and cutting through red tape.

27 Only a few weeks later, we had the great opportunity to exchange ideas with **Eric Fribourg-Blanc, Senior Programme Officer at Chips Joint Undertaking**. The visit was filled with inspiring conversations about the progress of the APECS pilot line, the role we're playing in this pioneering initiative, and the next steps toward strengthening Europe's position in semiconductor innovation and resilience.

28

Shared perspectives: A delegation from the BMFTR at FBH.

29

Open doors, open dialogue: a visit from CARLA Hub's "Entrepreneurship Experience".

28 In September 2025, we welcomed a delegation from the **Federal Ministry of Research, Technology and Space (BMFTR).** The visit featured an overview of our research topics, presentations on the APECS pilot line, our efforts to secure skilled talent in the high-tech sector through Microtec Academy, and our latest developments in quantum sensor technology.

29 The same month, we were visited by a group of master's students interested in a career in photonics as part of the **CARLA Hub's "Entrepreneurship Experience"** event series. We were delighted by the great interest in our activities in quantum technologies and quantum photonics. The program included a presentation of our institute, a lab tour, and a discussion round.

30 Also in September, we hosted finalists of the **Quantum Future Awards** by BMFTR. We provided insights into our current work and showed how modern quantum technologies are finding their way into application. Our guests were able to experience our research infrastructure up close and used their time for networking.

31 In November 2025, we had the pleasure of welcoming **Bart Brosius, General Delegate of Flanders in Germany** together with his colleague **Susanne Boy (Belgian Embassy, Representation of Flanders in Germany)**. The exchange focused on getting to know our activities in the field of securing skilled labor and discussing approaches for possible cooperation.

> Through visits and dialogue, we strengthen connections with stakeholders from science, industry, politics, and young talent.

30

All about quantum: the Quantum Future Awards finalists.

31

Exchange between Flanders and Berlin on how to secure a skilled workforce.

Research – results & developments

FBH's four research areas

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 57.

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 71.

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 83.

Find out more about our developments in this field.

Photonics

Quantum technologies for medical diagnostics and environmental monitoring

Early cancer detection and the reliable identification of microplastics are among the most pressing challenges in modern medicine and environmental monitoring. At FBH, we develop a new generation of quantum-based sensing technologies that analyze materials and biological samples with unprecedented sensitivity.

We focus on miniaturized quantum light modules for hyperspectral imaging and spectroscopy in the mid infrared (MIR) spectral range, as illustrated in Fig. 1. These compact devices exploit quantum entanglement to probe samples with MIR light while detecting only the entangled – and thus correlated – near infrared (NIR) photons. Since detection can be performed with conventional silicon-based spectrometers, the approach avoids costly and technically complex MIR detectors and sources. This innovative concept enables the examination of materials and biological tissue in a wavelength range that has been difficult to access so far. It thus creates new opportunities for applications in spectroscopy and sensing.

We apply this concept to the detection of microplastics in wastewater and to the early detection of cancer cells. Both applications rely on spectroscopic analysis of the valence vibrations of, e.g., C-H_2 groups in biochemical molecules. Because the method probes intrinsic molecular signatures, it enables label-free sensing without additional markers or dyes.

Our system uses high-performance laser sources developed exclusively at FBH, operating at 720 nm. This setup enables access to an MIR range of 3.2 – 3.6 µm and a corresponding NIR detection window between 900 - 930 nm. A key objective of our current research is to extend the accessible MIR spectrum toward the so-called fingerprint region between approximately 5 and 10 µm. In this spectral window, molecules exhibit highly distinctive absorption patterns that allow precise identification of chemical structures and functional groups. Access to this region will significantly enhance diagnostic capabilities, especially for complex biological and environmental samples.

We have also increased the efficiency of the quantum light source. By using the nonlinear crystal as an optical cavity, we achieve resonant enhancement of spontaneous parametric down conversion. This approach increases the photon pair generation rate by roughly three orders of magnitude and leads to significantly stronger signals and improved measurement reliability.

Fig. 2 shows a representative NIR spectrum obtained with our micromodule while probing a sample in the MIR range. The data illustrate how quantum interference fringes are partially or completely extinguished when introducing a polymer sample into the MIR beam path. By comparing reference and sample measurements, we reconstruct the transmission spectrum of the material in the MIR range. Using this method, we have already identified various plastic samples.

Despite the complexity of the underlying quantum optics, we have successfully miniaturized the entire system into a compact micromodule with a footprint of only 75 × 90 mm^2. This level of miniaturization paves the way for portable quantum sensors for use in clinical diagnostics, laboratory analysis, and environmental monitoring. With these advances, we are pushing quantum spectroscopy closer to real-world applications in medicine and environmental protection.

This research work is supported by the German Federal Ministry of Research, Technology and Space (BMFTR) in the projects SIM-QPla (FKZ 13N15943) and QEED (FKZ 13N16381).

Fig. 1. Quantum light module with nonlinear crystal, folded reference path and fiber connectors integrated into the housing for simple delivery of pump radiation and quick connection to the spectrometer.

Publications

"Nonlinear Quantum Interferometer: Generating and Sensing Mid-Infrared Radiation for Cancer Diagnostics", doi.org/10.1117/ 12.3080529 (2026)

"Efficient MIR sensing with undetected photons: High brightness, miniaturized SPDC module for real world applications", doi.org/10.1117/12.3041088 (2025)

"High-power semiconductor laser systems at 720 nm: tailored laser light delivery for quantum technologies", doi org/10.1117/12.3041040 (2025)

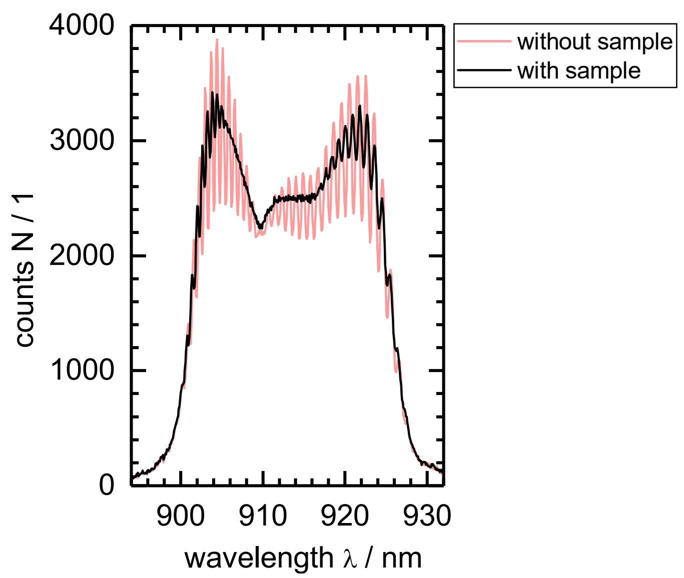


Fig. 2. Quantum interference spectrum with and without polymer sample in the MIR beam path. The corresponding MIR transmission spectrum of the sample can be calculated from both spectra combined.

Field-scale soil mapping with mobile Raman sensor system for precision agriculture

Maintaining healthy soil is essential for sustainable agriculture and to mitigate the impacts of climate change and inadequate soil management. Such efforts align with several sustainable development goals defined by the United Nations. Therefore, site-specific farming, also known as precision agriculture, is gaining global importance in modern agricultural practice. This approach aims to manage soil nutrients more efficiently, optimize fertilizer usage, and improve crop productivity. Achieving these goals requires detailed knowledge of the current soil composition across the field.

Conventional soil analysis relies on mixed samples collected from large areas. Such sampling approaches do not adequately consider the spatial heterogeneity that characterizes many agricultural fields. Farmers and researchers therefore need analytical techniques that provide molecule-specific and spatially resolved soil information directly in the field.

To address this challenge, we apply Raman spectroscopy for on-site soil composition analysis [1]. This spectroscopic method provides a fingerprint on molecular level but is often affected by fluorescence and ambient daylight. To overcome these interferences, we use shifted excitation Raman difference spectroscopy (SERDS) as a physical approach. This method employs two slightly different excitation wavelengths to separate the Raman signals from background contributions.

Our SERDS approach uses in-house developed one-chip dual-wavelength distributed Bragg reflector (DBR) diode lasers emitting at 785 nm, recording two Raman spectra sequentially. Raman signals follow the wavelength shift of about 0.6 nm (10 cm^{-1}), while interferences remain unaffected. This enables us to effectively separate both contributions from each other.

Initial experiments with a portable SERDS system at selected locations on an agricultural field revealed a spatially heterogeneous distribution of carbonates and organic carbon [2, 3]. Such information is vital for agricultural management, for example when planning liming and fertilization strategies. To extend this point-measurement concept to continuous soil monitoring, we realized a tailor-made SERDS instrument. We integrated the system into a mobile sensor platform developed and operated by our project partner Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB). Fig. 1 exemplarily illustrates the field deployment.

The Raman probe head is located in a plough that maintains direct contact with the soil surface. This configuration enables continuous SERDS measurements while the platform moves across the field. For the first time, we demonstrated the detection of specific soil constituents during movement under field conditions. As exemplarily depicted in Fig. 2, elevated carbonate concentrations in silt loam could be detected within 12 m wide test plots containing different soil types, with spatial resolution in the meter range.

We extended the investigations towards larger spatial scales on an experimental agricultural field where the soil composition varies continuously from sand in the south to loam in the north. As sandy soils contain increased amounts of quartz, we used the Raman signal of quartz as an indicator. Fig. 3 displays a decrease of the quartz Raman signal intensity along the measurement path of 240 m from south to north. This observation demonstrates that SERDS can capture such spatial variations of the soil composition across the field – as can be seen in this video.

In the future, our method could enable molecule-specific on-site soil mapping at field scale. Such information would support more targeted, resource-saving, and environmentally friendly liming and fertilization in modern agriculture.

This work was funded by the Federal Ministry of Research, Technology and Space (BMFTR) through the project RaMBo (031A564C, 031B0513C, 031B1069C) within the I4S (Intelligence for Soil) consortium in the frame of the funding measure BonaRes (Soil as a Sustainable Resource for the Bioeconomy). Further funding was provided within Research Fab Microelectronics Germany (FMD) framework (16FMD02).

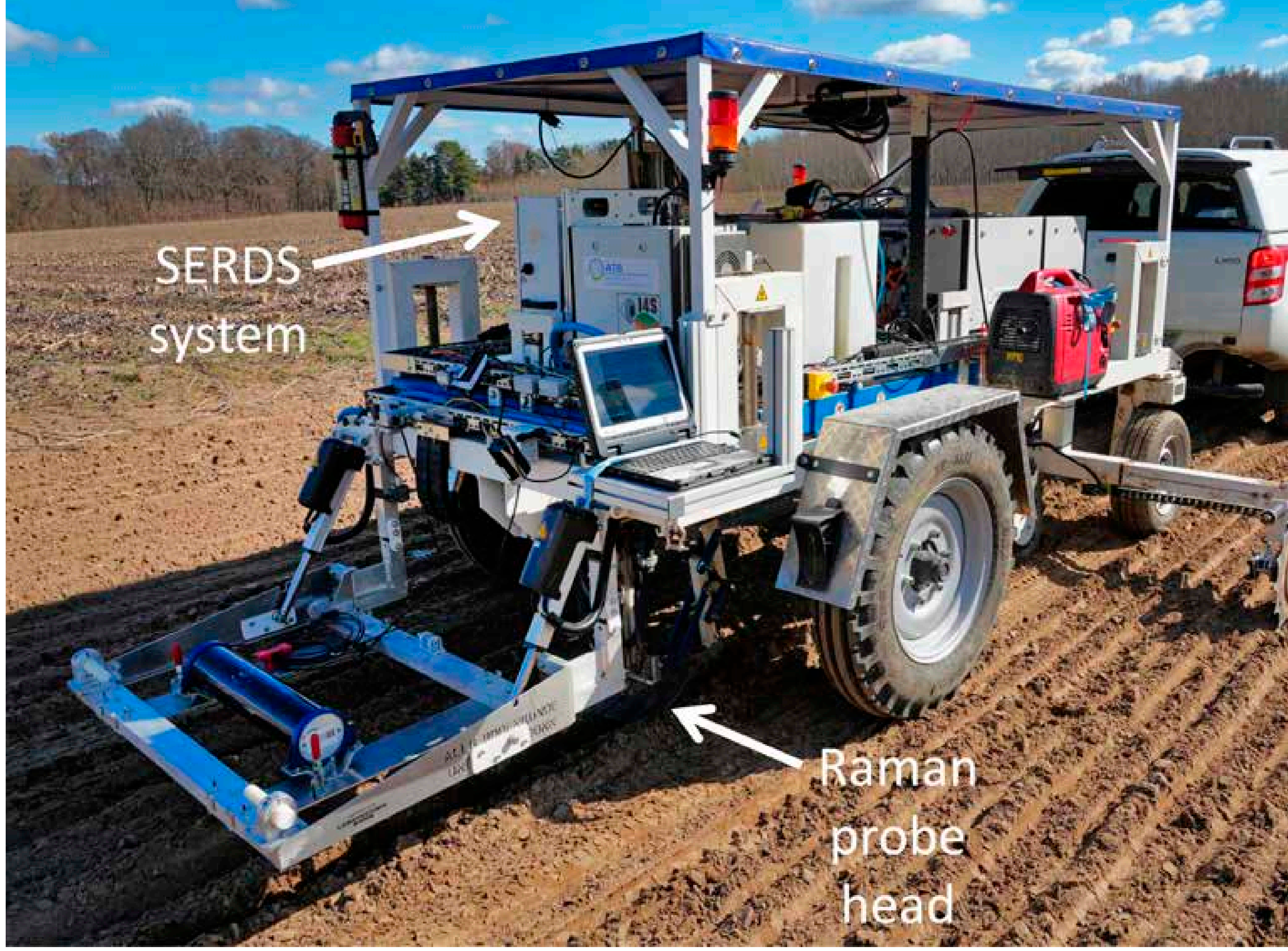


Fig. 1. Continuous soil mapping on an agricultural field using a compact SERDS instrument realized at FBH and integrated into a mobile sensing platform operated by the project partner ATB.

Publications

[1] "2025 photonics for agrifood roadmap: towards a sustainable and healthier planet", doi:10.1088/2515-7647/adbea9 (2025)

[2] "Qualitative and quantitative soil characterization on an agricultural field using a portable shifted excitation Raman difference spectroscopy instrument", doi:10.1039/D5AN00178A (2025)

[3] "Molecule-specific soil analysis using shifted excitation Raman difference spectroscopy – From laboratory investigations towards field deployment of portable sensors", doi: 10.1117/12.3080331 (2026)

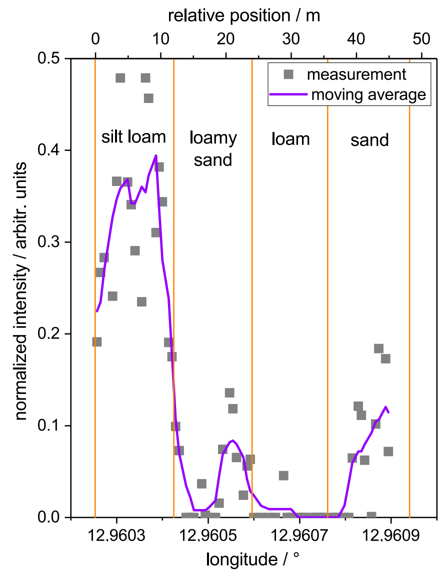


Fig. 2. Spatial distribution of normalized carbonate Raman signal intensity measured continuously across four test plots over a distance of 48 m. Vertical orange lines mark the borders of the individual plots (each 12 m wide).

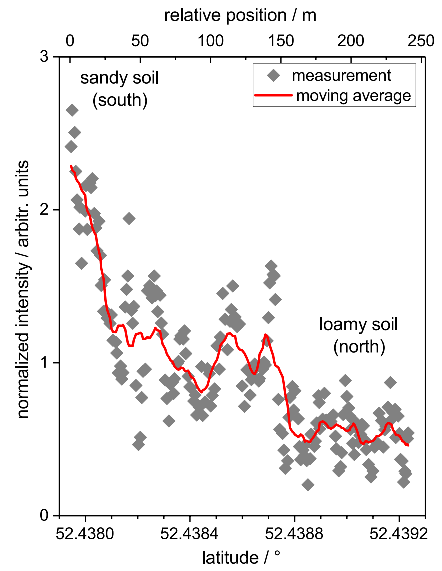


Fig. 3. Spatial distribution of normalized quartz Raman signal intensity measured continuously across an experimental agricultural field over a distance of 240 m.

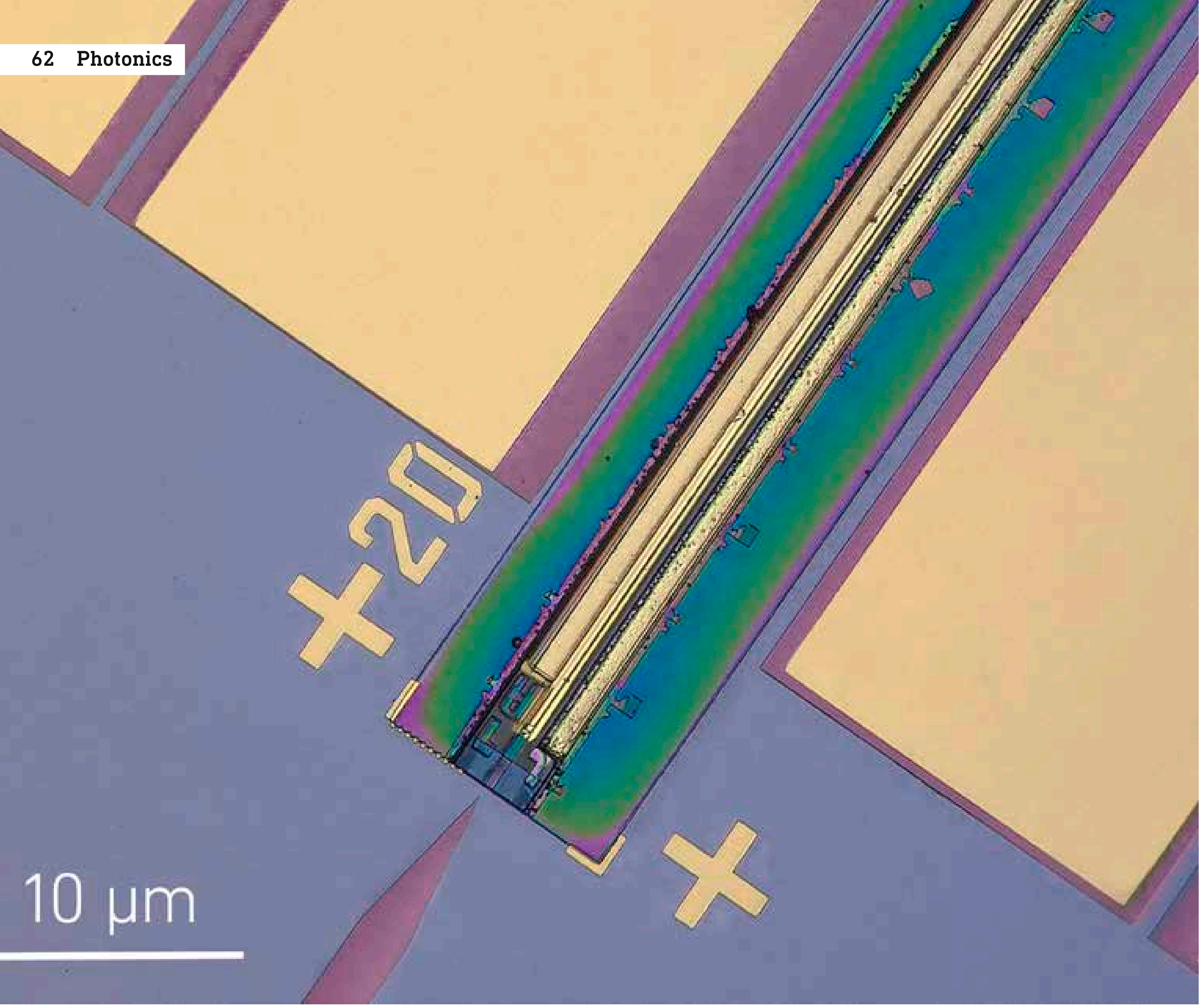


Fig. 1. Microscope image of an edge-coupled laser chiplet printed into a recess on a silicon nitride PIC platform.

