



Fraunhofer Institute for Physical
Measurement Techniques IPM

Annual report 2025/2026

Measuring • Monitoring • Optimizing



JOSEPH VON
FRAUNHOFER
1787–1826

Annual report 2025/2026

Measuring • Monitoring • Optimizing

*Cover photo: Efficient underwater status monitoring. The Underwater
LiDAR System ULi is an autonomous laser measurement system.
[For more information on autonomous measurement robotics see pp. 33–34.](#)*

New Space—new opportunities for demanding measurement technology

Robust and reliable systems for applications in space and on earth

Dear customers,
dear partners,

Building and launching satellites has never been cheaper and easier than it is today. Small satellites for communication, navigation, Earth observation, logistics and much more pave the way for new business ideas and create a booming space market. We are determined to take advantage of the opportunities offered by the emerging private space industry, or New Space—for the benefit of our customers and to drive our own research and development.

All four of our business units conduct research for New Space. Here are some examples of the work they have been doing: We use a drone-based system to collect terrestrial reference data, which are used to validate and calibrate satellite data and instruments. We develop measuring methods for testing cameras and sensors for space applications. Our systems are also able to check the quality of commercial off-the-shelf (COTS) components for the large-scale production of satellites. Our sensors detect undesired remanence, and our heat pipes and Peltier coolers ensure effective temperature management in satellites. All business units were represented at the Space Tech Expo in Bremen in November 2025, where the optimistic mood was palpable!

The history of Fraunhofer IPM started with rockets for atmospheric research under the leadership of Prof. Dr. Karl Rawer. The first developments to come out of our institute already boasted a high TRL and extreme robustness. These characteristics continue to shape our expectations for our own work—whether in the New Space sector or in any other domain where our technologies and systems are applied. Our products are built to last and reliable, performing robustly even under highly adverse conditions, including extreme temperatures, corrosive environments, intense vibration, and contamination.

We are ready for launch—towards new success stories in the New Space sector and on our beautiful planet Earth.

Make sure you don't miss anything: subscribe to our [monthly newsletter](#) and follow us on social media, particularly LinkedIn. Or else, why not get in touch directly!

Kind regards,



Karsten Buse, Director



New Space offers vast economic opportunities. We will work with our industry partners to seize them."

Prof. Karsten Buse, Director

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Overview Fraunhofer IPM



*A steady hand is required
when setting up mirror
optics—sometimes it even
takes several hands.*

Who we are. What we do.

Our optical technologies and systems make industrial processes more efficient, sustainable and reliable. We work at the interface between science, research and business to develop customized solutions ranging from measurement and inspection systems to high-end optical components for use in cutting-edge research.

Our mission

We develop measurement technology and expand the scope of what can be measured. Our research focuses on physical technologies, particularly photonic technologies. We develop new methods of analyzing measurement data to maximize its potential. This allows us to develop solutions that promote an efficient use of resources, as well as quality and reliability.

Our vision

We are establishing ourselves as a leading institute for industrial measurement technology and productive use of measurement data. Our excellent research raises technology readiness levels and makes a significant contribution to sustainability, safety, and progress.

Cooperating with us

Our industrial customers benefit from our team's scientific expertise as well as our first-rate technical infrastructure. Drawing on our knowledge and creativity, we work closely and tirelessly with you to create innovations tailored to your specific needs.

There are various ways of working with us.

Industrial contract research projects

We develop solutions for specific industrial measuring tasks—from the generation of initial ideas to system development, the production of small batches, and the installation of measuring systems on site.

Joint publicly funded projects

We tackle complex technical problems and new research fields together with other Fraunhofer institutes, research units, and industrial partners with the support of regional, national, or EU funding.

Long-term strategic partnerships

We form strategic partnerships with customers looking for long-term support with technology and innovation processes. We offer exclusivity for large subject areas. Our long-term customers benefit from even greater efficiency the more we work with them.

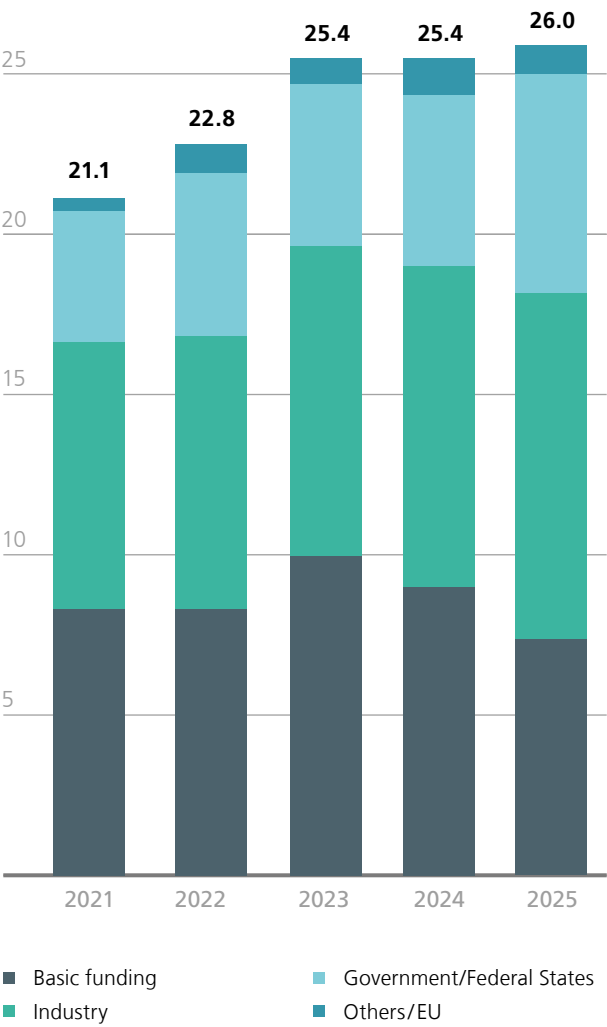
Our services

- Technology studies and consultations
- Analyses and measurements
- Technology and system development
- Installation and servicing