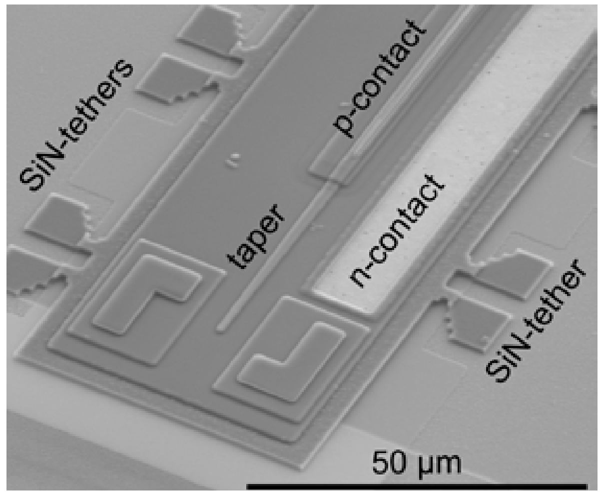


Fig. 2. Scanning electron microscope image showing one end of an amplifier chiplet designed for evanescent coupling via the taper at the end of the waveguide ridge. The chiplet is underetched but still connected to the GaAs wafer by SiN tethers.

Fig. 3. Photograph of our X-Celeprint micro-transfer-printing tool in the process of transferring laser chiplets from a GaAs source wafer to a six-inch target wafer.

From chiplets to integrated light sources: FBH establishes heterogeneous laser integration

Photonic integrated circuits (PICs) combine light emitters with waveguide circuitry for on-chip light manipulation. They provide essential functionality for quantum technologies, precision sensing, and biomedical diagnostics. At FBH, we have developed sources in the near infrared that are monolithically integrated on GaAs [1]. For compact and robust systems suitable for large-scale production, however, heterogeneous integration of emitter and detector chips with passive optical waveguides offers more flexibility. This approach enables PICs tailored to specific applications.

As part of the European VISSION project, we developed transfer-printable GaAs gain chiplets for this purpose. These components are just a few micrometers thick. We fabricate them by selectively etching away a sacrificial GaAs layer [2]. The process leaves the active structures free-standing and connected to the substrate only by fine silicon nitride (SiN) tether structures. Precise microstructuring allows us to define chiplet geometries suitable for both evanescent-coupled and edge-coupled integration concepts. Using this technology, we already cover wavelengths with red emission at 638 nm and in the near infrared at 890 nm as well as the 900 – 1000 nm spectral range. These wavelengths provide the basis for versatile, application-specific PIC solutions [2, 3, 4].

We place the manufactured chiplets onto the target photonic platform using micro transfer printing (MTP). An elastomeric stamp picks up the free-standing components from the source wafer and positions them on the PIC chip with sub-micrometer accuracy. We create a low-loss connection between the gain chiplet and passive SiN waveguide structures using suitable adhesive layers and CMOS-compatible hydrogenated amorphous silicon (aSi:H) intermediate waveguides. This enables efficient evanescent coupling between the active and passive elements [3].

During the VISSION project, we established the chiplet fabrication process. Building on this expertise, we are now expanding our capabilities in heterogeneous chiplet integration within the APECS pilot line. Our goal is to develop a complete process chain that includes chiplet manufacturing, MTP-based heterogeneous integration (available from X-Celeprint), electrical contacting, and optical characterization. This process will establish a comprehensive platform for heterogeneous integration of photonic systems at FBH. Ultimately, it will enable scalable integrated laser sources delivering output powers from 10 to 100 mW and intrinsic linewidths below 1 kHz.

These developments lay the foundation for high-precision, miniature laser sources for quantum sensing, optical clocks, and portable measurement systems. With this capability, FBH is among the few facilities that combine chiplet design and manufacturing with MTP-based heterogeneous integration, all from a single source.

These activities are funded by the European Union in the frame of the Horizon Europe Program within the VISSION (Grant Agreement ID: 101070622) project as well as 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 (Grant Agreement ID: 101183307).

Publications

[1] "GaAs-based photonic integrated circuit platform enabling monolithic ring-resonator-coupled lasers", doi.org/10.1063/5.0223134 (2024)

[2] "Design and Fabrication of Transfer-Printable Evanescently Coupled GaAs-Based Amplifier Coupons", doi.org/10.1109/CLEO/Europe-EQEC65582.2025.11111399 (2025)

[3] "Heterogeneously Integrated Evanescently Coupled Laser Systems on SiN Emitting in the Near-Infrared Band", doi.org/10.1109/CLEO/Europe-EQEC65582.2025.11110515 (2025)

[4] K. Akritidis et al., "Heterogeneously Integrated Evanescently Coupled Lasers Emitting in the Submicrometer Wavelength Range", accepted for publication in APL Photonics (2025)

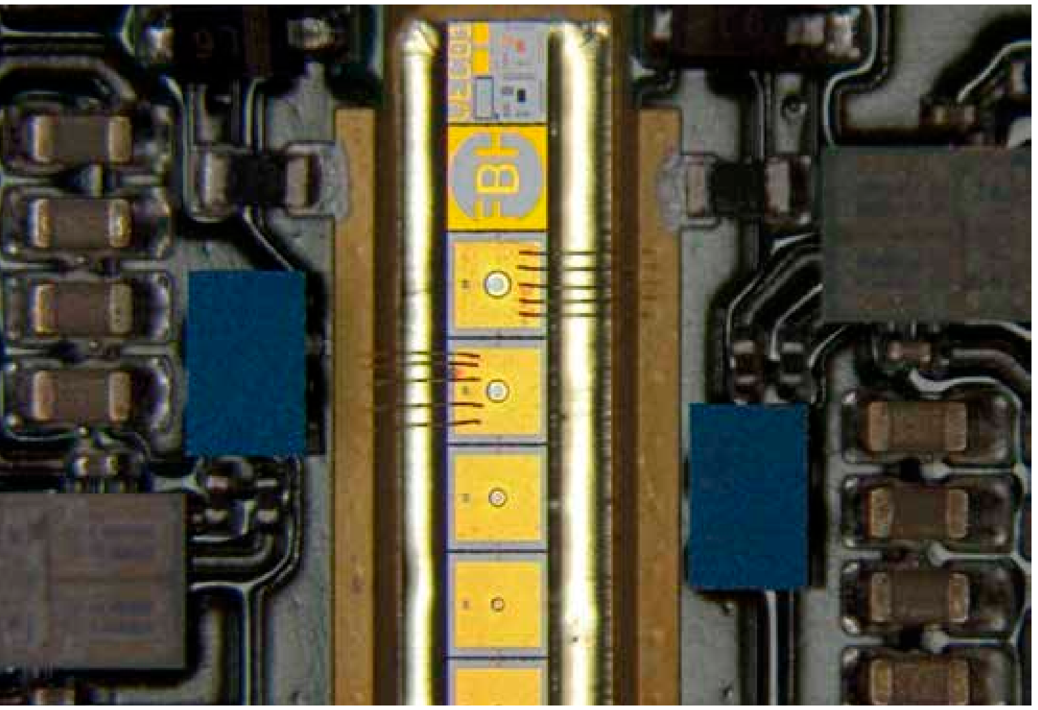


Fig. 1. Oxide-free 1030 nm electrically driven VECSEL bar mounted on a ns-pulse driver. Two wire-bonded chips feature implanted current apertures with diameters of 80 µm and 100 µm.

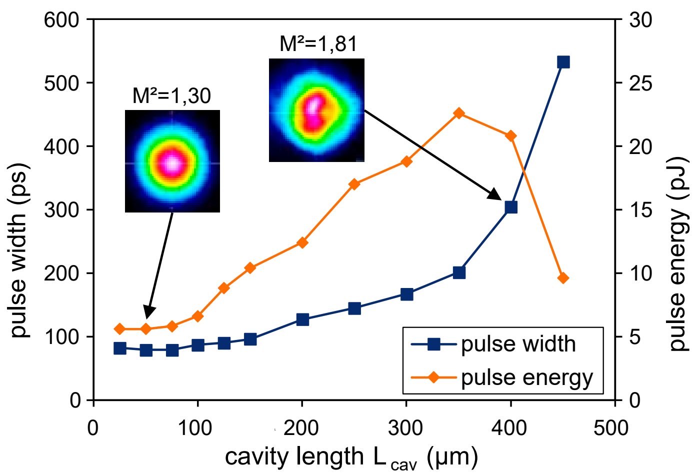
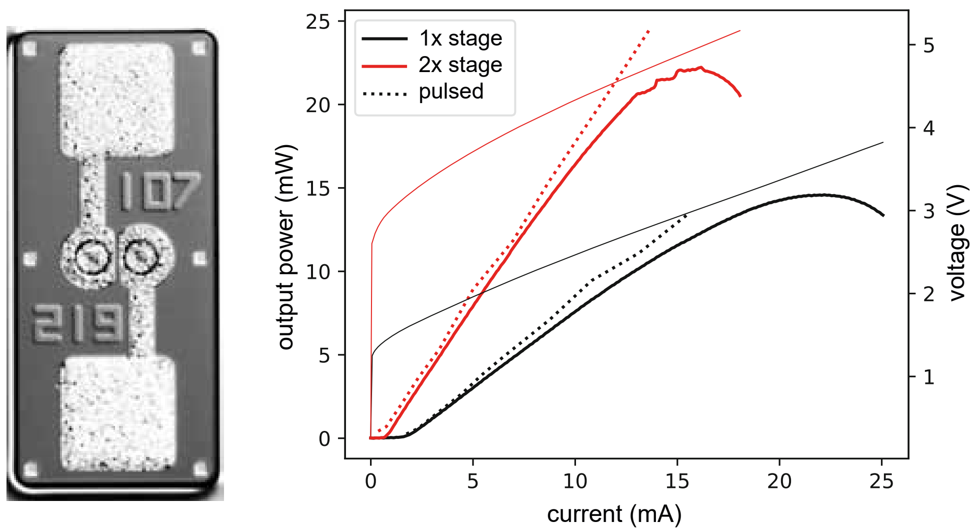


Fig. 2. Pulse width (left axis) and pulse energy (right) of an electrically driven VECSEL chip with a current aperture diameter of 20 µm and varied cavity length up to 450 µm. The measured pulse width is limited to 80 ps by a 10 GHz photo diode. Single-mode Gaussian optical modes with M^2 of 1.3 are achieved for short cavity lengths < 250 µm.



(a) (b)

Fig. 3. Oxide aperture of a 794 nm pump VCSELs for space gyroscope applications, (a) light-microscopic top-view image of two VCSEL emitters, (b) LIV-characteristics of single-stage (black) and double-stage (red) epitaxial designs.

Compact, efficient, scalable: surface-emitting VCSEL and VECSEL technologies for advanced applications

FBH is well known for its broad portfolio of edge-emitting laser diodes, covering a wide range of wavelengths, emission powers, and beam properties. For specific applications, however, surface emitting lasers deliver clear advantages over the standard portfolio. Surface-emitting lasers provide a circular beam profile. This simplifies beam shaping and allows for easy mounting, integrated wavelength stabilization, wafer level processing and testing. They also avoid facet coating on bar level. As a result, Vertical-Cavity Surface-Emitting Lasers (VCSELs) enable compact, lightweight, and cost-efficient solutions.

Within the BMFTR-funded project "QYRO", we contribute to the development of a quantum gyroscope. We have developed the epitaxial growth of VCSELs emitting at 794 nm, which will be used for pumping and interrogating excited rubidium atoms in a gas cell. TRUMPF Photonic Components processed the wafers, which were then mounted by TRUMPF Laser Berlin. Arda Atomics (formerly Q.ANT) integrated the lasers with a measurement cell from Bosch. The VCSEL-based setup passed all functional tests.

Standard circular emitters are used to probe the exited atoms. An array of coherently coupled emitters serve as pump laser, which delivers the higher power required to excite the gas atoms. Currently, the gyroscope with VCSELs instead of bulkier DBR laser modules is being built for the upcoming satellite mission. This opens new paths for VCSEL-based sensors in space applications that are especially sensitive to volume, weight, and power consumption.

In another BMFTR project, we develop electrically driven Vertical External-Cavity Surface-Emitting Lasers (VECSELs) together with Laserzentrum Hannover. These devices are to be used as seed lasers in pulsed laser systems. They resemble VCSELs but use an external reflector instead of a top semiconductor DBR mirror to allow for larger optical modes.

We pursue an innovative approach and define the current aperture by ion implantation of a GaAs tunnel junction with subsequent regrowth. This tunnel junction is located between the top p-side of the active region and the n-layer on top. It transports current to the electrical aperture without changing the refractive index. This approach creates current confinement and allows the optical mode to be wider than the electrical aperture.

Several active regions can be stacked and connected vertically by tunnel junctions. These junctions are also patterned by ion implantation but feature a much wider aperture than the top current aperture. Already in the first device generation, VECSELs with two active regions emitting around 1030 nm achieved pulses below 160 ps with up to 23 pJ energy. They also showed a Gaussian beam shape for easy collimation into an optical amplifier. We now integrate chips with higher CW output power into a module for pulse generation.

These activities were supported with funding from the German Federal Ministry of Research, Technology and Space (BMFTR) within the projects "Kernspin-basierte Quantengyroskope für New Space Anwendungen (QYRO)", FKZ 13N16317, and "Elektrisch gepumpte Halbleiterscheibenlaser zur Ultrakurzpulserzeugung (ED-VECSEL)", FKZ 13N16751.

Publication

"Phase-engineered distributed grating reliefs for high-power single-mode 795-nm VCSELs with on-axis emission", doi.org/10.1364/OL.599551 (2026)

High power meets beam quality: new concepts for all-semiconductor PCSELs

High-power diode lasers are an essential component in applications like material processing, 3D printing, LiDAR, and research on laser-driven fusion for power generation. Conventional high-power (> 1 W) edge-emitting semiconductor lasers convert electrical energy to optical energy with very high efficiency. However, their beam quality remains relatively poor compared to fiber and solid-state lasers. Photonic crystal surface emitting lasers (PCSELs), in contrast, can generate high optical powers exceeding 1 W in a circular, narrow beam with near diffraction-limited beam quality. This makes them an attractive alternative for applications that require both high power and high beam quality.

In PCSELs, schematically shown in Fig. 1, light is emitted vertically from the device surface, while the resonator is formed in-plane. Optical feedback originates from a monolithically integrated two-dimensional photonic crystal (PC) layer, consisting of a periodic array of identical unit cells. Currently, PCSELs that deliver the highest performance utilize regrown encapsulated air voids as a PC unit cell feature. The high index contrast between semiconductor material and encapsulated air causes strong two-dimensional optical feedback. The PC is designed to ensure that the device is held in a (nearly) single optical mode with Gaussian profile that extends across the whole device. This configuration therefore allows the output power of PCSELs to scale with device size. The PC structure also directs the emission out through the substrate, while a p-side distributed Bragg reflector (DBR) maximizes optical outcoupling. As a result, PCSELs emit in a narrow spectral line with a very narrow far field.

Despite these advantages, the conversion efficiency of PCSELs remains significantly lower than that of conventional edge-emitting semiconductor lasers. At FBH, we investigate new PCSEL concepts that aim to combine high optical power with high efficiency while maintaining excellent beam quality. Our approach replaces conventional air voids with index contrast between two semiconductor materials, which is particularly suitable for large-area, high-power PCSELs. These studies exploit techniques developed earlier at FBH to scale the output power and efficiency in grating-stabilized edge-emitting lasers.

In cooperation with Weierstraß-Institut in Berlin, we developed an efficient numerical software to simulate the behavior of PCSELs with different unit cell designs. Utilizing this tool, we identified an innovative "stretched isosceles triangle" (SIT) unit-cell shape that is predicted to perform well in a patented all-semiconductor design. Simulations predict that PCSELs based on the SIT design can achieve performance comparable to conventional air-void devices while offering higher conversion efficiency and improved fabrication yield [1].

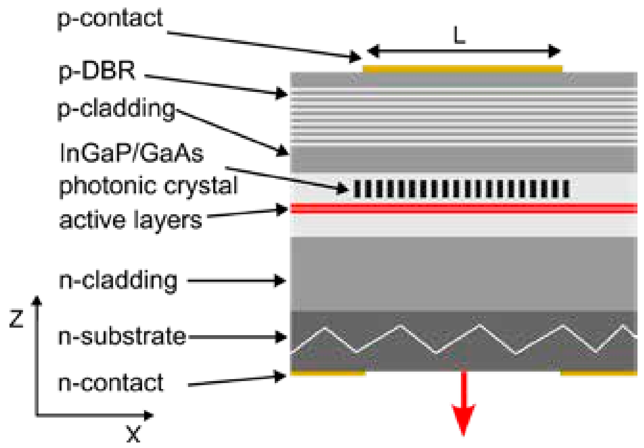
In 2025, we produced the first experimental demonstration of these devices using a two-step epitaxial regrowth process. The fabrication begins by etching the desired unit-cell feature shape into a semiconductor layer (here InGaP). We then overgrow the resulting pillars with another semiconductor material with a different index (here GaAs), following the approach described in [2]. A report on the first all-semiconductor SIT-based PCSEL lasers devices will be presented at CLEO Conference in 2026.

Fig. 2 shows initial results for a device with a 700 µm-wide circular emission aperture. In cooperation with University of Glasgow, we were able to confirm that the geometry of the fully regrown SIT photonic crystal unit cells broadly matches our design, albeit smaller and slightly rotated. The reduced size weakens the optical feedback, while the rotation affects mode selection. The figure shows a measured slice reconstruction of four unit cells taken from a special angled transmission electron microscopy (TEM) section. By combining a series of cross sections from different locations of neighboring PC features, we reconstruct the three-dimensional profile of the overgrown structures.

The realized PCSELs emit at a wavelength around 1070 nm and reach optical output powers above 2 W in a 500 ns pulsed measurement. This value represents the highest power reported to date for an all-semiconductor PCSEL, even though the devices were produced using a relatively simple wafer process. The spectrum at 200 mW output power under continuous wave operation shows a single peak at 1075 nm (Fig. 2 inset). The far-field distribution (not shown) is narrow in one axis (< 0.8°) but broadened along one axis (~ 15°), which can be attributed to deviations from the ideal PC shape.

These first demonstrations provide an important step toward high-power, high-efficiency all-semiconductor PCSELs. Ongoing analysis and further design optimization will support the development of devices that combine scalable output power with excellent beam quality.

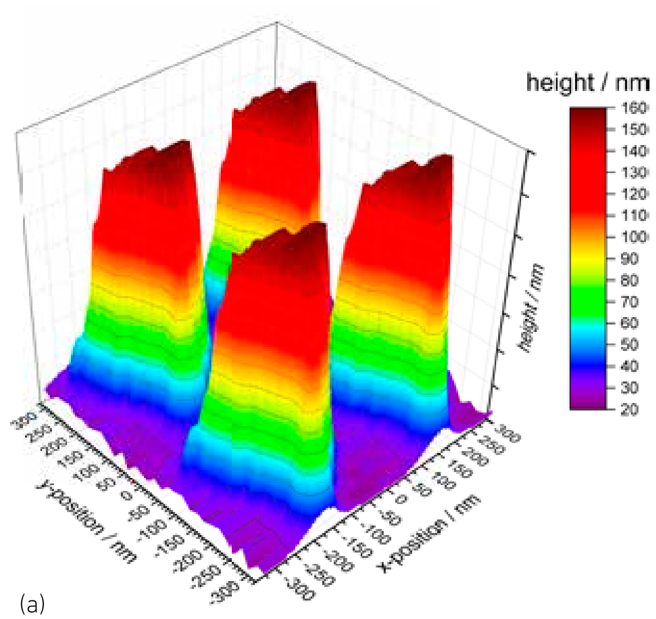
This work was performed in the frame of the project PCSELence (K487/2022) funded by the German Leibniz Association.



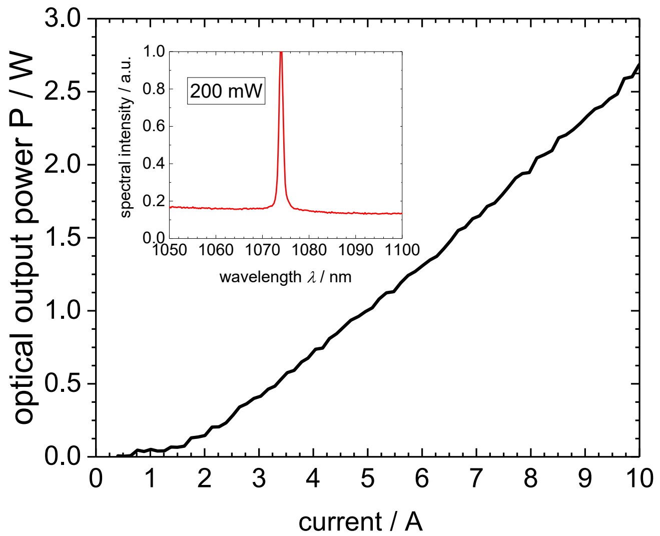
(a)

(b)

Fig. 1(a) Schematic drawing of the vertical structure for a PCSEL, (b) picture of a mounted PCSEL for characterization of the device.



(a)



(b)

Fig. 2(a) Measured 3D profile of a collection of four InGaP pillars after regrowth with GaAs, each forming a SIT unit cell within the PC layer. Image derived from TEM analysis. (b) Pulsed (500 ns) optical output power of a PCSEL as a function of bias current, with the measured spectrum at 200 mW (CW) optical output power (inset).

Publications

[1] "Comparison of Design Tolerance for High-Power PCSELs", PCSEL Workshop, Aston, UK, abstract no. 42, p. 104 (2025)

[2] "Process development to realize all-semiconductor InGaP-GaAs based photonic-crystal surface emitting lasers", doi.org/10.1016/j.mne.2026.100354 (2026)

Patent

B. King, H. Wenzel, P. Crump, E. Kuhn, M. Radziunas, "Large-area high-power single-mode all semiconductor photonic crystal surface emitting lasers", DE102024116 972B4

Longer lifetimes and broader wavelength range: expanding the applicability of GaN-based diode lasers

The performance and applicability of laser diodes (LDs) strongly depends on their emission wavelength and long-term stability. Many applications require specific wavelengths as well as long-term stable emission power, without significant readjustment of neither operating current nor voltage. Degradation effects at the facets, within the semiconductor crystal or at the electrical contacts, can lead to increased operating current or voltage. This, in turn, may also increase heat generation, accelerate degradation, and ultimately limit overall device lifetime.

At FBH, we continuously improve InGaN-based LDs emitting in the blue-violet spectral range (Fig. 1). Through systematic long-term stability investigations, we identified key device properties that significantly determine the lifetime and can be assessed even before the first operation of our LDs. One critical parameter is the degree of deviation of the p-contact characteristic from an ideal ohmic behavior, expressed as Schottky voltage Vp.

We measure Vp on wafer using the transfer length method at the very beginning of LD fabrication, i.e., long before facet coating or chip mounting. Our investigations show that the forward voltage of LDs with Vp > 1 mV increases by more than 0.5 V within 500 h during operation. This effect results from an amplified inhomogeneous current flow through the p-contact. In contrast, LDs with Vp < 1 mV maintain stable forward voltage over the same period. Minimizing Vp is therefore crucial for ensuring electrical stability of the p-contact and a long device lifetime. Consequently, we established a clear quality criterion for our manufacturing process that allows early selection of devices with high lifetime potential.

By combining this insight with further optimization of the heterostructure as well as the wafer process parameters, we achieved InGaN-based LDs with operating times of several thousand hours. In these devices, the forward voltage changes only due to the increase in operating current but not due to contact degradation.

To further expand the applicability of LDs with lifetimes approaching 3,000 hours, we also significantly extended the emission wavelength range of our devices. By precisely tuning the growth temperature of the InGaN/GaN active region during epitaxy, we realized emission wavelengths from 384 nm to 451 nm (Fig. 2). Notably, laser diodes emitting up to 435 nm show no significant deterioration in performance and maintain similar threshold currents and slope efficiencies. This underscores the robustness of our heterostructure design within this range.

As the emission wavelength approaches 450 nm, however, the threshold current increases and the slope efficiency decreases. We are currently optimizing the heterostructure to mitigate these effects and expand the wavelength range even further. The extended spectral coverage opens the door to a broad spectrum of high-impact applications, including photopolymerization, advanced sensing and spectroscopy, and emerging quantum technologies such as atomic cooling and integrated quantum photonics.

This work is partially supported by the Leibniz Collaborative Excellence program in the framework of the project "Far UVC compact laser module (UV-COLA)" (contract K596/2024) as well as by the German Ministry of Defense and the Ministry of the Interior, represented by the Cyberagentur, through subcontracting in the project "Mobiler Quantencomputer".

Publication

"Long-term stable single-mode AlInGaN laser diodes by overcoming degradation mechanisms", doi.org/10.1117/12.3075743 (2026)

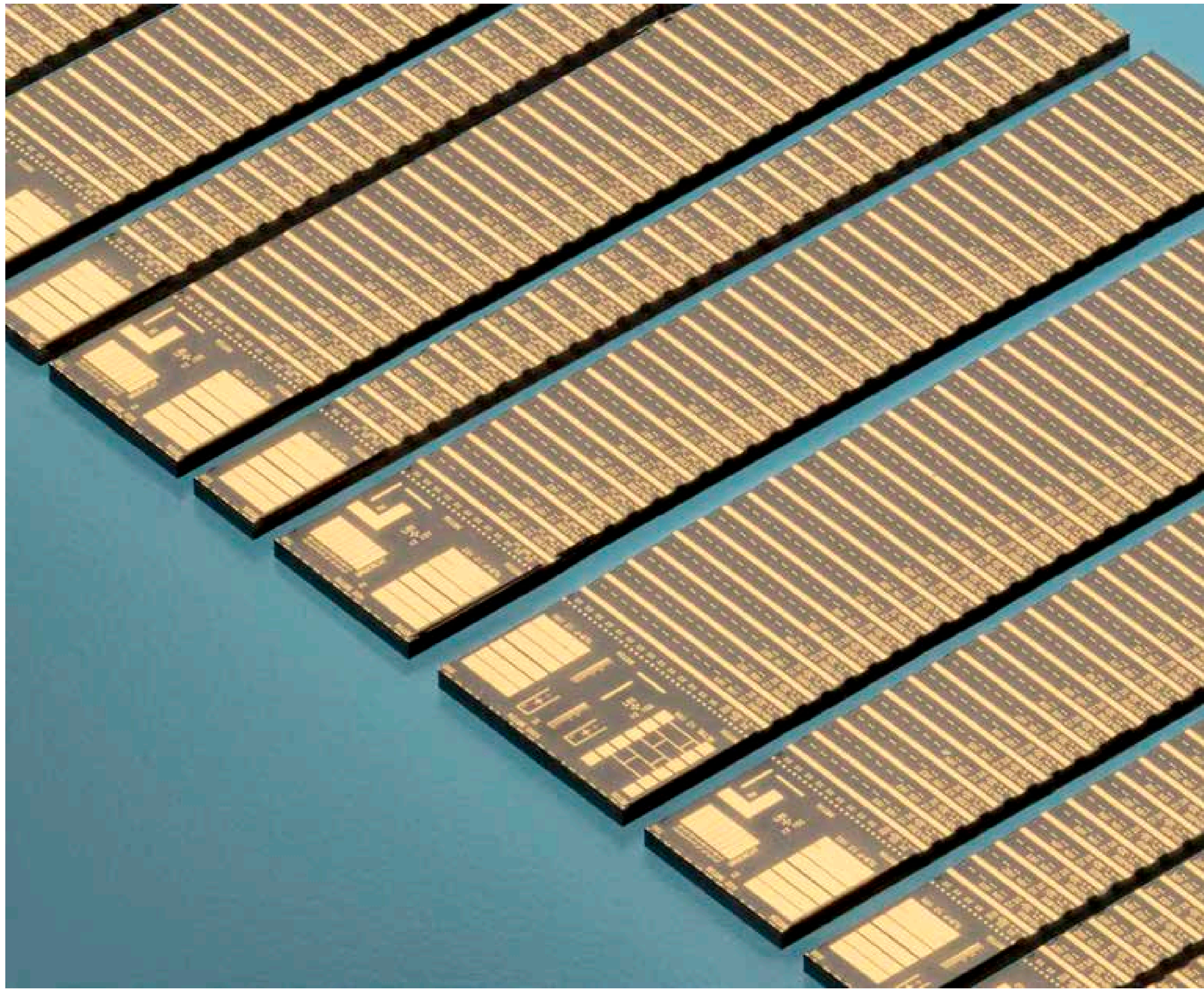


Fig. 1. GaN-based blue-violet laser diodes with different resonator lengths on bars before separation.

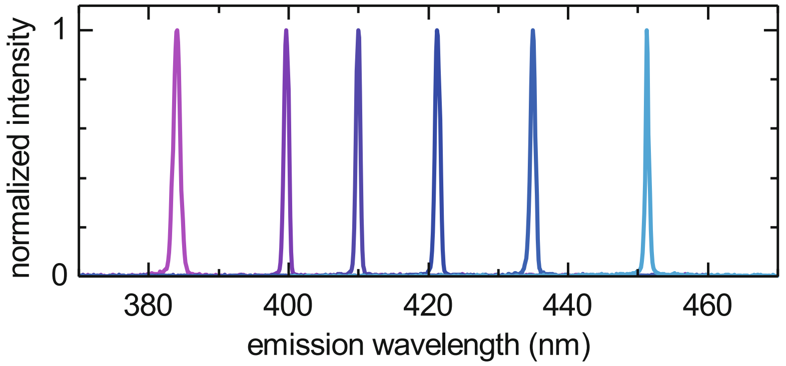


Fig. 2. Emission spectra of InGaN-based laser diodes, covering wavelengths from deep violet to blue.

Integrated Quantum Technology

Compact laser technology enables optical clocks for space applications

Optical atomic clocks provide frequency stability far beyond conventional microwave-based atomic clocks. They enable next-generation applications, including ultra-precise Global Navigation Satellite Systems (GNSS) and synchronized quantum communication networks. Deploying optical clock technology in space requires laser systems that combine compact integration, mechanical resilience, and reliable autonomous operation under extreme environmental conditions.

At FBH, we meet these requirements by developing hermetically sealed, miniaturized, micro-integrated diode laser modules for space-based optical clocks. The current design builds on the technological heritage of laser modules that have flown and operated successfully in multiple sounding-rocket missions [1, 2]. The state-of-art laser module (as shown in Fig. 1), combined with the spectroscopy unit and control electronics, serves as the optical frequency reference for a rubidium-based optical atomic clock [3]. This development leverages FBH's full photonics expertise, spanning semiconductor laser design, micro-integration, and system-level space qualification.

A key innovation of the laser module [4] is its low-stress, thermally decoupled micro-optical bench, protected by a German patent granted in 2024. As illustrated in Fig. 1, the design integrates all optical and opto-electronic components directly onto this bench, creating a compact, mechanically stable core. The architecture minimizes alignment sensitivity while meeting strict satellite mass and volume constraints.

Flexible-and-stress-bearing structures of ultra-high tensile strength mechanically and thermally decouple the bench from the housing. These flexures 'absorb' launch-induced vibration and shock load as well as thermally induced stress caused by mismatched thermal expansion coefficients between housing and micro-optical bench. The flexures and micro-optical bench are carefully designed so that all induced stresses stay within the elastic range of the materials. As a result, the optical bench experiences only negligible deformation and the mechanical system can recover autonomously after launch. Mechanical testing and simulations confirm that the module withstands launch-relevant loads with comfortable safety margins. In contrast to conventional laboratory-based systems, the module uniquely combines compactness, robustness, and space compatibility in a single platform, making it ideal for operational space missions.

Stable optical frequency operation requires precise temperature control. The laser module therefore incorporates a thermal management system that isolates the optical core from external temperature fluctuations while actively stabilizing its operating point [5]. Integrated thermal control units combine thermo-electric coolers with flexible, high-performance thermal straps to precisely stabilize the temperature of the micro-optical bench. These straps create dedicated heat-flow paths while mechanically decoupling the optical core, thereby minimizing the transfer of mechanical stress. This approach ensures reliable laser performance across the temperature variations expected during in-orbit operation.

The laser module is designed for maintenance-free, long-term operation and is activated only once the satellite reaches its designated orbit. By combining compact integration, mechanical robustness, and thermal stabilization, we provide a key enabling technology for space-based optical clocks. The patented design highlights FBH's ability to deliver fully integrated, space-qualified photonic solutions, developed through close collaboration across teams – from micro-integration to system validation.

Developments are carried out in collaboration with Technische Universität Berlin and Menlo Systems GmbH. This work is supported by the DLR Space Administration with funds provided by the Federal Ministry of Research, Technology and Space (BMFTR) under grant numbers DLR 50WM2164, 50WM2564, and 50WM2351C.

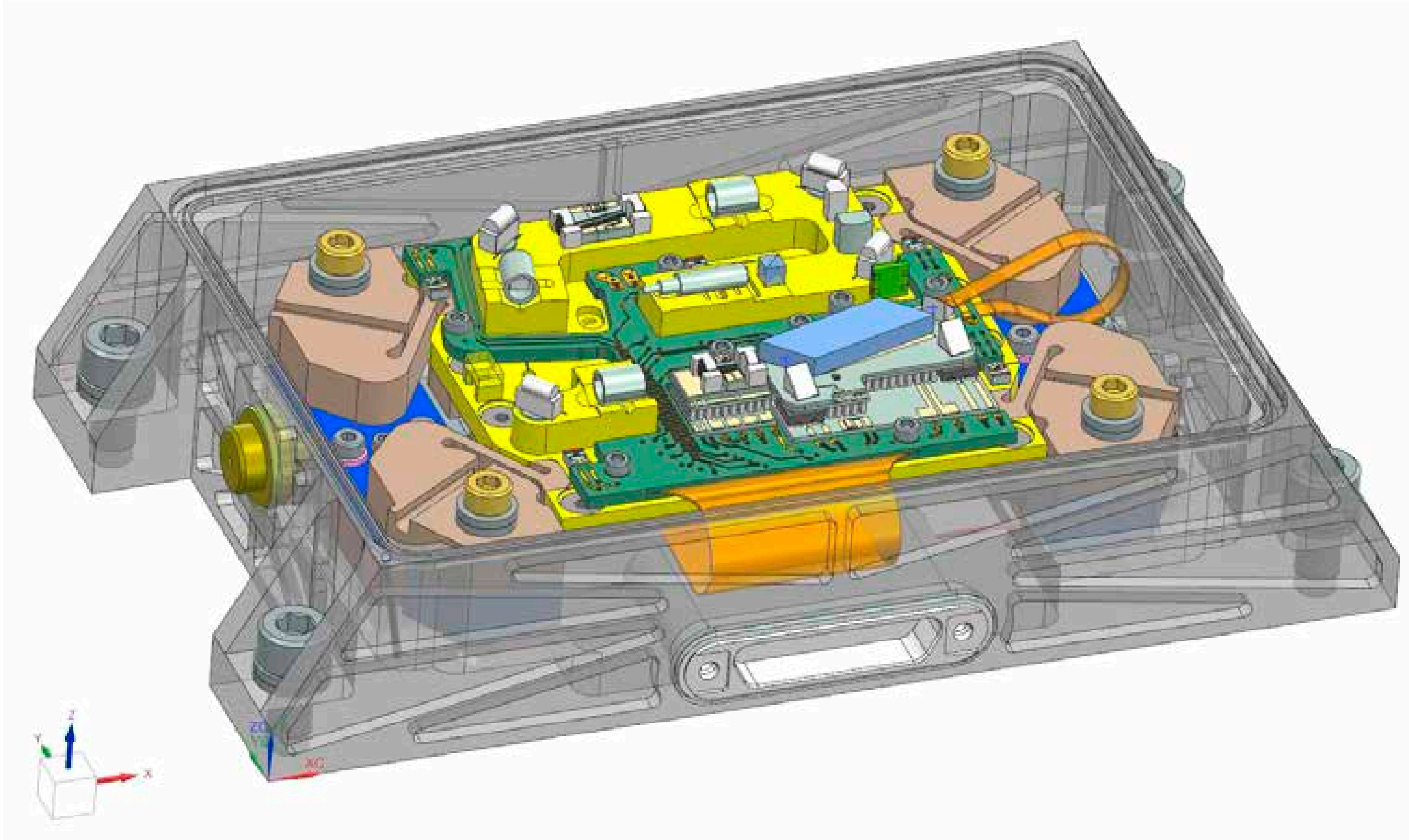


Fig. 1. Patented design of the hermetically-sealed laser module, demonstrated via a 3D view (with housing lid, electrical feedthroughs, and connectors hidden for clarity). The laser module includes a micro-optical bench with monolithic optics mounts (yellow), rigid-flex PCBs (green: rigid part, orange: flexible part), flexures (light brown), thermal control system (blue), optical feedthrough (gold), and housing (grey).

Publications

[1] "Extended cavity diode laser master-oscillator-power-amplifier for operation of an iodine frequency reference on a sounding rocket", doi.org/10.1364/AO.379955 (2020)

[2] "Narrow linewidth diode laser modules for quantum optical sensor applications in the field and in space", doi.org/10.1117/12.2253655 (2017)

[3] "Mechanical simulation of a hybrid micro-integrated diode laser module developed for space-borne application", doi.org/10.1364/CLEO_AT.2023.JTh2A.70 (2023)

[4] "Development of a Micro-Integrated Diode Laser Module for Application in a Space-Borne Optical Clock", doi.org/10.1109/ICSOS66026.2025.11443187 (2025)

[5] "Micro-integrated diode laser modules enabling mode-hop-free tuning and long-term frequency stabilization", doi.org/10.1364/AO.571474 (2025)

Patent

D. Zou, M. Schiemangk, C. Tyborski, S. Hariharan, N. Müller, A. Wicht, "Low-stress optical bench with thermal decoupling", DE102023111589B3

Towards miniaturized two-photon optical clocks utilizing micro-fabricated MEMS vapor cells and chip-scale diode lasers

At FBH, we develop and integrate advanced atomic devices that combine chip-scale laser systems with microfabricated vapor cells. Alkali vapor cells are a key component of a wide range of integrated quantum optical devices including optically pumped magnetometers, electric field sensors, and optical clocks. They also serve as absolute optical frequency references for stabilizing laser systems used in quantum sensing, communication and computing.