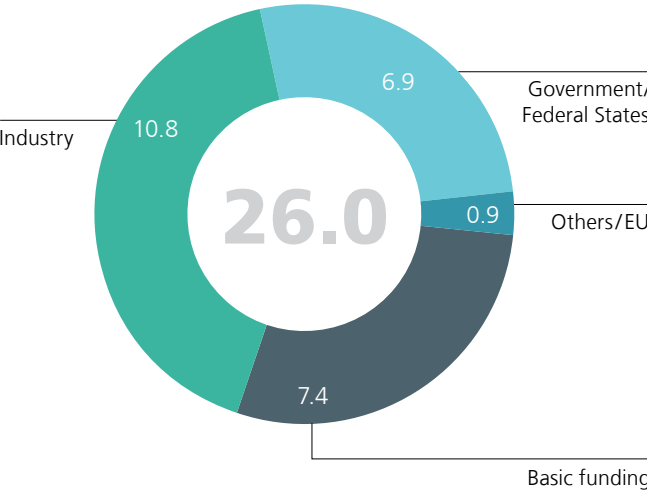


Figures Fraunhofer IPM

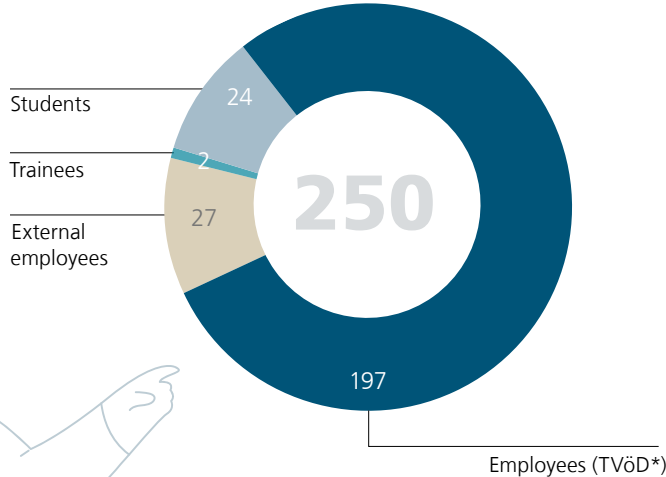
Development Operating budget in million euros



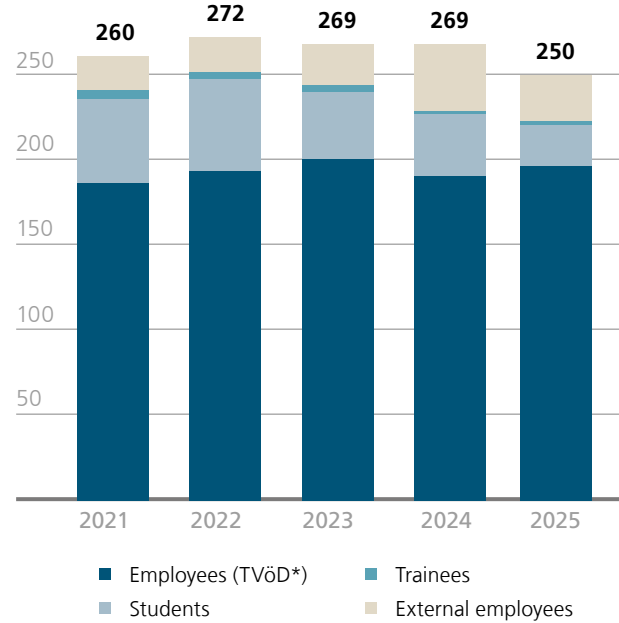
Operating budget 2025 in million euros



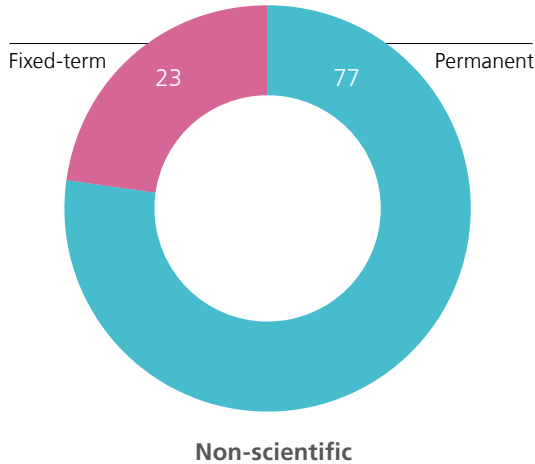
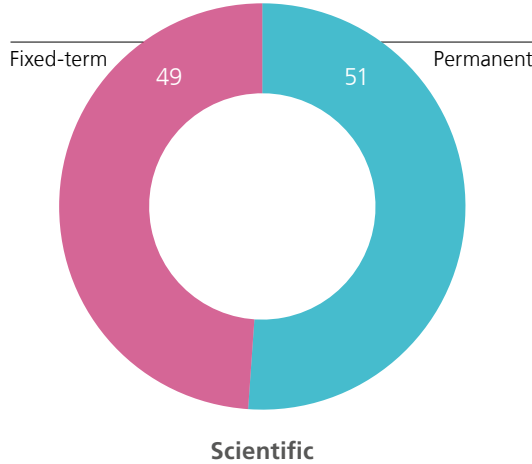
Employees 2025