Miniaturized two-photon optical frequency references based on two-photon spectroscopy offer a promising route toward compact atomic clocks. By combining microfabricated vapor cells with a novel chip-scale diode laser, we aim to realize user friendly, cost effective, and miniaturized clocks. Such clock systems are particularly attractive for field applications in synchronization, navigation, and communication, where low maintenance and long-term relative stabilities of 10^{-15} are needed. Precise timekeeping also plays a critical role in modern information and telecommunications infrastructures. Data-driven industrial processes, high-speed trading, and machine learning systems all depend on reliable timestamping to avoid process errors or data loss. Compact optical clocks could provide the necessary highly stable time references for these applications.

Our optical frequency references are based on two-photon spectroscopy of hot rubidium vapor. In contrast to microwave standards that operate in the radio frequency regime, our devices probe atomic transitions in the optical range and therefore offer improved frequency stability.

We have developed a compact spectroscopy demonstrator module. This module utilizes microfabricated, wafer-bonded vapor cells filled with atomic rubidium. We use MEMS cells based on wafer-level fabrication techniques that enable scalable production with high reproducibility (Fig. 1). The process begins with structuring a silicon wafer using plasma and laser etching methods to generate two chambers that are interconnected by micro channels. We then bond a glass wafer to each side of the cell. One chamber serves as reservoir, while the second functions as spectroscopy cell. Before bonding the second glass, we place an alkali metal dispenser inside the reservoir chamber. This step finally seals the MEMS cell. This wafer-level process allows up to 105 cells to be manufactured in a single production run. After dicing the wafer into chips, we activate the individual cells by decomposing the precursor with controlled high-power laser light in a dedicated activation setup. The demonstrator module with a volume of just 72 ml (67 x 32.5 x 33 mm^3) is depicted in Fig. 2.

Fig. 3 shows a two-photon spectrum of the $5S_{1/2} \rightarrow 5D_{5/2}$ transition of rubidium 87 measured with our demonstrator. The observed linewidth of 4.8 MHz is, to our knowledge, narrower than values reported for commercially available MEMS cells. We are currently investigating additional improvements, including specialized optical filter coatings to the spectroscopy windows and integrated planar heating structures to enhance device functionality.

The atomic transition at 778 nm is excited by light from a chip-scale, monolithically integrated extended-cavity diode laser (mECDL). The mECDL combines the small form factor and wafer-scale manufacturability of state-of-the-art distributed Bragg reflector (DBR) lasers with the ultra-low noise emission characteristics of an ECDL. Its high optical power, low frequency noise, and small form factor make it particularly suitable for compact applications.

These results demonstrate the potential of chip-scale rubidium two-photon frequency references and mark an important step toward more robust and scalable optical clock systems. We will further advance this work toward compact and scalable rubidium optical two-photon clocks and other devices that can utilize micro-fabricated vapor cells, such as optically pumped magnetometers.

This work is supported by German Space Agency (DLR) with funds provided by the Federal Ministry of Research, Technology and Space (BMFTR) under grant numbers No.50WM2166 and 50RK2580A and by the BMFTR within the research program quantum systems under grant number 13N17491.

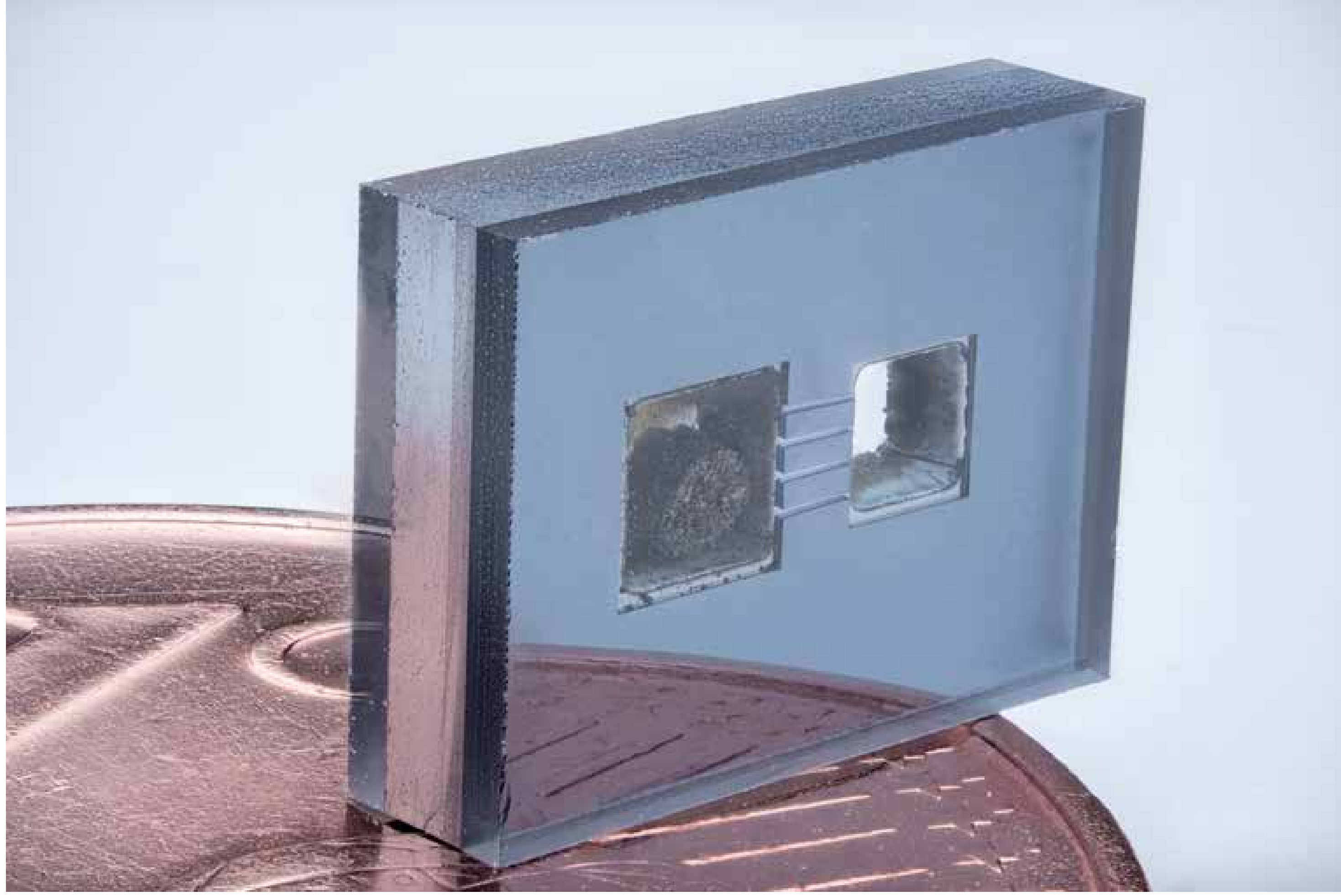


Fig. 1. Alkali vapor reference cell (2 x 6 x 8 mm^3) before activation (decomposition) of the Rb-containing pill. Channels connect the reservoir chamber with the spectroscopy chamber.

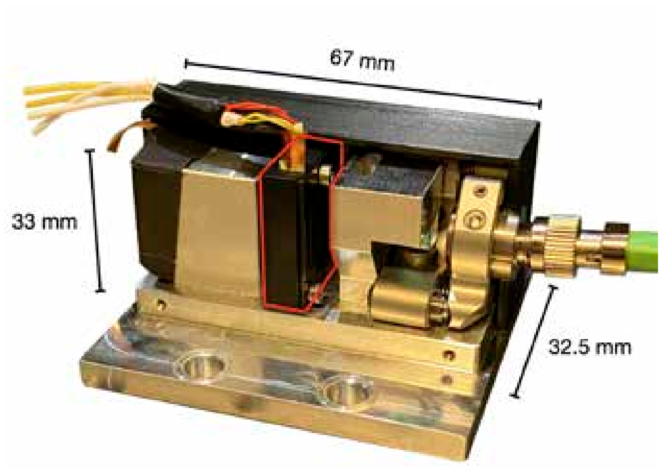


Fig. 2. Demonstrator consisting of the alkali vapor reference cell (marked in red), the fiber coupling system (right), and a light collection and detection block (left).

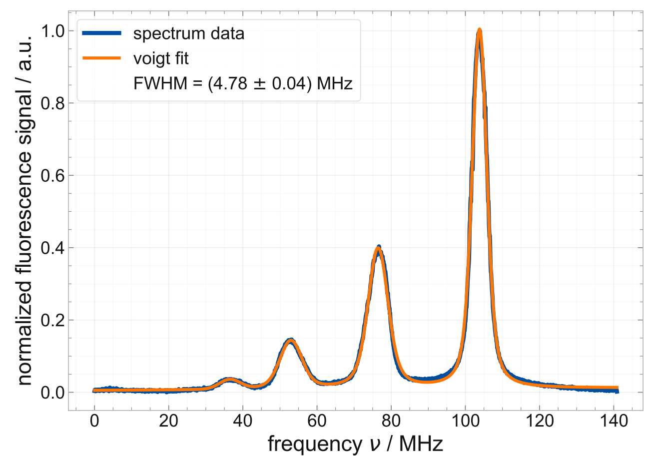


Fig. 3. Fluorescence spectrum of the ^{87}Rb $5S_{1/2}$ F=2 $\rightarrow$ $5D_{5/2}$ transition of the best performing MEMS cell. Peaks F=1 to F=4 from left to right. FWHM of F=4 was determined by fitting a multi-Voigt profile.

Publications

"Towards Miniaturized Spaceborne Rubidium Two-Photon Frequency References", DPG Jahrestagung (2025)

"Development of a Rubidium Two-Photon Frequency Reference for Demonstration in Space", doi 10.1109/EFTF/IFCS64367.2025.11194432 (2025)

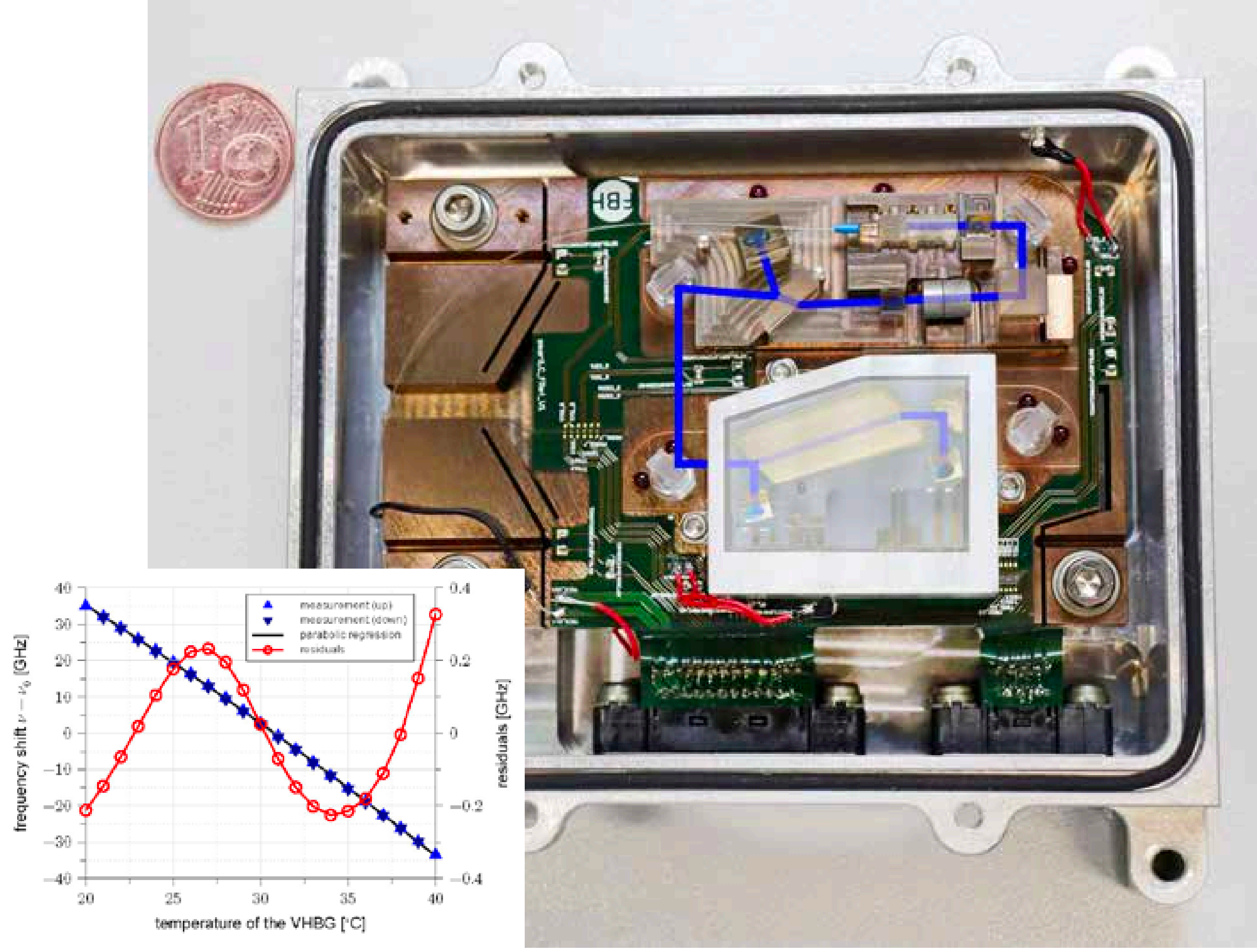


Fig. 1. The emission frequency of the locked laser as a function of the temperature of the frequency reference's VHBG (blue). A parabolic regression is shown in black, and the corresponding residuals are plotted in red.

Photograph of the frequency reference module with the beam path highlighted in blue. A separate image of the Peltier element setup is overlaid on the lid to illustrate the internal components.

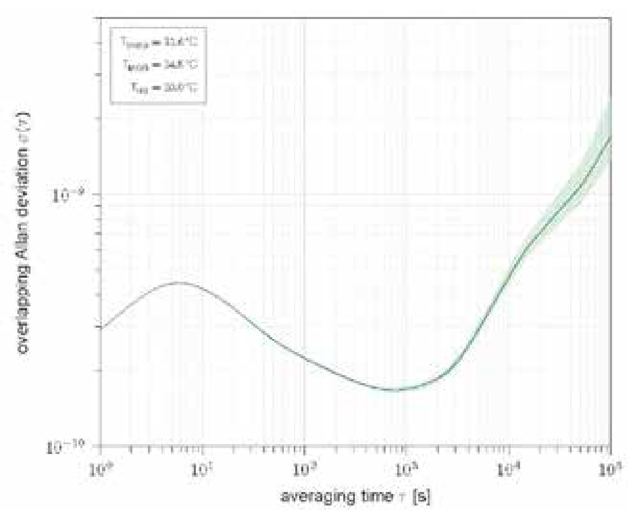


Fig. 2. The overlapping Allan deviation of the stabilized laser as a function of the averaging time τ. The light green areas indicate the 1-σ confidence intervals of the overlapping Allan deviation calculation.

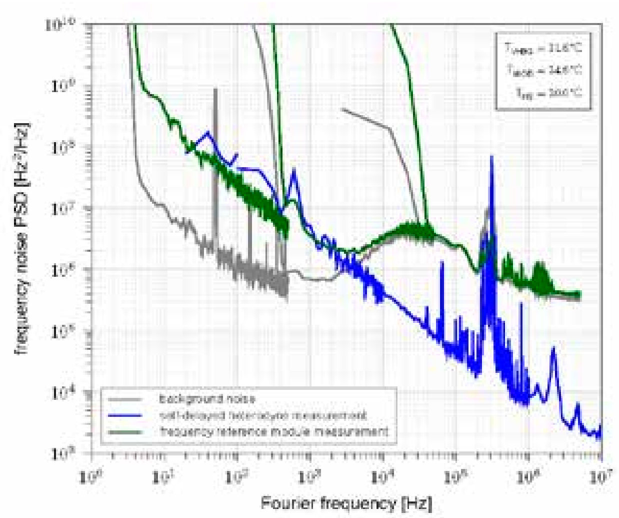


Fig. 3. The frequency noise power spectral density of the free-running laser is measured by using a self-delayed heterodyne method (blue) and by using the frequency reference module as a spectrometer (green). The noise background of the spectrometer setup is shown in gray.

A tunable optical frequency reference module for quantum technology applications

Quantum technologies are rapidly advancing from laboratory-scale experiments to deployable systems. They enable advances in quantum sensing, communication, computation, and timekeeping. Many of these emerging applications require laser systems that combine laboratory-grade performance with the compactness and robustness needed for field or space deployment. To address this demand, we developed a precise, micro-integrated optical frequency reference module. This module enhances the long-term frequency stability of a laser operating at a wavelength of 767 nm and supports quantum technology experiments that manipulate neutral, ultra-cold potassium atoms in an atom interferometer.

The frequency reference module relies on spectroscopy of a temperature-controlled volume holographic Bragg grating (VHBG). By selecting an appropriate VHBG, we can realize different operating wavelengths, while temperature control enables fine tuning of the reference frequency , as can be seen in Fig. 1. This approach differs from references based on atomic transitions, whose operating frequencies remain inherently fixed. Our module therefore offers greater flexibility for system integration.

The system can be operated in three distinct modes, extending the capability of conventional frequency reference modules:

- Laser stabilization: improving the frequency stability of a laser
- Wavemeter operation: directly measuring the emission frequency of a laser
- Spectrometer operation: analyzing the frequency noise of a laser.

In laser stabilization mode, the system achieves a minimum frequency instability of $1.7 \cdot 10^{-10}$ at an averaging time of 1000 s and $1.5 \cdot 10^{-9}$ at 24 h. We determined these values from the overlapping Allan deviation of the fractional frequency, see Fig. 2. The results demonstrate long-term frequency stability suitable for precision quantum technology applications. The frequency of the module is tunable over more than 65 GHz by adjusting the temperature of the VHBG (Fig. 1).

In wavemeter mode, this tuning range directly corresponds to a capture range exceeding 65 GHz and enables flexible frequency determination across a wide spectral window. A parabolic fit yields residuals below 330 MHz, corresponding to the uncertainty of the wavemeter's frequency measurement determination.

When operated as a spectrometer, the module acts as a frequency discriminator, enabling direct access of the laser's frequency noise. For Fourier frequencies below 1 kHz, the measured frequency noise agrees well with results obtained using the established self-delayed heterodyne method. At the same time, the module allows measurements in frequency ranges where the heterodyne method becomes ineffective (Fig. 3).

This work was supported by Investitionsbank Berlin and funded by European Union under grant 10168115.