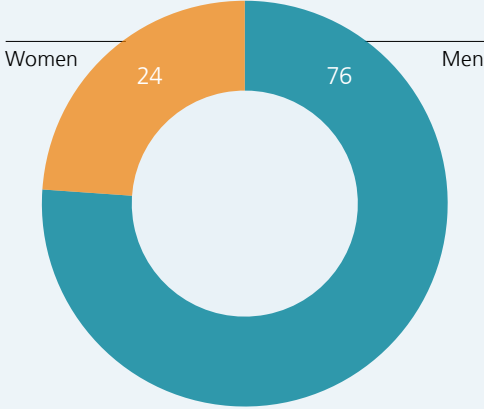
Development Number of employees



Staff under the terms of TVöD*
Percentages of fixed-term/permanent contracts of employment 2025 in %



Scientific staff 2025 in %



Nationalities of our staff 2025



Organization

MANAGEMENT



Director
Prof. Dr. Karsten Buse



Deputy Director
Prof. Dr. Daniel Carl



Research and Strategy
Dr. Milena Hugenschmidt



Organizational Development
Dr. Heinrich Stülpnagel



Technical Equipment and Maintenance
Benjamin Schlegel



Mechanics and Construction
Thomas Hinrichs

ADMINISTRATION AND IT



Head of Administration
Angelina Waigand



Administration
Marvin Steinebrunner



Information and Communications Technology
Gerd Kühner



Recruiting and Human Resource Development
Saskia Sailer

COMMUNICATIONS AND MEDIA



Head of Communications and Media
Holger Kock

PRODUCTION CONTROL ▶ Page 23



Head of Department
Prof. Dr. Daniel Carl



Optical Surface Analytics
Dr. Alexander Blättermann



Inline Vision Systems
Dr. Tobias Schmid-Schirling



Geometrical Inline Measurement Systems
Dr. Alexander Bertz

OBJECT AND SHAPE DETECTION ▶ Page 29



Head of Department
Prof. Dr. Alexander Reiterer



Mobile Terrestrial Scanning
Dr. Philipp von Olshausen



Airborne and Underwater Scanning
Dr. Christoph Werner



Autonomous Measurement Robotics
Dr. Dominik Merkle



Mobile Railway Measurement Techniques
Dr. Kira Zschiesche



3D Geodata Analytics
Benedikt Rombach

GAS AND PROCESS TECHNOLOGY ▶ Page 35



Head of Department
Prof. Dr. Jürgen Wöllenstein



Integrated Sensor Systems
Dr. Benedikt Bierer



Spectroscopy and Process Analytics
Dr. Raimund Brunner



Thermal Measurement Techniques and Systems
Dr. Katrin Schmitt



Caloric Systems
Dr. Kilian Bartholomé

PHOTONIC SYSTEMS ▶ Page 41



Head of Department
PD Dr. Frank Kühnemann



Nonlinear Optics and Quantum Sensing
Dr. Jens Kießling

Advisory Board Keeping us on track

When it comes to making fundamental decisions and strategic issues, we rely on a highly qualified team that can draw on experience and expertise from the worlds of business, politics and science. Once a year, the advisory board holds a meeting in Freiburg, which is also attended by representatives of the Fraunhofer-Gesellschaft. At the beginning of 2026, our long-standing board member Stephanie Busse assumed the chairmanship of the board.

Chairwoman

Stephanie Busse
DB InfraGO AG

Members

Sebastian Bannert
Robert Bosch GmbH

Mehran Ghahremanpour
Ministry of Economic Affairs, Labour and
Tourism Baden Württemberg

Dr. Mathias Jonas
International Hydrographic Organization

Prof. Dr.-Ing. Katharina Klemmt-Albert
RWTH Aachen University, Institute
of Construction Management, Digital
Engineering and Robotics in Construction

Dr. Fabian Lausen
Federal Ministry for Research,
Technology and Aeronautics

Dr. Stefan Raible
Sciosense Germany GmbH

Prof. Dr. Michael Totzeck
Carl Zeiss AG

Prof. Dr. Ulrike Wallrabe
University of Freiburg, Department of
Microsystems Engineering IMTEK

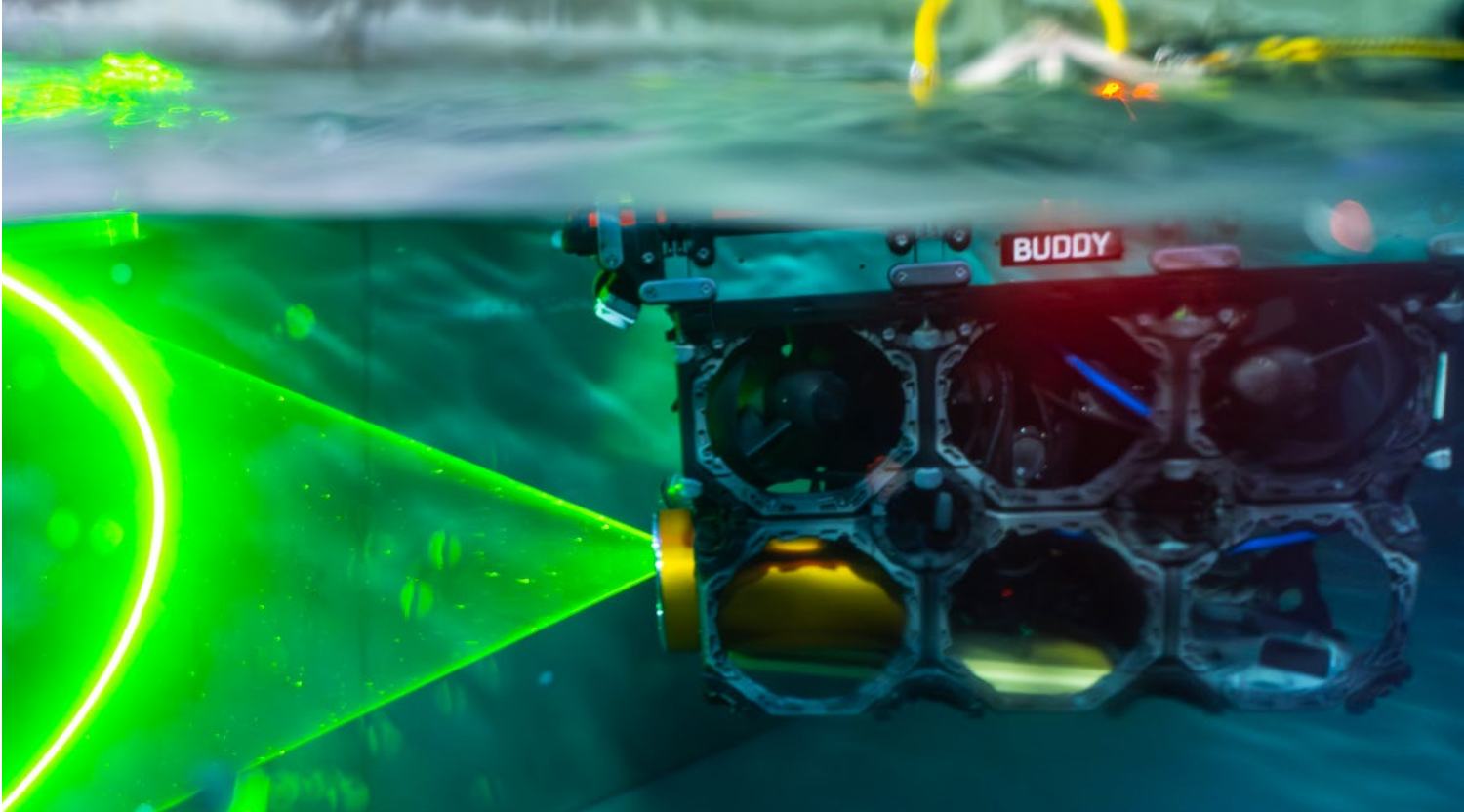
High spirits at the Board of
Trustees meeting in July 2025.
The board's composition changed
over the course of 2026.



Investments 2025

To create optimal research conditions, we continued to invest in equipment and infrastructure in 2025. In addition to the expertise and commitment of our employees, successful research and development depends on excellent technical infrastructure.

Mounted on a sensor platform, our LiDAR system is capable of autonomous navigation and collecting measurements underwater.



Two new carrier platforms for autonomous measurement robotics

We have purchased a robotic dog as a mobile platform for surveying hard-to-reach or hazardous environments. The four-legged robot can navigate uneven terrain and climb steps or obstacles, which makes it suitable for diverse environments, such as construction sites, buildings, tunnels, mines, or forests. Equipped with our LiDAR and camera sensors, the robotic dog can perform new measurement tasks and open up new areas of application, such as rescue robotics.

A high-performance drone expands our opportunities in the development of airborne autonomous measurement systems. The Unmanned Aircraft System (UAS) meets the requirements for future Specific Operations Risk Assessments (SORA) and is equipped with various safety devices (e.g. a parachute) for this purpose, allowing operation over densely populated areas in the future.

Optical tracking system

For the development of autonomous robotic measuring platforms, we have a new optical tracking system at our disposal. OptiTrack's multi-camera system can measure the position and orientation (six degrees of freedom) of multiple objects within a calibrated measurement volume with high spatial and temporal precision. Tracking mobile platforms and sensors allows us to research Simultaneous Localization and Mapping (SLAM) methods, which are used for the autonomous navigation of measurement platforms. In addition, the information collected by the tracking system can be used to calibrate multisensor systems.

Remote-controlled underwater vehicle

Since August 2025, we have been able to test our underwater sensor technology on our own remote-controlled underwater vehicle. The ROV (Remotely Operated Vehicle) can be used as a carrier platform for the Underwater LiDAR System ULi. It is equipped with Doppler Velocity Logs (DVL), an inertial navigation system, a pressure sensor, and a camera to support the positioning of the measuring system underwater. The Robot Operating System (ROS) interface can be used for autonomous measurement operation. We will use the platform to perform measurements in the institute's underwater test track as well as in various bodies of water under real operating conditions.

Industrial robot with safety fence

Our fluorescence laser scanners are used by industrial companies around the world, primarily to inspect small- to medium-sized components with surface areas of about half a square meter. To further develop our systems, we have acquired a high-performance collaborative robot (cobot) that moves the laser scanner across component surfaces and enables the inspection of components measuring several square meters. In the future, this will allow us to perform in-house tests and feasibility studies for quality control in gigacasting and other applications involving large components, such as those used in the aerospace industry and for hydrogen production. To obtain realistic process speeds, cobot mode can be deactivated; the setup includes a safety fence to protect personnel during operation.