Publications

"Micro-integrated diode laser modules for operation in quantum technology applications", doi.org/10.1117/12.3002234 (2024)

"A tunable optical frequency reference module based on a volume holographic Bragg grating", doi.org/10.1109/JPHOT.2026.3654409 (2026)

Patent

J. Hirsch, M. Schiemangk, A. Wicht, "Device and method for frequency stabilization of a laser", DE102022117050A1 (DE) and JP7756832 (JP)

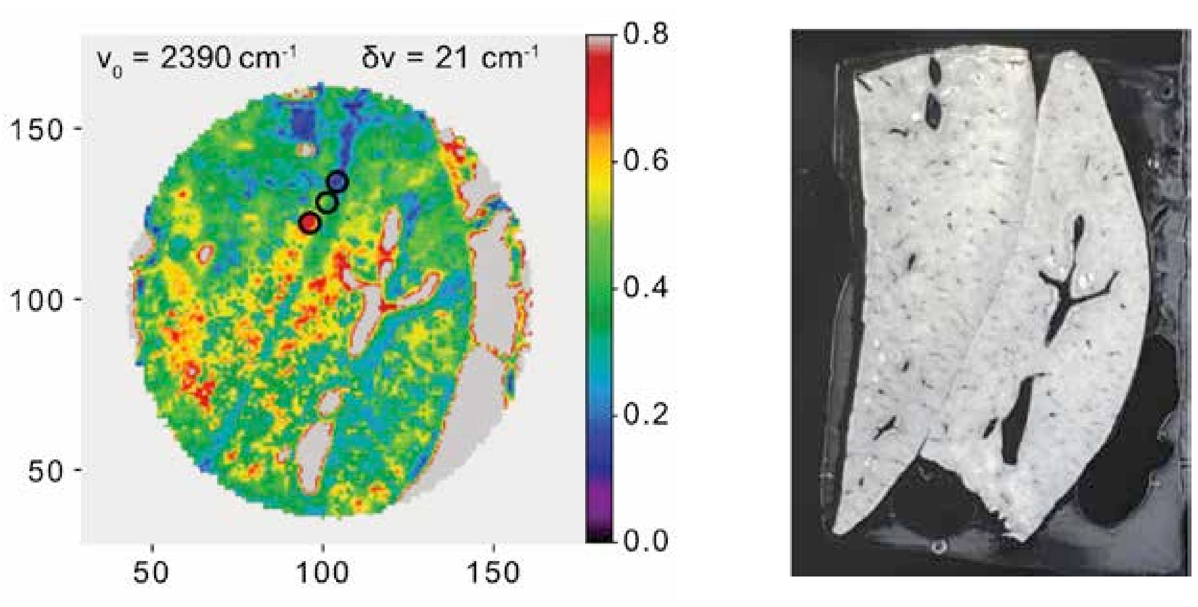
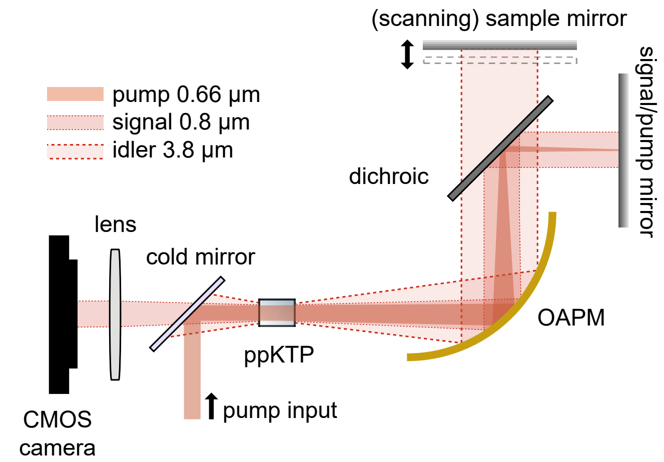


Fig. 1. Conventional photo (right) and wavelength-selective image of light transmission (left) of a tissue sample. In the mid-infrared spectral range around 2390 cm^{-1} (4180 nm), the organ section of a rat liver shows central island-like structures with high transmission and isolated highly absorbent areas at the edge.

Fig. 2. Experimental setup for transferring mid-IR specific sample information to the near-IR sensitivity range of the silicon-based camera detector. The spectral transmission is extracted from pixelwise Fourier analysis of the broadband signal-idler interferograms.



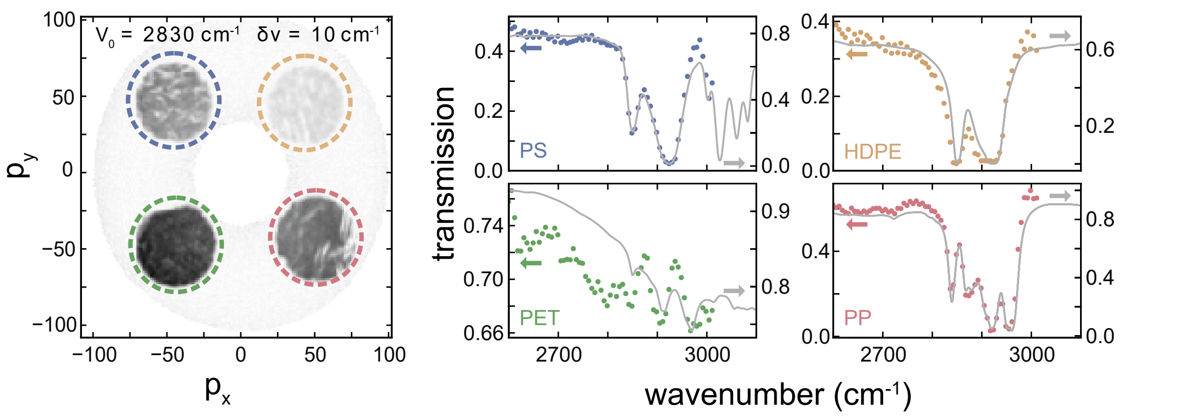


Fig. 3. Hyperspectral analysis (imaging left, spectroscopy right) of various polymer films in the fingerprint region of hydrocarbon vibrations. To compare experimental data recorded with undetected photons (colorful dots), reference spectra obtained with a commercial Fourier-Transform Infrared Spectroscopy interferometer are included (grey lines).

Hyperspectral mid-infrared imaging with undetected photons

Mid-infrared (MIR) spectroscopy uses the molecular fingerprints of samples to perform biomedical or environmental analyses without chemical staining or labeling. Highly specific vibrational states of the different molecules contained therein provide characteristic signatures. Infrared spectroscopy thus allows almost any sample to be examined (bio)chemically in a non-destructive manner and without pretreatment.

In practice, however, widespread use often fails due to the complex and cost-inefficient MIR technology. Compared to established, marker-based methods, the light sources and detectors required for such spectroscopic methods are often not yet practical, for example for use in clinics.

A research team from Humboldt-Universität zu Berlin and Ferdinand-Braun-Institut (FBH) within their Joint Lab Nonlinear Quantum Optics has now developed an alternative spectral imaging method in collaboration with Fraunhofer IPM in Freiburg. Using the quantum-optical effect of sensing with undetected photons, the researchers transfer molecular MIR information from biological and industrial samples into the detection range of silicon-based cameras – see comparison in Fig. 1 between a conventionally taken photo and wavelength-selective imaging. All that is needed is a cost-effective red laser pumping a special nonlinear crystal that generates entangled photon pairs, each consisting of a near-infrared and a mid-infrared photon. Fig. 2 shows the experimental setup.

Interference between two such photon-pair generation processes transfers the spectral information of the MIR photon to the near-infrared range. By combining imaging optics and Fourier-transform spectroscopy, not only two-dimensional imaging information but also spatially resolved MIR transmission spectra of the respective samples are recorded. The result is a three-dimensional data set consisting of spatial and spectral information, see Fig. 3. On this basis, the biochemical composition of tissue samples, for example, can be visualized – without markers and without direct MIR detection.

Parallel to the further development of the underlying measurement principle, FBH is developing compact interferometer modules in its Laser Modules Lab. These modules lay the foundation for transferring the process to practical applications in the fields of medical technology and environmental analysis.

This work is funded by the German Federal Ministry of Research, Technology, and Space (BMFTR) under grant numbers 13N15944 and 13N16384. It was recently published in the Optica Journal, the high-impact journal of the Optica Publishing Group.

Publication

"Mid-IR hyperspectral imaging with undetected photons", doi.org/10.1364/OPTICA.573220 (2026)

Towards scalable quantum photonics: heterogeneously integrating diamond nanostructures on an AlGaN/AlN platform

Quantum technologies promise powerful new possibilities in communication, sensing, and computing. However, building quantum devices that are reliable and scalable remains challenging. No single material can provide all the properties required for efficient quantum processors. Some materials excel at generating or storing quantum states, while others guide and control light with very low optical losses. Practical quantum systems therefore require combining these different strengths on one platform. Heterogeneous integration provides a promising route to combine these strengths on a single chip.

At FBH, we focus on integrating diamond nanostructures into photonic integrated circuits (PICs) based on aluminum gallium nitride (AlGaN). Diamond can host point defects known as color centers that act as spin-photon interfaces. When embedded into carefully designed nanostructures, such as photonic crystal cavities, these emitters experience enhanced light-matter interaction and an improved photon emission. Both effects are essential for quantum photonic applications. AlGaN, on the other hand, has shown great potential for building PICs for guiding and processing light. Such AlGaN-based PICs offer low optical losses, can be reconfigured, and operate across a wide spectral range. The material also exhibits strong nonlinear and electro-optic properties and can be fabricated at wafer scale, which is important for manufacturing complex integrated devices.

Our work focuses on combining these two platforms into a single system. We design a low-loss coupling section between diamond and AlGaN waveguides using numerical simulations. In parallel, we optimize the fabrication of diamond nanostructures, including waveguides and photonic crystal cavities, as well as the AlGaN photonic circuits themselves. We then physically combine the two platforms using pick-and-place and/or transfer-printing techniques. Fig. 1 provides a schematic overview of these approaches.

Simulations predict coupling efficiencies as high as 97 %. Initial heterogeneous integration experiments using pick-and-place methods confirmed the feasibility of the concept, demonstrating coupling efficiencies of up to 57 %. While these results validate the approach, more complex quantum devices require both higher performance and scalable integration. We therefore continue to improve the fabrication of AlGaN photonic circuits to enable the fabrication of high-coupling-efficiency interfaces and to refine the integration process.

In our initial pick-and-place approach, a tungsten probe tip picks up diamond nanostructures and places them on the PIC platform. To achieve scalability, we are now advancing toward transfer printing of diamond chiplet structures, as illustrated in Fig. 2. In this method, we fabricate polymer stamps made of polydimethylsiloxane (PDMS) to handle and position diamond nanostructures with high precision. This approach enables controlled and repeatable integration across the photonic chip.

Ultimately, this low-loss heterogeneous integration strategy represents an important step toward scalable quantum photonic circuits that combine efficient quantum emitters with advanced photonic functionality.

This work was supported by the German Federal Ministry of Research, Technology and Space (BMFTR, grants 13N15858 (QPIC-1) and 13N16957 (DIAQUAM)).

Publication

"Hetero-integrated diamond-on-AlGaN/AlN waveguides for optical color center interfacing", doi:10.1038/s44310-025-00099-w (2026)

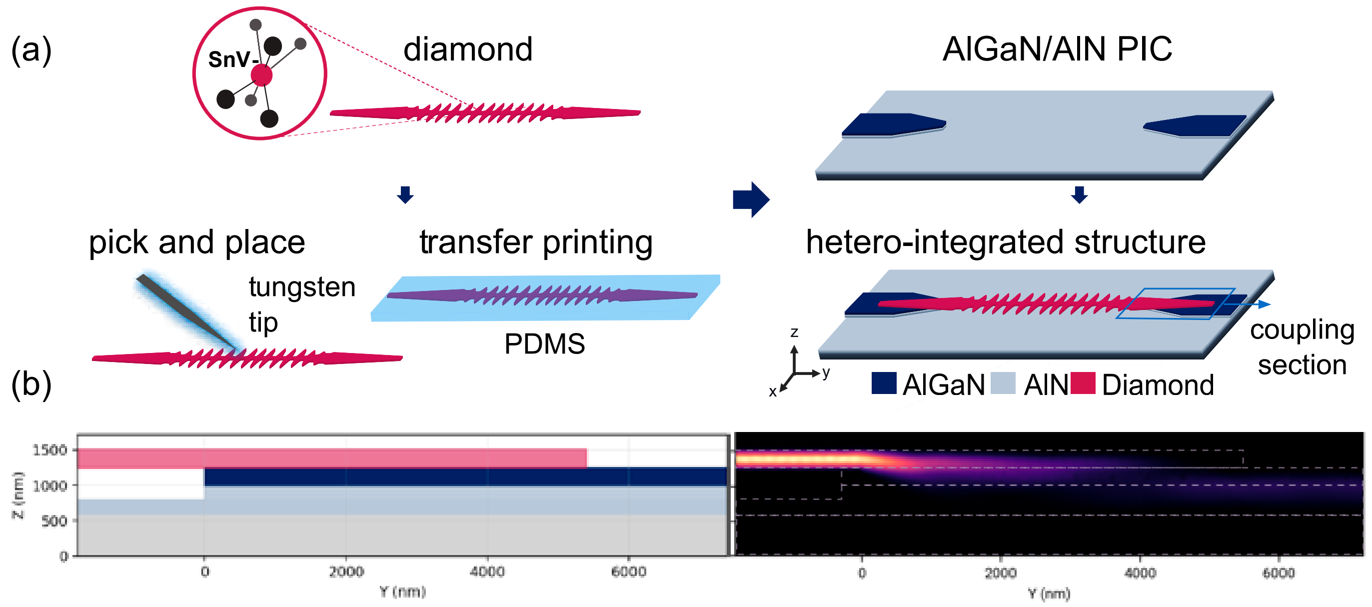


Fig. 1. Heterogeneous integration of diamond into an AlGaN platform. (a) Heterogeneous integration scheme highlighting the pick-and-place and transfer-printing approach. (b) Cross-section of the YZ interface showing the optical mode transfer from the diamond to AlGaN waveguide.

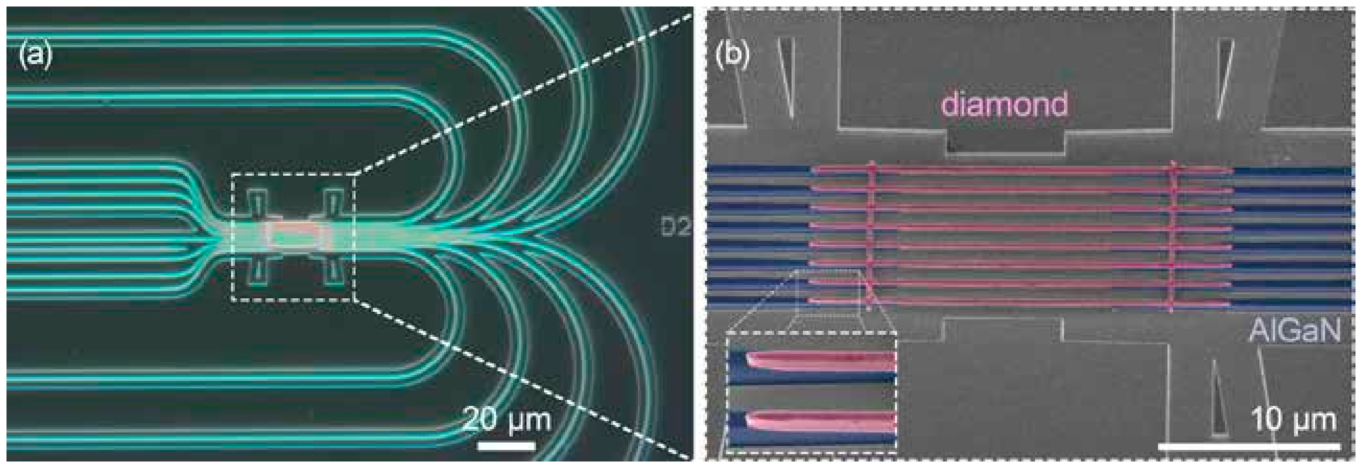


Fig. 2. AlGaN chiplet architecture for complex scalable heterogeneous integration.
(a) Optical microscope image of a heterogeneously integrated chiplet structure.
(b) Zoomed scanning electron microscope (SEM) image highlighting structural details of the integrated region.

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III-V Electronics

Novel GaN-based full-duplex front-end topology for communication and sensing systems

Data traffic has increased steadily in recent years. As a result, certain frequency bands face growing congestion since they are already heavily occupied by 5G, Internet of Things, and Wi-Fi applications. Conventional half-duplex systems use the available spectrum inefficiently. They either assign certain frequencies or timeslots for transmit and receive, thus losing typically half of the available channel capacity. In time-multiplexing operation, the receiver additionally switches off during the anticipated transmit time slot. Full-duplex transceivers overcome these limitations by transmitting and receiving on the same frequency channel at the same time. This approach enables higher data rates, improves spectrum efficiency, and reduces communication latency.

The main challenge in full-duplex systems is self-interference. The transmitted signal has higher power than the received signal to be able to cover a required distance over air. As a result, transmit signal leakage into the receiver must be strongly suppressed. Effective suppression ensures reliable data recovery and protects the circuit from overload or damage.

In cooperation with the Joint Lab BTU-CS FBH Microwave, we introduced a novel full-duplex front-end concept (Fig. 1). The approach performs self-interference cancellation in the analog domain. It utilizes a quarter-wave transmission line (λ/4-line) placed between the shared antenna and the receiver. The receiver consists of a low-noise amplifier (LNA), while a digital power amplifier (PA) generates the transmit signal. A portion of this signal crosstalks to the receiver, where it is cancelled by an auxiliary amplifier (copy of the PA), thus suppressing this interference.

We evaluated this concept using demonstrators based on monolithically integrated circuits (MMICs) fabricated in-house. These include digital class-E PAs and a rugged LNA designed for operation at 4 GHz. We combined the MMICs with a PCB based on a Rogers RO4003C laminate. Two different versions were realized: one without LNA and one including the LNA. The configuration without LNA allowed us to evaluate the potential suppression under simplified conditions, since creating the cancellation signal becomes less complex.

Our design focuses on reaching high suppression without relying on a directive device while achieving high output power. The front-end shows transmit losses of 5.2 dB, mainly due to the use of two PAs, one of which reaches a drain efficiency of 61 %. The insertion loss of the receiver path amounts to 5.2 dB. Combined with the measured noise figure (NF) of the LNA of 2.4 dB, the overall NF amounts to 7.6 dB. This result is higher than that of front-end architectures with directive devices.

An advantage of this GaN-based concept lies in its potential to reach higher transmit power. Measurements showed transmit powers up to 34 dBm, whereas CMOS-based full-duplex implementations typically reach only 30 dBm, often remaining well below this level.

In continuous-wave operation without the LNA, we measured a peak suppression of 52 dB at 4 GHz and an average suppression of 40 dB across the frequencies range from 3.6 to 4.0 GHz, see Fig. 2. Paired with the linearity and ruggedness of the GaN-based LNA, this concept enables a full-duplex front-end without a directive device. The architecture also offers option of integration into a single chip with a minimal footprint. Furthermore, it shows potential to be operated over a wider frequency range, which is mainly limited by the λ/4 transmission line.

These results demonstrate the feasibility of a novel full-duplex transceiver front-end architecture. The concept offers strong potential for the next generation communication and sensing systems.

This work received partial funding from the Federal Ministry of Research, Technology and Space (BMFTR) within Research Fab Microelectronics Germany – FMD framework under grant 16FMD02 and through the project "GreenICT@FMD" under grant 16ME0505.

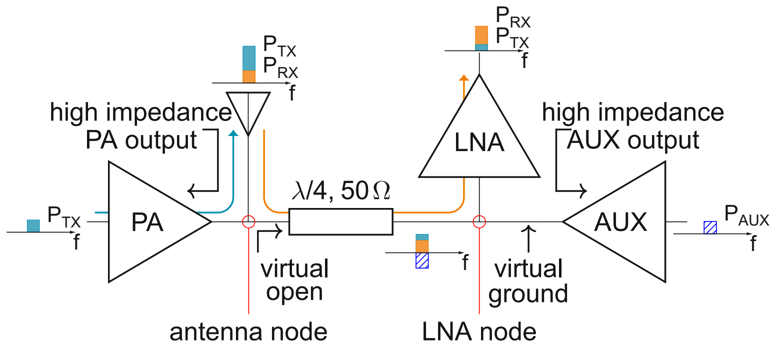


Fig. 1. Block diagram of novel full-duplex topology (left) and demonstrator module (top).