Professorships University of Freiburg

Fraunhofer IPM is represented at the University of Freiburg by four professorships and one private lectureship. Thanks to our close ties with one of Germany's leading engineering faculties, we are involved in cutting-edge research and the education of exceptional young talent.

universität freiburg

Department of Microsystems Engineering—IMTEK

Laboratory for Optical Systems

Prof. Dr. Karsten Buse

PD Dr. Ingo Breunig

imtek.de/laboratories/optical-systems



Research foci

- Nonlinear optical materials
- Optical whispering gallery resonators
- Miniature solid-state lasers
- Optical frequency converters
- Integrated optics

Laboratory for Gas Sensors

Prof. Dr. Jürgen Wöllenstein

Dr. Katrin Schmitt

imtek.de/laboratories/gassensors



Research foci

- Micro-structured gas sensors
- Micro-structured IR emitters for the MIR spectral range
- Laser spectroscopy
- Compact optical gas measuring systems
- Photoacoustics
- Catalytic sensors for flammable gases
- Systems integration

We have excellent connections on the "Airport Campus" and work closely with the technical faculty of the University of Freiburg



Department of Sustainable Systems Engineering—INATECH

Chair for Monitoring of Large-Scale Structures

Prof. Dr. Alexander Reiterer

Dr. Annette Schmitt

inatech.de/alexander-reiterer



Research foci

- Inspection and monitoring of large structures
- Development and implementation of innovative sensor concepts based on laser scanners and cameras
- Data analysis and interpretation with a focus on linkages to influence parameters, causative forces and changes measured
- Development and implementation of complete system chains, from data acquisition to data evaluation

Professorship for Production Control

Prof. Dr. Daniel Carl

ipm.fraunhofer.de



Research foci

- Research into new optical measurement and testing methods with a focus on flexible application in harsh production environments along the entire value chain
- Complete automation of quality assurance through intelligent interaction with robotics and hybrid approaches combining rule-based data evaluation and AI
- Development of feedback procedures for controlling and regulating production processes
- Traceability of components throughout the entire product life cycle

Magazine Briefly reported



*Cleaning lithium niobate
crystals requires delicate skill
and experience.*

Groundbreaking ceremony for the Engineering Center for Sustainability

On July 22, 2025, around 90 guests from government, academia and industry gathered at our institute to celebrate the groundbreaking ceremony for the Engineering Center for Sustainability (IZN). Located on the airport campus, the new building will foster closer collaboration between Freiburg’s five Fraunhofer institutes and the University of Freiburg under the umbrella of the Department of Sustainable Systems Engineering (INATECH).

Spanning around 2,700 square meters, the IZN’s three-story building will feature state-of-the-art technical infrastructure, a modern working environment and sustainable architectural design. Sustainability research activities will be centralized in one place—just a stone’s throw from Fraunhofer IPM, the Faculty of Engineering, the Freiburg Innovation Center (FRIZ) and the new building of the Hahn-Schickard-Gesellschaft. Interdisciplinary research, development, and testing for a sustainable industry will soon be conducted at this site, spanning topics from energy efficiency to smart materials. The 36-million-euro investment is funded by the Fraunhofer-Gesellschaft, the German federal government and the Land of Baden-Württemberg.



The new building symbolizes our goal to place research at the center of society—serving as a driver of innovation in sustainable developments, a foundation for economic strength and a catalyst for shaping our future responsibly.”

Michael Kleiner, Ministry of Economic Affairs, Labor and Tourism of Baden-Württemberg



The ground for the new building for the Engineering Center for Sustainability was broken in July 2025. It will be home to the Fraunhofer chairs of the Department of Sustainable Systems Engineering (INATECH).

Fraunhofer in Freiburg

Freiburg is one of the largest Fraunhofer locations in Germany. The city is home to five institutes that have been working on pioneering technologies for many years. Together, they employ around 2,700 people and generate a total revenue of approximately 300 million euros through development and research of technologies in areas such as materials, semiconductors, safety, resilience, measurement technology, photonics and renewable energies.

Space Tech Expo Europe: Launching into New Space

For the first time, Fraunhofer IPM was represented at Space Tech Expo Europe in Bremen in 2025. The exhibition stand attracted tremendous interest! Our team of scientists presented technologies for thermal management, magnetic shielding and magnetic cleanliness testing. We also discussed the use of our optical processes for component and material testing in New Space applications. In the future, the aerospace industry will utilize an increasing number of standard components—referred to as commercial off-the-shelf (COTS) parts—all of which must meet stringent quality requirements. This calls for high-performance measuring systems. There was also significant interest in customized light sources and technologies

for the quality control of optical materials. In addition, we demonstrated how data generated by our drone-based measurement systems can be used to validate and calibrate thermal satellites.

With this initiative, we reconnect with our origins as the Fraunhofer Institute for Physical Space Research IPW. Following a strategic shift toward industrial measurement technology in the 1980s and a name change, we now see significant potential in supporting the emerging New Space sector with our measurement techniques and components, leveraging our extensive experience with space projects.

[More information](#)



Recent successes indicate that our technologies can provide substantial added value to aerospace companies.”

Prof. Dr. Karsten Buse, Director



Our exhibition stand at Space Tech Expo Europe in Bremen drew big crowds.