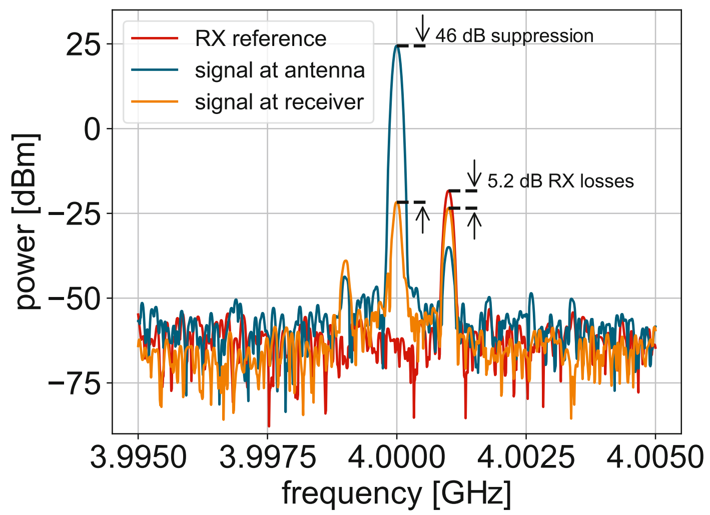


Fig. 2. Exemplary spectrum of transmit and receive signal at 4 GHz and 4.001 GHz, respectively, for a measured suppression of 46 dB.

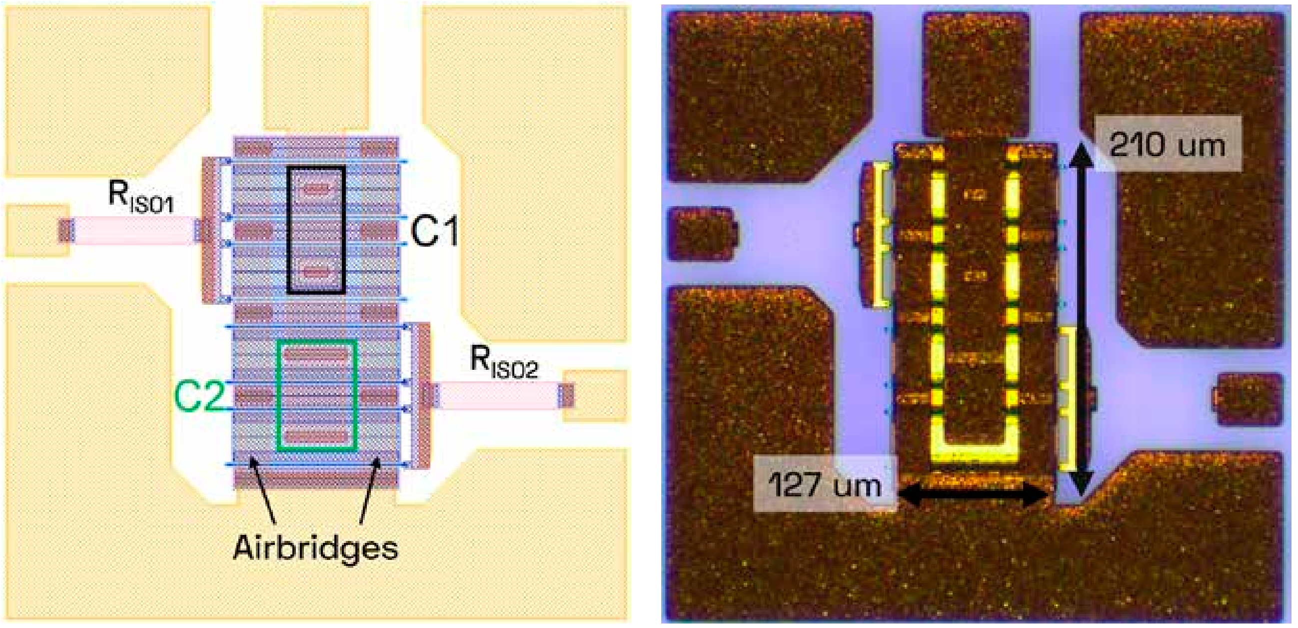


Fig. 1. Layout (left) and photo (right) of the reconfigurable capacitor cell. The gate resistors are not visible in the photo since they are on a lower layer covered by passivation.

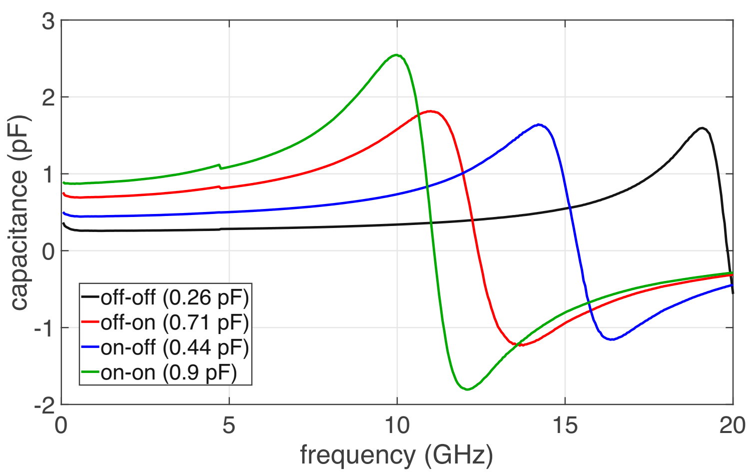


Fig. 2. Extracted capacitance values of the reconfigurable capacitor cell for all possible states.

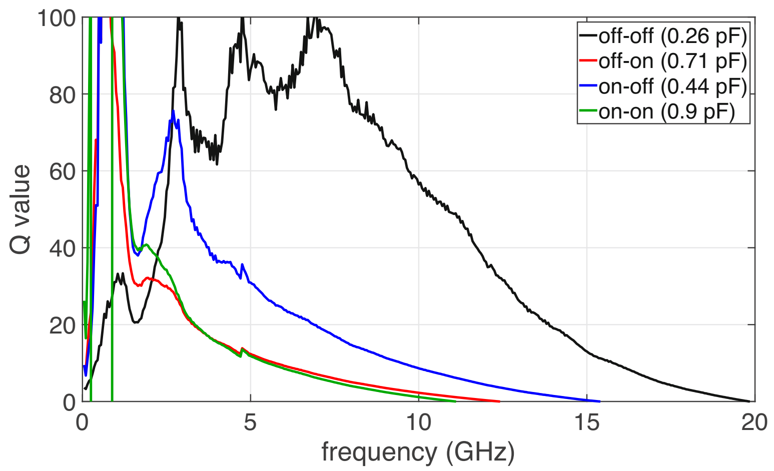


Fig. 3. Extracted Q-values of the reconfigurable capacitor cell for all the possible states.

An innovative integrated reconfigurable capacitor cell for multiband RF transceivers and radar systems

Modern radio-frequency (RF) microwave integrated circuits, such as transceivers for telecommunications and radar systems, require an ever-increasing level of complexity while delivering maximum performance. Circuits that can operate in several distinct frequency bands enable flexible, cost efficient, and compact solutions for such applications. To realize multiband operation, designers integrate reconfigurable or tunable components into the circuits to change their behavior, with the lowest possible increase in dissipated power and area consumption.

At FBH, we have developed an innovative digitally reconfigurable capacitor cell that addresses these requirements through a high level of integration. The solution combines reconfigurable elements (capacitors) and switches (GaN transistors) within a single compact cell. Placing the capacitors between the transistors' fingers considerably reduces the interconnections and thus the occupied chip area.

We designed the full device with two branches, each comprising a transistor switch and a capacitor connected in series. An air-bridge connects the two branches, as shown in Fig. 1. To maximize integration density, each capacitor is split into two smaller units connected in parallel. In the demonstrated example, the top branch integrates a capacitance of 0.15 pF, while the bottom branch provides 0.3 pF, reaching a combined maximum capacitance of 0.9 pF. Isolation resistors connect to the transistor gates to DC control the branches, enabling digital on/off switching of each branch and thereby adjusting the overall capacitance. The total area of the reconfigurable cell occupies only 127 x 210 μm^2 (without considering measurement pads). Its footprint is comparable to that of a fixed capacitor, which makes insertion inside a complex RF circuit almost area-neutral.

The reconfigurable cell supports four different switching states, each corresponding to a distinct capacitance value, as shown in Fig. 2. The capacitance remains almost constant up to 5 GHz, after which the parasitic inductive effects of the metal connections start to degrade performance. Depending on the selected state, the cell can be used even up to 15 GHz, which enables coverage of multiple frequency bands within a single reconfigurable RF circuit.

Losses introduced by the transistor switches currently limit performance. When turned on, the transistors exhibit a non-negligible on-resistance (R_{ON}). Fig. 3 shows the Q values of the reconfigurable cell for all operating states, which represents the ratio between capacitance obtained and losses. In states where the transistors remain off, the Q value is quite high, with peaks up to 100. However, when the transistor switches turn on, the value decreases but remains above 10 across the intended frequency range of operation in all states.

We now focus on improving performance and functionality further. To substantially extend the tuning range above 2 pF and reduce losses altogether, we are increasing the size of the transistor switches and placing bigger capacitors between their fingers. We also plan to expand the number of selectable states from 4 to 16 and ultimately reduce some connections, thus further increasing the maximum operating frequency. With these upgrades, we can implement this capacitor cell in numerous reconfigurable circuits to improve overall system performance and flexibility.

Activities were funded by the German Federal Ministry for Economic Affairs and Energy (BMWE) through the Project DigiRad. This work was also partly funded by the German Federal Ministry of Research, Technology and Space (BMFTR) under project reference FMD02 (Research Fab Microelectronics Germany – FMD).

Publication

"A Digitally Reconfigurable Shunt Capacitance in RF GaN Technology Based on Inter-Finger Capacitors", doi 10.23919/EuMIC65284.2025.11233867 (2025)

High-voltage switching with next-generation GaN transistors and UWBG transistors based on AlN and Ga_2O_3

At FBH, we explore the potential of novel wide-bandgap and ultra-wide bandgap-based power electronics. To this end, we develop lateral and vertical transistors in the GaN, AlN and Ga_2O_3 material systems and demonstrate their high-voltage switching performance.

Vertical GaN-based power transistors offer clear advantages over their lateral counterparts. In particular, they achieve an exceptionally low specific on-resistance, which directly reduces the required chip size. We fabricated vertical trench MOSFETs with > 600 V breakdown voltage and demonstrated stable switching operation up to 200 V / 6 A (Fig. 1b). These dynamic switching tests revealed a remarkable stability of the dynamic on-state resistance as well as a low threshold voltage shift. We processed the transistors on native GaN substrates with a gate width up to 1800 mm on 3 × 3 mm² chip area (Fig. 1a). These chips can easily be inserted into discrete power modules for kW power class operation.

AlN-based power-electronic devices benefit from the exceptionally high critical electric field strength of the ultra-wide bandgap semiconductor, estimated as > 10 MV/cm and thus approximately three times higher than for GaN. The high AlN thermal conductivity of ~ 340 W/(m·K) enables good heat dissipation from the active power device structure. We use high-quality AlN substrates with defect densities < 1000 cm⁻². These substrates are developed in Germany at Fraunhofer IISB and at Leibniz Institute for Crystal growth. We demonstrated AlGaN/GaN/AlN HEMTs on these AlN substrates (Fig. 2a), which show an average breakdown voltage scaling of 125 V/µm and a power figure of merit of $V_{Br}/(R_{ON} \cdot A)$ = 1.17 GW/cm². These are record values for high-voltage GaN channel transistors on AlN substrates. We achieved more than 2200 V breakdown voltage. We further demonstrated the applicability of this technology for high-voltage power conversion with wafer-based 1 A switching transients up to 760 V (Fig. 2b).

A second ultra-wide bandgap semiconductor, β-Ga_2O_3, has emerged as a promising material for next-generation high-voltage and high-efficiency power devices. The material offers a high estimated critical electric field (> 8 MV/cm) and enables low-cost bulk native substrates. While devices with kilovolt-class breakdown strength have been reported, investigations on the dynamic power switching performance remain limited. In addition, reports on large-periphery β-Ga_2O_3 transistors delivering currents above 10 A are currently lacking, hindering progress toward Ga_2O_3-based switching converter demonstrators.

We addressed these challenges by fabricating large-periphery Ga_2O_3 MOSFETs using silicon ion implantation (Fig. 3a). The devices reach peak drain currents of 13 A – the highest reported for a β-Ga_2O_3 transistor – and 720 mΩ on-state resistance. We also measured switching transients at 4 A / 300 V (Fig. 3b). These results demonstrate the first kilowatt-class switching operation in β-Ga_2O_3 power transistors and emphasize the potential of β-Ga_2O_3 for next-generation power electronics.

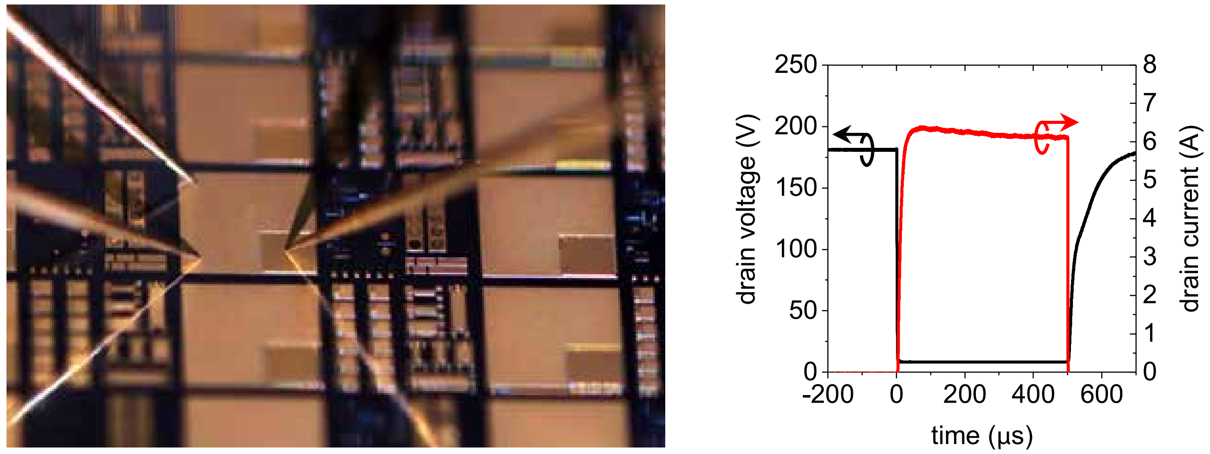
This work was funded in parts by the German Federal Ministry of Economic Affairs and Energy (BMWE) under reference 03EN4033E, joint project 01247760/1 – HoverGaN as well as the German Federal Ministry of Research, Technology and Space (BMFTR) within Research Fab Microelectronics Germany (FMD) framework under grant 16FMD02 and within the ForMikro project LeitBAN, funding no. 16ES1109K.

Publications

[1] "Vertical GaN Trench MOSFETs with HfO_2/Al_2O_3 Layered Gate Dielectric", doi 10.1109/TSM.2025.3596980 (2025)

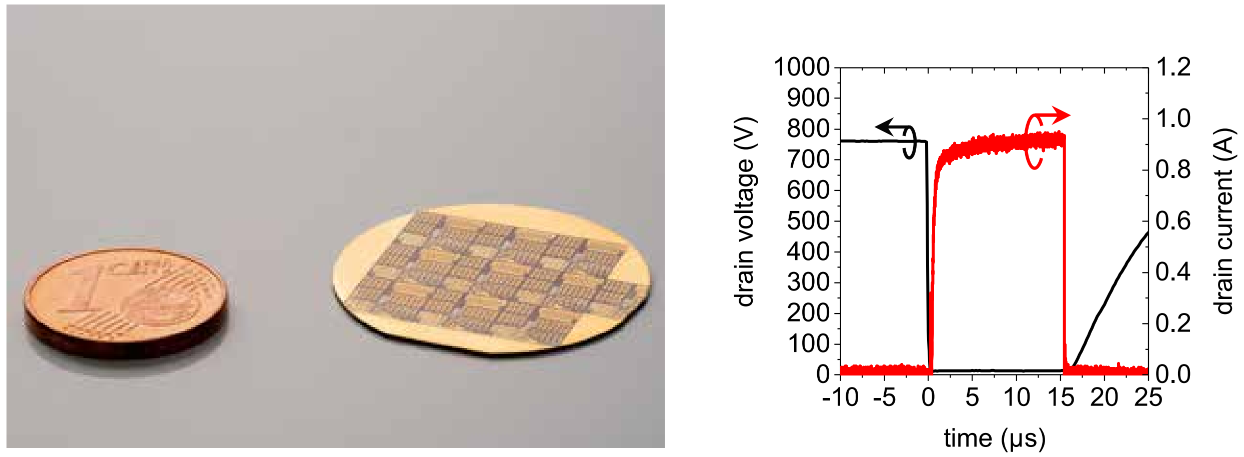
[2] "Beyond 650 V Dynamic Switching of High Voltage AlGaN/GaN/AlN HEMTs on Monocrystalline AlN Substrates", doi 10.23919/ISPSD62843.2025.11117262 (2025)

[3] "4A/300 V Switching of Lateral β-Ga_2O_3 MOSFET Devices", doi 10.1109/LED.2025.3590836 (2025)



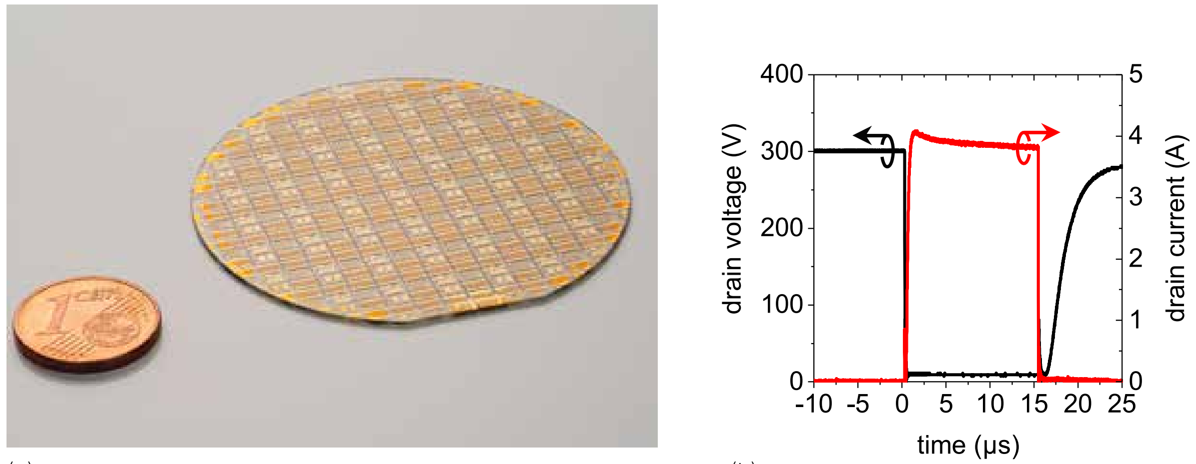
(a) (b)

Fig. 1. Photo of a 3 × 3 mm² wide vertical GaN trench MOSFET during on-wafer characterization (a) and switching transients performed at 180 V/6 A on the same transistor (b).



(a) (b)

Fig. 2. One-inch AlN wafer with processed 120 mΩ and 1.2 Ω AlGaN/GaN/AlN HEMTs for high-voltage power switching (a) and on-wafer captured soft-switching 760 V/0.9 A switching transient of a 1.2 Ω transistor from this AlN wafer (b).