11th Gas Sensor Workshop: Exchange between science and industry

The 11th Gas Sensor Workshop was a resounding success. On March 20, 2025, approximately 80 participants from research and industry gathered at Fraunhofer IPM to discuss innovations and emerging trends in gas sensor technology under sunny skies. Eight specialist presentations by internationally recognized experts covered recent technological developments and applications, and ample time was devoted to networking.

Sophie Emperhoff from Infineon Technologies AG presented a differential MEMS-based thermal conductivity sensor developed for the precise detection of hydrogen in fuel cell-powered vehicles. Dr. Martin Herold from ScioSense B.V. addressed the use of gas sensors in battery safety, highlighting the hazards posed by gases in battery systems and the role of gas sensors in mitigating these risks.

We also discussed the capabilities and limitations of capacitive humidity sensors. What are the limitations of this technology and what innovative approaches are available? Dr. Katrin Gajo from Innovative Sensor Technology IST AG answered these questions during her presentation. Capacitive moisture measurement plays a central role in the accurate determination of moisture content, which is particularly relevant to the food and pharmaceutical industries.

Fraunhofer IPM was represented by a contribution from Dr. Johannes Herbst, who demonstrated how natural gas pipelines can be surveyed for leaks from a moving vehicle using resonant laser photoacoustics.

The workshop underscored the broad application potential of gas sensors,

particularly in relation to sustainable and future-oriented technologies. Sharing ideas and experiences strengthens collaboration within the industry, and we are already looking forward to reuniting in 2027 to shape the future of gas sensor technology.



**Save the date:
The 12th Gas Sensor Workshop
will be held on March 18, 2027.**

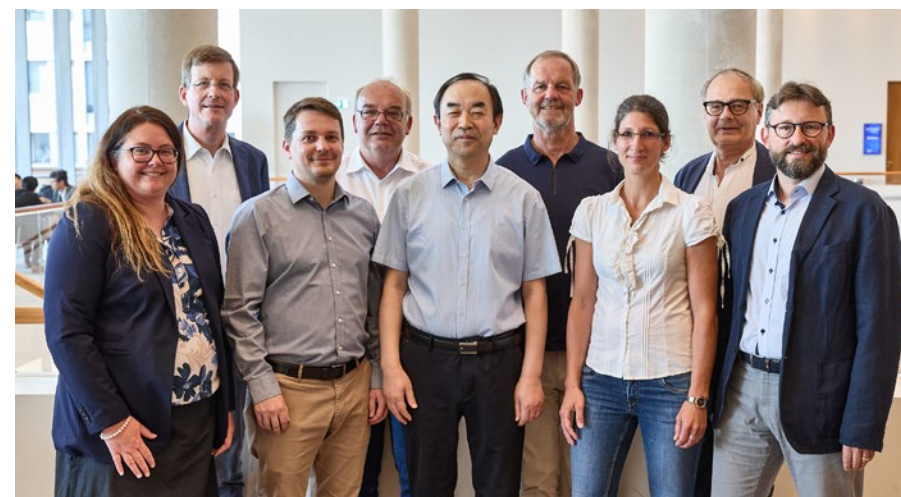
Favorable weather, stimulating presentations and engaging discussions: Over 80 experts from industry and research explored trends in gas sensor technology.

Focus on chemical sensors: Fraunhofer IPM hosted the IMCS 2025

More than 300 experts from research and industry convened in Freiburg for the twentieth edition of the International Meeting on Chemical Sensors (IMCS). Chaired by Fraunhofer IPM for the first time, the conference took place from June 22 to 26. Participants from around the world came together to discuss scientific advances and industrial applications in chemical sensor technology.

The presentations spanned the entirety of the field, covering electrochemical sensors, metal oxide sensors, biosensors, nanosensors and MEMS/NEMS sensors as well as lab-on-chip systems, sensor materials, simulations and data analysis.

Topics included biosensors for monitoring physiological functions, MEMS and NEMS sensors for high-precision trace gas detection and lab- and organ-on-chip applications in medicine and climate research. Alongside the oral presentations, the program featured two poster sessions and an industry exhibition. The opening event at Fraunhofer IPM and the accompanying evening events provided ample networking opportunities.



The core organizing team of IMCS 2025 (from right to left): Jochen Kieninger (Publication Chair), Gerald Urban (Program Chair) Katrin Schmitt (Local Scientific Chair), Albert van den Berg (Plenary Speaker), Lanqun Mao (Plenary Speaker), Jürgen Wöllenstein (Conference Chair) Andreas Günter (Plenary Speaker), Peter Lieberzeit (Executive Steering Committee Chair), Carolin Pannek (Local Organization Chair).

International Meeting on Chemical Sensors (IMCS)

The **IMCS** has been held biennially in cities around the world since 1983. The next conference is scheduled for July 2027 in Montreal, Canada.

Fraunhofer Photonica 2025: Starting point for a research career

From September 22 to 27, 19 young international scientists visited three Fraunhofer institutes to gain insight into photonics research. The week-long program began at Fraunhofer IPM in Freiburg, continued at Fraunhofer IOSB in Ettlingen and Karlsruhe and concluded at Fraunhofer ILT in Aachen.

The Summer School program was varied, opening with a short but memorable electric guitar solo. Did you know that the vibrations of guitar strings can teach us a lot about optical frequency conversion? Alongside lectures on topics like non-linear optics, digital holography, infrared technology and spectroscopy, participants took part in hands-on experiments involving laser scanning, a laser labyrinth, crystal growth and schlieren photography. The students visited the laboratories and spoke with researchers and institute directors about their work. This gave them the opportunity to learn more about applied research and potential careers at

Fraunhofer. The program was well received: "I really enjoyed the whole experience. With every visit and every lecture, the idea of combining research with industry became clear, and I found that particularly compelling."