(a) (b)

Fig. 3. Fully processed 2-inch β-Ga_2O_3 wafer featuring 92 mm large-periphery MOSFETs (a) and respective high-voltage switching transients of such devices demonstrating 300 V/4 A switching (b).

Highly scaled InP HBTs for next-generation G-band applications

Indium Phosphide (InP) Heterojunction Bipolar Transistor (HBT) Monolithic Microwave Integrated Circuit (MMIC) technology offers several significant advantages for high-frequency and high-performance applications. InP HBT MMICs combine high electron mobility with saturation velocity, which enables operation at extremely high frequencies, often well into the millimeter-wave and sub-terahertz range. These properties make InP technology particularly suitable for applications such as high-speed optical communications, radar, and satellite systems.

Another important advantage is their high breakdown voltage combined with high current density, which enables higher output power while maintaining efficiency. Integrating multiple high-frequency components – such as amplifiers, mixers, and oscillators – on a single chip reduces parasitics, improves performance consistency, and lowers overall system size and weight. These characteristics make InP HBT MMIC technology an attractive solution for advanced RF, microwave, and high-speed digital systems where performance beyond conventional semiconductor technologies like silicon or GaAs is required.

G-band applications, from 110 GHz to 300 GHz, require transistors with f_{max} above 500 GHz. To meet these requirements, node scaling is unavoidable. However, this introduces new challenges: Parasitic elements of the transistor do not scale down linearly with the critical dimensions, as they strongly depend on the overall device layout.

To overcome this limitation, we developed a new device process which allows the formation of metallic posts with high aspect ratios on the transistor metallization layers in the range of 1 µm in diameter. This approach allows for a much more compact transistor layout (Fig. 2) and minimizes its peripheral capacitance. As a result, we directly improve the transistor's maximum oscillation frequency.

The development of f_{max} over several transistor generations are shown in Fig. 1. For the smallest node size of 400 nm, we achieve a maximum of approximately 550 GHz. This performance ensures sufficient gain for circuit applications up to 300 GHz.

These developments enhance the use-case for InP HBTs and highlight them as a serious candidate for high-frequency applications in the G-band.

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.

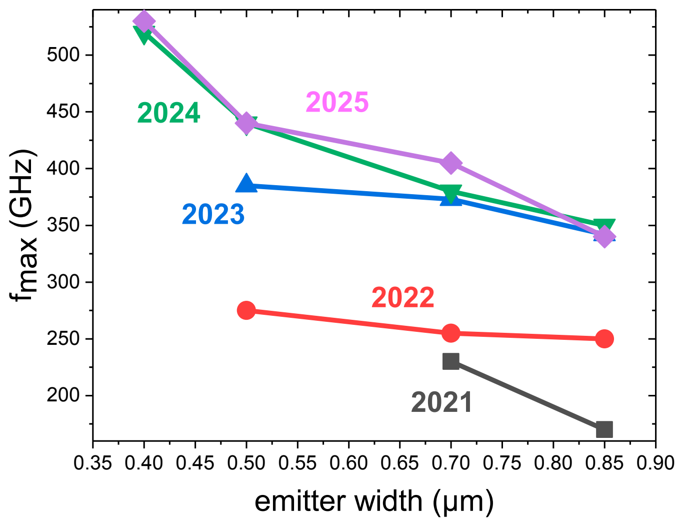


Fig. 1. Evolution of the transistor f_{max} over the last five years.

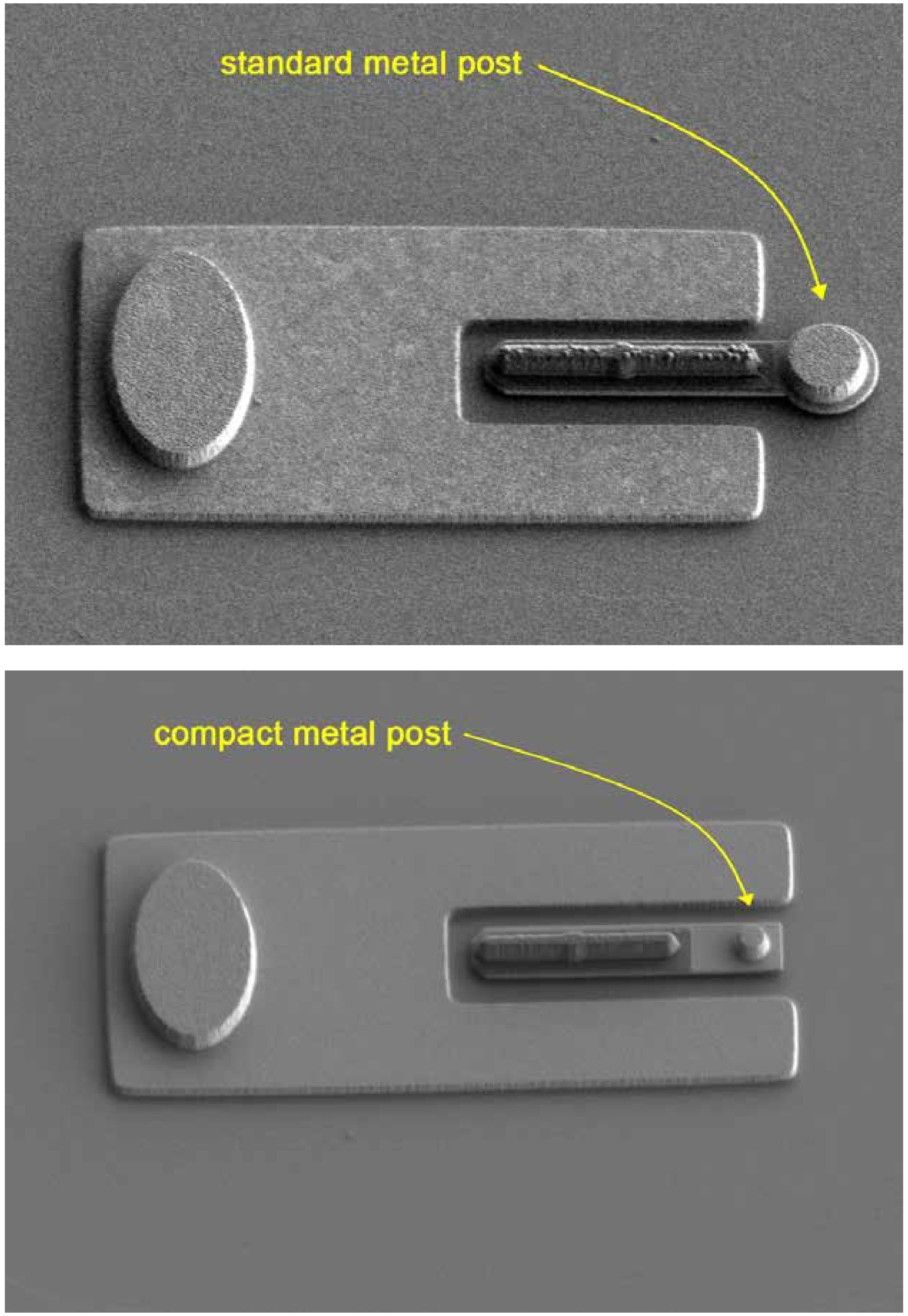


Fig. 2. (top) SEM image of a standard transistor cell without optimization. (bottom) Optimized transistor cell with compact layout for minimal parasitics.

Heterogeneously integrated photonic-electronic modules for next-generation high-speed communications

High-performance computing and very high data rate fiber-based communications demand for electronic and photonic components with bandwidths beyond 100 GHz. At these frequencies, module performance is limited by bond wires and PCB assembly. To address these challenges, we have developed a heterogeneous integration platform for photonic-electronic components.

The transmit and receive modules are based on photonic devices from Fraunhofer HHI and electronic components from FBH, such as transimpedance amplifiers (TIA), driver amplifiers (TWA), multiplexers (MUX), and demultiplexers (DEMUX). The TIA achieves high transimpedance gain and broadband response while also providing the bias for the photodiode (Fig. 1). The driver amplifier reaches a bandwidth of up to 175 GHz, in good agreement with simulation results (Fig. 2).

The heterogeneous integration process is based on micro-bumps technology with bandwidths > 300 GHz. The process is compatible with the thermal budget of InP-based photonic components, which demand processing temperatures below 200° C. We use flip-chip assembly to place the electronic component on top of the photonic component. This approach necessitates a harmonization of the electronic chiplet dimensions and of the pad constellation on both the photonic and the electronic component.

As an example of the heterogeneously integrated modules, Fig. 3 presents the compact receiver module with individual components, including chip-level integration, assembly, and system-level configuration. The module integrates a TIA directly on top of a photodiode, where the TIA also provides the bias for the photodiode.

This development enhances our capabilities in cross-semiconductor technology and cross-device heterogeneous integration while supporting next-generation high-speed communication systems.

The work was partly funded by the German Federal Ministry of Research, Technology and Space (BMFTR) within Research Fab Microelectronics Germany (FMD) framework under ref. 16FMD02. Partial financial funding is acknowledged from the EU KDT Joint Undertaking (JU) under grant agreement no. 101097296.

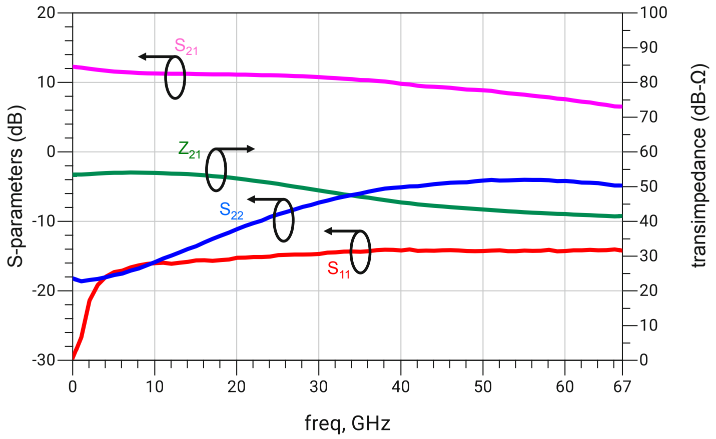


Fig. 1. S-parameter and transimpedance gain of TIA.

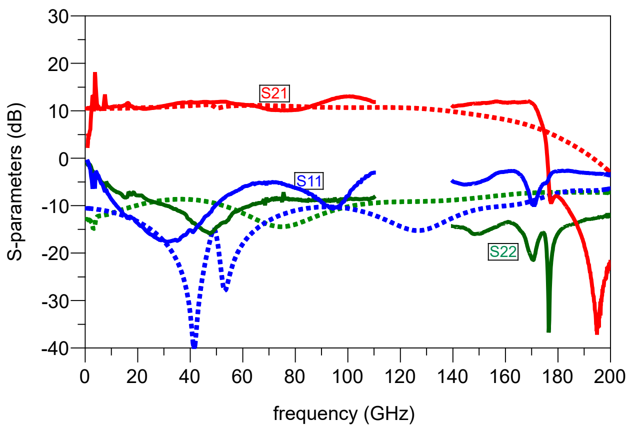


Fig. 2. S-parameter measurement (solid) and simulation (dotted) for the driver amplifier with a bandwidth of 175 GHz.

Publication

"Towards Terahertz Bandwidth Heterogeneous Integration of Semiconductor Technologies", Compound Semiconductor Week (2026)

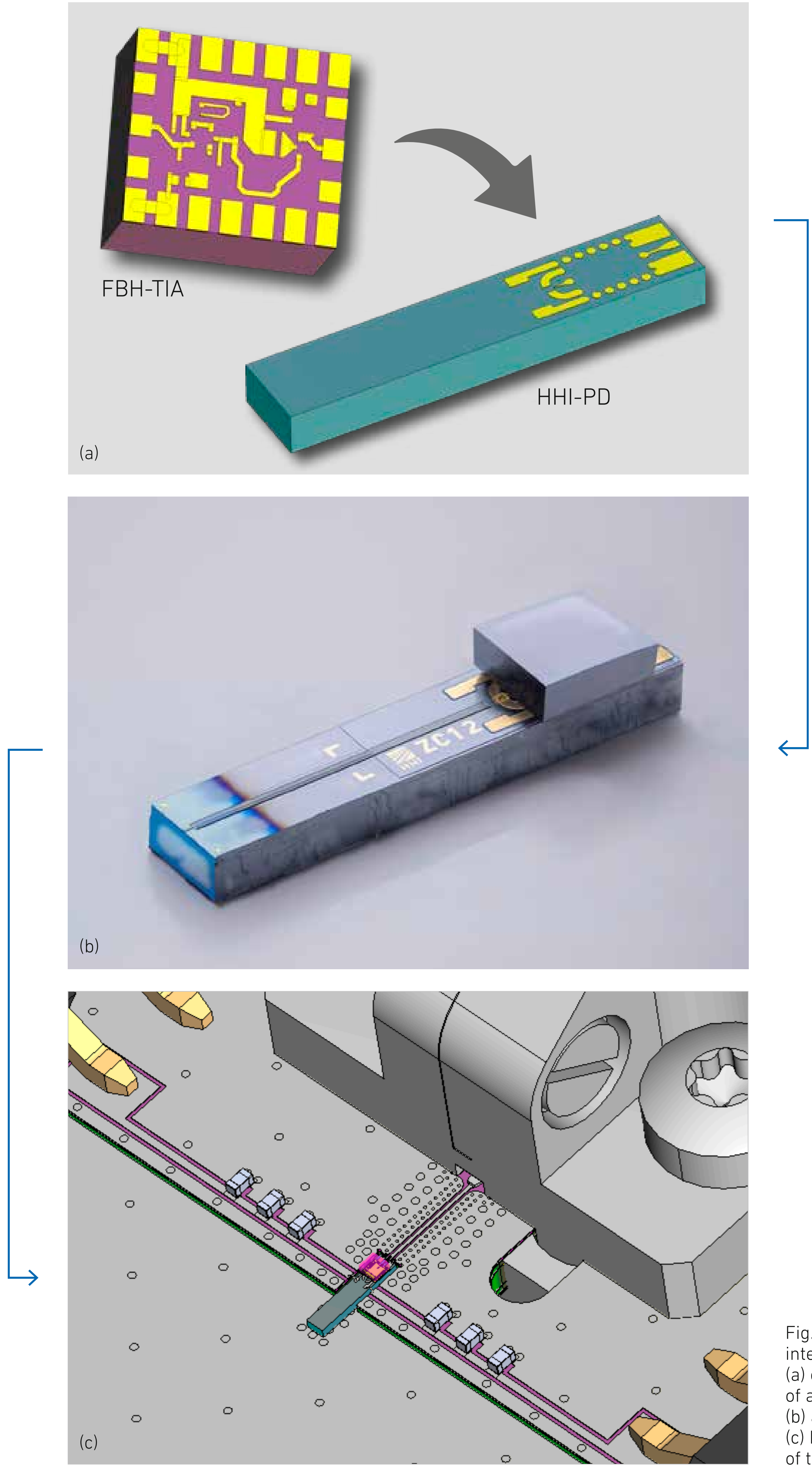


Fig. 1. Heterogeneously integrated receiver module: (a) chip-level integration of a TIA on a photodiode, (b) assembled module, and (c) PCB-level implementation of the receiver system.

Annex

Scientific excellence – personnel and awards

1

Gregor Pieplow (l.) and Tim Schröder (r.) receiving the award.

2

Ina Ostermay (l.) in front of her award-winning poster.

Our scientific achievements are reflected not only by our research results, but also the people behind them. Awards, appointments, and international recognition throughout the year underscore the strength of our teams and international visibility of our work.

1 The QPIS team won the **Grand Challenge in Quantum Communication** from the Federal Ministry of Research, Technology and Space (BMFTR). The project carried out by Tim Schröder (coordinator, HU Berlin & FBH), Gregor Pieplow (HU Berlin), and Kai Müller (TU Munich) aims to develop a highly efficient quantum storage architecture.

2 The poster by Ina Ostermay and further FBH co-authors (Nico Thiele, Ali Koyucuoglu, Pallabi Paul, Amer Bassal, Andreas Thies, Frank Brunner, and Olaf Krüger) was presented with the **Best Poster Award at CS MANTECH** conference in New Orleans (USA). The poster addresses a typical challenge in activating dopands in gallium nitride.

In addition, Enrico Brusaterra was awarded the **Best Student Paper Award** for his excellent presentation. His paper "Vertical GaN Trench MOSFETs with HfO_2/Al_2O_3 Layered Gate Dielectric" was recognized based on conference attendee online feedback and ratings.

3

4

Marco Stucki and the artist's interpretation of his project.

3/4 Marco Stucki has won **Berlin University Alliance's open knowledge lab competition**. He impressed with a novel process for manufacturing tiny diamond structures that serve as a source of quantum light in the quantum technologies category. As part of the prize, an artist's rendition of the project was advertised on posters throughout Berlin.

5

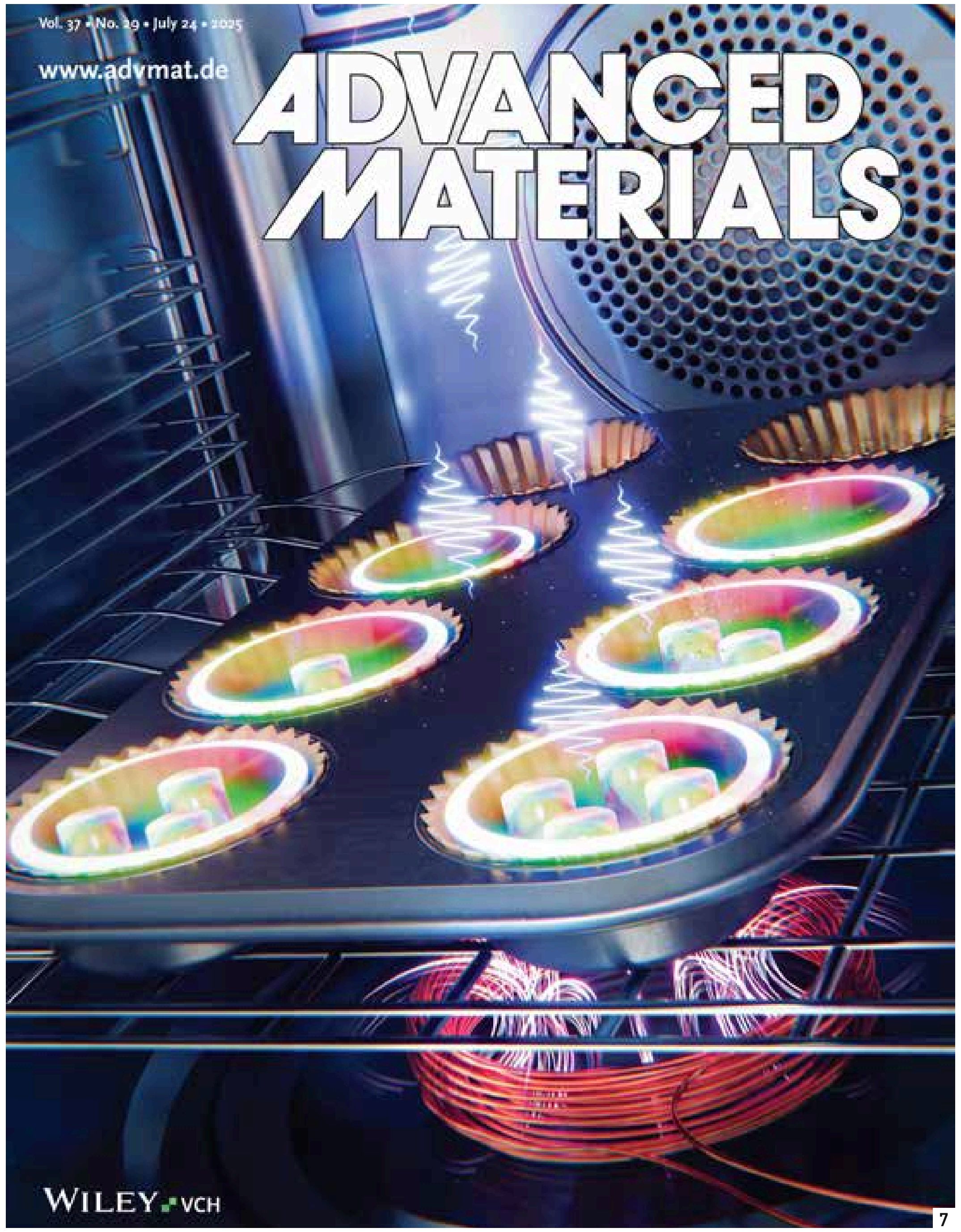
Markus Krutzik, Professor of Integrated Quantum Sensors at HU Berlin.

6

Sven Ramelow heads the Joint Lab Integrated Nonlinear Quantum Optics.

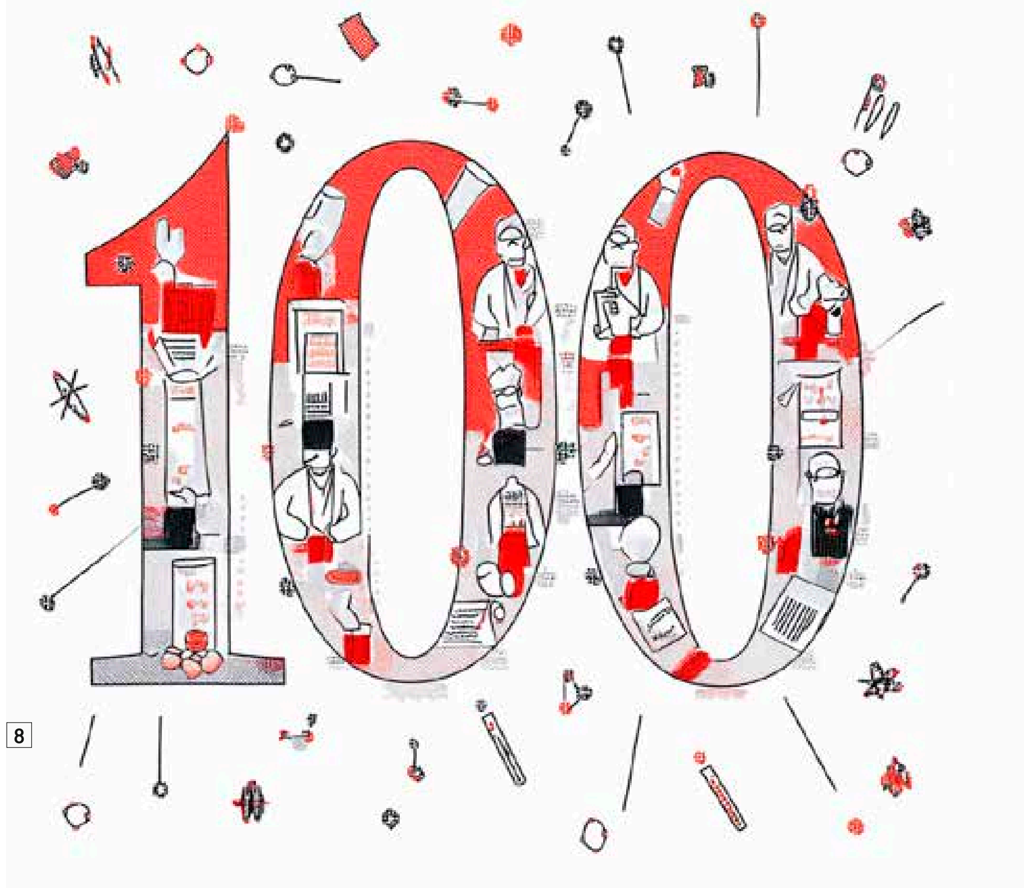
5 Markus Krutzik has been appointed **Professor of Integrated Quantum Sensors** at Humboldt-Universität zu Berlin (HU Berlin). He continues to head the Joint Lab Integrated Quantum Sensors, which is operated cooperatively by FBH and HU Berlin and has been combining cutting-edge research on atomic quantum systems with high technological and societal relevance for six years.

6 Sven Ramelow heads the **newly established Joint Lab Integrated Nonlinear Quantum Optics**. With this launch, FBH expands its collaboration with HU Berlin and strengthens its integrated quantum technology research area. The aim of the new Joint Lab is to link fundamental and application-oriented research, addressing applications of quantum light for photonic quantum sensing and quantum communication. For more information about our Joint Labs in the quantum technology field, see p. 21 (Highlights).



7

7 The joint paper “Controlled Formation of Skyrmion Bags” is featured on the **back cover of “Advanced Materials” Volume 12, Issue 13**. The paper was presented by Katja Höflich, head of our Joint Lab Photonic Quantum Technologies, and her co-authors. It shows how to create tiny magnetic structures, known as skyrmion bags, in a highly controlled way and at exact locations in a thin magnetic film.



8

9

Paul Crump, representing FBH on several high-profile committees.

8 Markus Krutzik and Tim Schröder have been recognized among **the 100 most influential figures in Berlin's scientific community** for 2025. The award, initiated by the Berlin newspaper Tagesspiegel, honors outstanding research, dedication to teaching and knowledge transfer, as well as exceptional contributions to science communication.

9 Paul Crump has been elected to the **Board of Governors of IEEE Photonics Society**. The board helps shape the society's strategic direction and guide key decisions that benefit both its members and the broader profession. Crump will begin his three-year term in 2026. Moreover, he is **co-chair of the expanded Diode Technology Working Group of IFE-STARFIRE Hub**. FBH joined the international collaboration focused on advancing inertial fusion energy in September 2025.

10

Winner of the Humboldt-Innovationspreis, Daniel Emanuel Kohl.

11

Julian Bopp (middle) with his fellow competition winners and the jury members.

10 Daniel Emanuel Kohl has received the **Humboldt-Innovationspreis** for his master's thesis. In his work, he demonstrates how microfabricated rubidium MEMS vapor cells can enable compact, highly stable optical atomic clocks based on two-photon spectroscopy – a key technology for future applications in telecommunications, synchronization, navigation, and precision metrology.

11 At **Falling Walls Lab Adlershof**, 13 young talents presented their socially relevant research projects at Berlin Adlershof Science City. Julian Bopp won the competition with his diamond chip-integrated magnetic field camera.

12

Valerie Fetzer at the award ceremony.

13

Nominated for his outstanding dissertation: Petros Beleniotis (l.).

> Our researchers contribute their expertise by sharing insights with professional networks and the interested public.

12 Valerie Fetzer received the **Friedrich Wilhelm Gundlach Prize** for her master's thesis. In her work, she experimentally validated a novel full-duplex frontend for the first time – an approach that enables simultaneous transmission and reception on the same frequency channel.

13 Petros Beleniotis was among the finalists for the **Adlershof Dissertation Prize 2025**. In his work, he develops methods for precise circuit design that improve the performance of future wireless technologies.

Several FBH publications have been selected as **Editors' Pick** by Optica Publishing Group. Among them, "Micro-integrated diode laser modules enabling mode-hop-free tuning and long-term frequency stabilization", a paper authored by Janpeter Hirsch and his team. The article "Diode laser pumps for future inertial fusion energy systems: status and perspectives" by Paul Crump and his colleagues additionally ranked among the **top downloads from October to December 2025**.

FBH scientists in the spotlight

14

Olof Bengtsson presenting FBH's 5G MIMO measurement system.

15

Ina Ostermay sharing her semiconductor annealing and coating expertise.

Our researchers also contributed their expertise by sharing insights with professional networks and the interested public. They provided a glimpse behind the scenes of their work, thereby strengthening the visibility of our research and the people behind it.

14 Olof Bengtsson was interviewed by Research Fab Microelectronics Germany (FMD). He presented FBH's worldwide unique 5G MIMO measurement system, enabling precise analysis and optimization of power amplifiers for mobile and satellite communications.

15 In a second installment of the FMD interview series, **Ina Ostermay** explains how advanced high-temperature processes and coating technologies have a decisive impact on semiconductor device performance. She also describes how FBH's PECVD and rapid thermal annealing systems help improve quality and reliability of wide-bandgap materials.

16

Katrin Paschke, featured in the IGAFA e. V. series "LaNA introduces".

17

Ekaterina Shabratova in her laboratory.

18

Domenica Bermeo Alvaro (l.) and Yasmin Rahimof (r.) during the opening of the exhibition.

16 Meet our colleague **Katrin Paschke**: In her interview in IGAFA's series "LaNA introduces", she talks about her work as head of FBH's Laser Modules Lab, her motivation, her professional career, and what else inspires her.

17 As part of its 30th anniversary, Leibniz Association featured early-career researchers across its institutes. In this interview series, researcher **Ekaterina Shabratova** shares insights into her work on metallic microstructures for terahertz technologies and her perspective as a female physicist.

18 At the Adlershof Summer Festival, a photo exhibition was opened featuring 14 female scientists from a wide range of research fields. **Yasmin Rahimof** and **Domenica Bermeo Alvaro** from our Integrated Quantum Technology Research Area are part of the exhibition. Their work spans efficient AI algorithms and laser optics simulation, as well as photonics research on diamond structures for quantum technologies.

Sharing research across communities

20

Hands-on insights and bright smiles: students explore careers in optics and photonics.

19

Frozen by physics: exploring science with dry ice.

Engaging with society is an integral part of our mission. Through career orientation events, conferences, and dialogue formats, we shared our research with students, founders, media representatives, and a wider audience – fostering exchange and encouraging interest in science and technology.

19 Girls'Day 2025 once again offered a great opportunity to inspire young talent to pursue careers in science and technology. Under the motto "A day as microtechnologist – research with a delicate touch," female students explored the world of microtechnology, marveling, experimenting, and putting their dexterity to the test.

20 The High Technology Education & Training Network (ANH Berlin), based at FBH, organized **Ausbildungsallianz Adlershof**, offering hands-on career orientation in optics, photonics, and microsystems engineering. The event received strong interest and very positive feedback from participating students.

21

Bringing science and entrepreneurial spirit together: Sascha Neinert (l.) and Marc Christ (r.).

> Engaging with society is an integral part of our mission.

22

Lively participation at Mädchen-Technik-Kongress.

At **Wissenswerte**, the conference for science journalism, Markus Krutzik discussed how quantum technologies are moving from laboratory research into practical applications. As a direct outcome of the conference, he was invited for an interview with the German radio news station **rbb24 Inforadio** for its "WissensWerte" segment, where he outlined current developments and offered orientation within this rapidly evolving field.

21 As part of Leibniz Start-up Days 2025, the **4Investors Day** provided an exchange forum for future users, stakeholders, and founders. Marc Christ and Sascha Neinert presented their work on optically pumped magnetometers based on additively manufactured technical ceramics developed within the MyoQuant project.

22 This year's **Mädchen-Technik-Kongress**, organized by FBH's education management team, was a great success. A total of 200 girls took part and spent a day stepping into the shoes of a researcher, programmer, or technician. The event supports girls and young women in their career and study orientation and aims to inspire them to pursue STEM careers and degree programs.

At this years' **Falling Walls Science Summit**, Michael Kneissl organized a discussion panel on the topic of "Deep-UV Innovation: Shaping the Future of Photonics". Further participants were Martina Meinke (Charité, Berlin), Tanja Mehlstäubler (National Metrology Institute of Germany, Brunswick) und Åsa Haglund (Chalmers University of Technology, Gothenburg).

Community life at FBH

23

Team spirit set the pace for the afternoon.

24

Fun and games at FBH's summer party.

Shared experiences beyond day-to-day research contribute to a strong sense of community at FBH. Sporting activities, celebrations, and team outings provided opportunities to connect across departments.

23 Once again, we laced up for this year's **Adlershofer Firmenstaffel** and had a fantastic afternoon full of energy, fun, and collaboration with colleagues and neighbors from the science and business community at Berlin Adlershof Science City.

24 FBH's **summer party** was once more a great day with our colleagues. We enjoyed fun team games, great conversations, good food and cold drinks in a relaxed atmosphere. **Our children's party** was another great success. A summer afternoon full of fun, games, and food delighted children and their parents alike.

FBH's **company outing** allowed us to strengthen our team spirit, get to know each other better, and share experiences and ideas outside of work. Various excursions took place allover Berlin.

Selected event highlights on international stages

25

Patrick Scheele presenting FBH's research at Laser World of Photonics.

Conferences and trade fairs remain important platforms for professional exchange. Through invited talks, contributed presentations, session chairs and exhibition booths, we shared our latest results with the global scientific community and engaged with partners from research and industry.

Once again, we contributed numerous talks to this years' **DPG Spring Meetings** in the Atomic, Molecular, Quantum Optics and Photonics Section (SAMOP) as well as the Condensed Matter Section (SKM).

GeMiC marked an opportunity for us to present our latest advancements in InP-based microwave and millimeter-wave integrated circuits and systems for high-frequency communication and sensing applications.

At **CS Mantech**, we presented current research in compound semiconductor manufacturing, addressing GaN device technologies and processes as well as advanced VCSEL fabrication.

We presented our latest research results at **DLR EEE Components Conference** and exhibited our work at a booth during the event. Our contributions focused on CW, QCW, and nanosecond pulsed laser light sources for LIDAR systems.

Our contributions to **IEEE MTT-S International Microwave Symposium (IMS)** covered advanced microwave and sub-THz components, on-wafer characterization methods, and high-efficiency driver circuits for GaN-based systems.

25 At the **Laser World of Photonics** trade fair, we demonstrated our expertise in the field of diode lasers – from design and chip development to ready-to-use modules and prototypes. More than 20 presentations at the accompanying **CLEO Europe** conference provided in-depth insights into current research and development results.

Our contributions to the **15th International Conference on Nitride Semiconductors** covered GaN and AlGaN materials, devices, and optoelectronic components from power electronics to UV light sources.

26

Showcasing FBH's laser technologies for space applications at Space Tech Expo Europe.

27

Discussing FBH's photonics technologies at Photonics Days.

At **EuMIC**, we contributed several presentations highlighting advanced GaN and InP integrated circuits and system concepts for high-frequency and future 6G communication applications.

26 At **Space Tech Expo Europe**, we showcased our expertise in III-V-based laser components and subsystems for space applications. There was strong interest in the 55 ultra-narrowband MiLas® laser modules we are currently producing for the BECCAL experiment on the ISS, enabling quantum optics with ultra-cold atoms.

27 At **Photonics Days 2025**, we took on an active role by chairing the Quantum-Quantum symposia and the LiDAR session. We also contributed presentations on far-UVC LEDs and laser modules, hybrid photonic integration, and careers in photonics. Additionally, we hosted a laboratory tour and exhibited at the accompanying trade show.

We were represented with several contributions at **MikroSystemTechnik Kongress**, addressing heterogeneously integrated sub-THz sensors, diode laser technologies for two-photon polymerization, Raman spectroscopy for material identification, and Microtec Academy. We were also present at the accompanying exhibition at the joint FMD booth.

We presented several talks and tutorials at **IEEE Photonics Conference 2025**, focusing on advanced diode laser technologies, reliability and modeling of laser components, and applications ranging from LIDAR and quantum technologies to ultra-high-energy laser systems.

Photonics West opened our event calendar in January 2026, where we presented our full portfolio, from device design to prototype development and small-series production. Highlights included our chip technology, with GaAs laser wavelengths extended from 620 to 614 nm for resetting barium ions in quantum computing, as well as tailored modules for direct material processing, mid-infrared hyperspectral imaging with entangled photons, and space applications. We also delivered 20 scientific presentations at the accompanying conferences.

Find out where else we have been and where you can find us in 2026!

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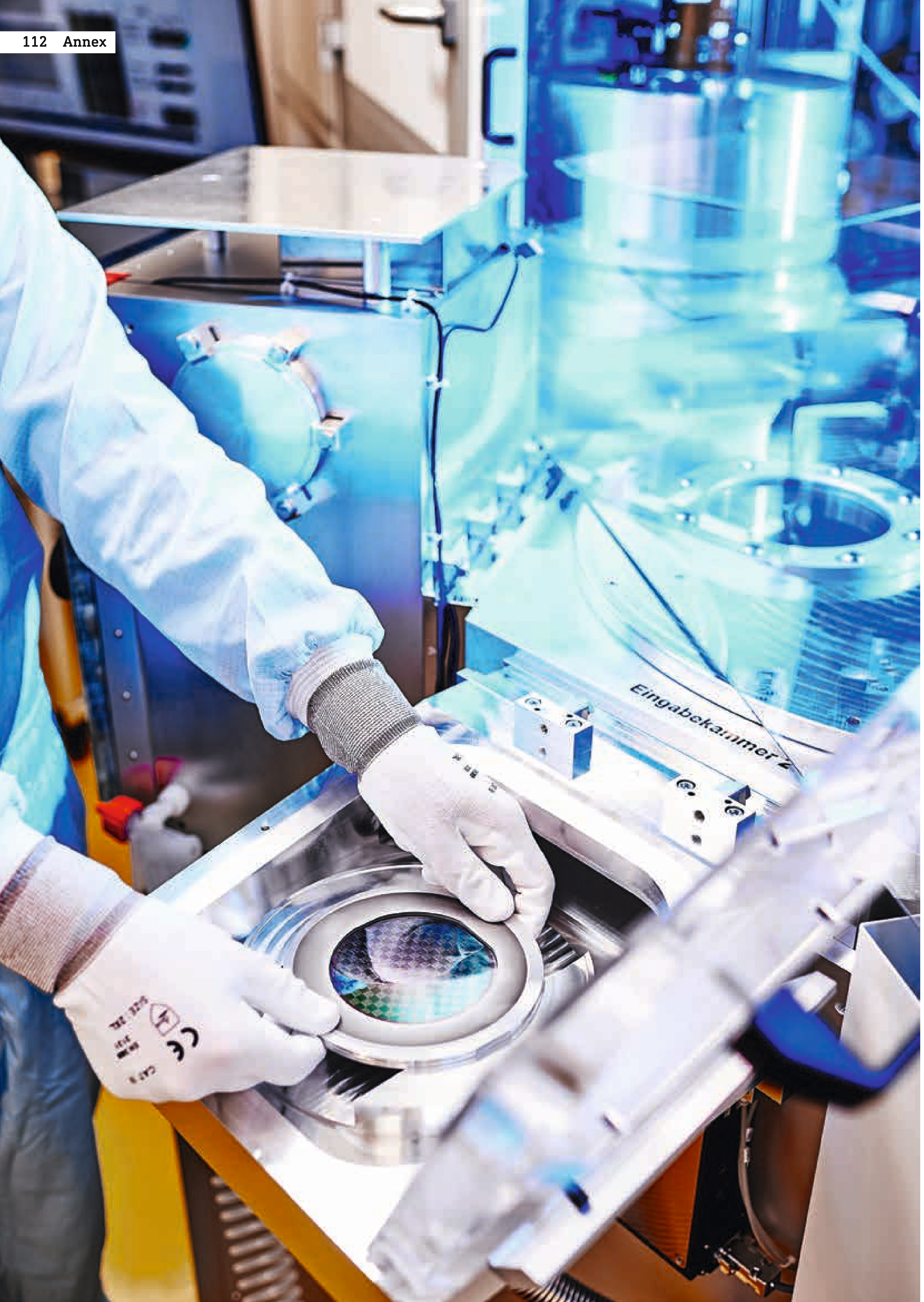

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