The Fraunhofer Photonica summer school was organized by the Fraunhofer Group for Light & Surfaces under the direction of Fraunhofer IPM. Dr. Milena Hugenschmidt, head of the organizing team and science advisor to the institute director at Fraunhofer IPM, accompanied the participants throughout the program.



The 19 participants started their journey through the world of photonics at Fraunhofer IPM, then visited Fraunhofer IOSB in Karlsruhe/Ettlingen and Fraunhofer ILT in Aachen.



It's wonderful to see how enthusiastic the participants are about applied research. We hope to welcome many of them back as colleagues."

Dr. Milena Hugenschmidt, head of the organizing team and science advisor to the institute director



Fraunhofer Photonica

The aim of the Summer School is to inspire talented early-career scientists to engage with the research topics of the Fraunhofer Group for Light & Surfaces. Another goal is to acquaint them with career opportunities within the Fraunhofer-Gesellschaft and the group in particular.

photonica.fraunhofer.de

Industry Workshop on Production Control: experiencing our systems firsthand

How can optical measurement and inspection systems help to optimize industrial production? How can companies collaborate with Fraunhofer to apply measurement technology to benefit their own manufacturing processes? These questions were addressed at the Industry Workshop on Production Control, which took place from September 25 to 26, 2025. Industry representatives joined us at our institute to gain firsthand experience with our many systems.

The event highlighted the enormous potential of our optical measurement and inspection technology for quality

assurance and process control. Our scientists demonstrated how a range of optical technologies can be used for automated quality control. These technologies include holographic 3D component measurement, rapid free-fall inspection, assessment of component cleanliness using fluorescence methods and inspection of ultra-thin layers based on infrared spectroscopy. The more than 20 participants were impressed by the readiness level of the systems.

Some participants brought their own components and were able to test our technology firsthand and on-site. In addition to the technical presentations, Philipp Klemenz and Hülya Sevgin from the Chamber of Industry and Commerce (IHK) for the Southern Upper Rhine region gave guest lectures on the practicalities of a collaboration between Fraunhofer and industrial companies, including funding options. A follow-up event is planned for 2026.

Participants were able to test their own components using our systems—and were impressed with the readiness level of the technologies.



Three questions for Angelina Waigand

Angelina Waigand has been head of administration at Fraunhofer IPM since July 2025. Before joining us, she worked as a clinic manager at Oberberg Kliniken. The potential for change is her top priority—at work and at home.

What was your first impression of your new workplace?

I was struck by the wide range of topics at Fraunhofer IPM. I was impressed—and still am—by how, despite working in different technical fields, we manage to find a common language. It is surprisingly similar to the hospital. People with very different areas of expertise work together to achieve a common goal.

What does modern administration mean to you?

“Administration” sounds so 90s! The term is very old school. I would prefer to call it “Central Services”, because after all we are service providers for the other departments. At the hospital, the core business is medical care and nursing: everything that directly involves the patients. At Fraunhofer IPM, the core business is research and development. But we are more than just “support”; we keep the business running. If IT or procurement isn’t functioning, the scientists can’t do their work. In order for the various

departments to work together efficiently, it is essential to think ahead and communicate clearly. I have developed checklists to simplify processes. And I also work with fixed tandems in each team who can cover for one another. That’s how we keep things running, even when a staff member is not here. As we prepare for a generational change, one of the main focus areas I’m working on is knowledge management. I am constantly reminded of the fact that we are all cogs in the machine. If one stops turning, it may not be immediately noticeable, but if several do, we start experiencing problems.

How do you see the future of our institute?

I see a bright future ahead because this is a very strong institute, which consistently demonstrates its excellence year after year. We accomplish quite a lot here. And it is important to me to take our staff’s needs into account. We have to think from the bottom up and also across departments. We need formats where we can work together to identify topics that matter to individual employees and groups. Professional development is critical to achieving this and a significant tool for personnel development. As leaders, we are role models who must continue to evolve, recognize needs, and respond to them. As an employer, we need to adopt a leadership style that also meets



the expectations of younger generations. It is essential to stay adaptable, open to change, and be willing to learn. What I like most about administrative work is precisely this. Many processes can be changed and optimized, and we have the freedom to shape them. My hope or vision for the institute is that we work together even better and look out for

each other. That we shift towards prevention and keep the focus on people rather than just performance! We should always keep an eye on everyone’s mental health. It’s one of the most important issues of our time.

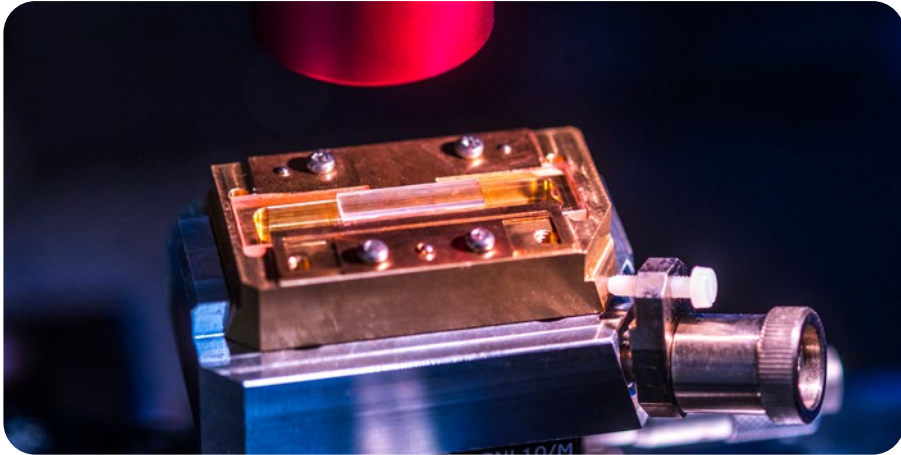
“
I want us all to work together and look out for each other. Teamwork is important to me, and so is the spirit!”

Angelina Waigand, Head of Administration

Day in the lab:
What is this process?*



I am holding a periodically poled lithium niobate (PPLN) crystal in chip format with my tweezers. First, I thoroughly clean its surfaces with a lens-cleaning cloth.



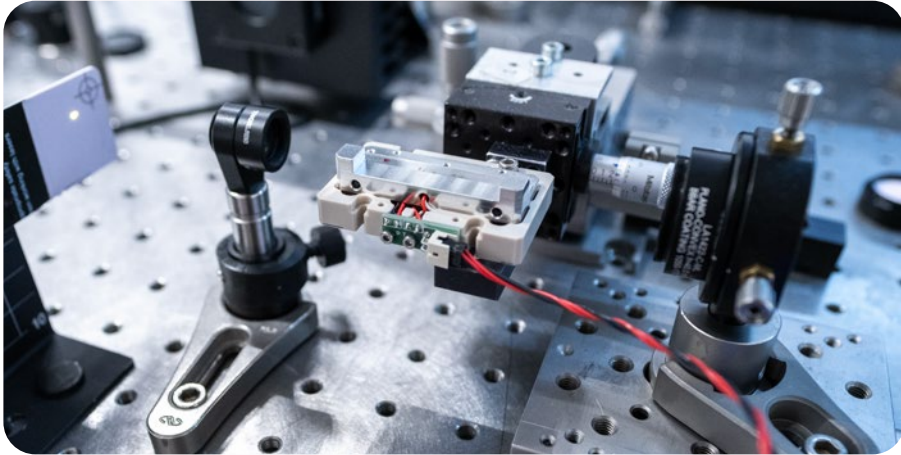
Then it's time to punch some holes! Using a laser, I etch waveguides into the crystal, that guide the light through microscopic channels.



I control the process from my computer. On the left screen, I see the program code. On the right screen, I monitor the laser process.



Then I check my crystal chip with the waveguides under the microscope. Is it worth continuing to use it?



Yes! I insert the chip into my lab setup and switch on the laser. The processed crystal converts the wavelength of the laser light.



I have created customized light—and the waveguide has made this process more efficient!

Anna-Rosa Waidhas, Project Manager

* nonlinear frequency conversion in PPLN waveguides

Customer interview

Schütz GmbH Messtechnik

“Innovation is the only driver.”

Volker Heimbürger

Schütz Messtechnik develops, operates and sells measurement technology for gas grid operators. We spoke to Managing Director Volker Heimbürger about the pressures the industry is experiencing, why collaboration with research partners such as Fraunhofer IPM is essential for mid-sized companies, and how laboratory solutions are translated into market-ready field technology.

Fraunhofer IPM: Mr. Heimbürger, what is Schütz Messtechnik—in two sentences?

Volker Heimbürger: We are a service provider and equipment manufacturer for gas grid operators. Our core competence is innovative gas measurement technology, which we develop and manufacture

ourselves and sell around the world.

How did you become the company’s managing director?

I have a degree in telecommunications engineering. I started my career in the development department at Schütz and took over the company from Gelsenwasser AG at the end of 1999. I have been leading it since January 2000—for over two decades now.

What is your business model: services or equipment technology?

Both. The synergy this creates is what gives us a leading edge. Before launching new devices on the market, we integrate them into our own service operations,

where we can test them under real-world conditions.

Why do you cooperate with research institutions?

Because we are simply too small to maintain an in-depth scientific pool of expertise ourselves. As a mid-sized company, developing a team of highly qualified specialists in niche technologies is close to impossible; that is why we deliberately seek out partners like Fraunhofer IPM.

What was your specific goal in collaborating with us?

We were looking for highly sensitive, fast methane measurement technology that would significantly outperform the



Volker Heimbürger is not only Managing Director of Schütz GmbH Messtechnik, but also Chair of the Working Group on Pipe Network Inspection at the Technical-Scientific Association of Companies in the Gas and Water Industry (figawa).

Schütz GmbH Messtechnik

Schütz GmbH Messtechnik has been serving gas grid operators as a service provider and equipment manufacturer for more than 50 years. The company’s core competence lies in the development of innovative gas measurement technology. All devices are developed and manufactured in-house and sold around the world. To incorporate the latest scientific findings into product development, Schütz is in close contact with universities, colleges and research institutions. The product range extends from gas measuring instruments and emissions measurement technology to probes, extraction systems and specialized measuring devices, all the way to complete measurement vehicles.

state of the art. We had no preference as to the method, photoacoustics or not; what mattered was that the method was sensitive, responsive and robust in real-world use.

What would you describe as ‘typical of Fraunhofer IPM’?

The practical approach. When we have a problem, it gets addressed—quickly, directly and pragmatically. There is always a dedicated contact for addressing any issues. That means a great deal to us because we are often operating under pressure.

What forces are currently having the biggest effect on your market?

Two things: first, the regulatory pressure due to EU requirements on methane emissions, and second, the shortage of personnel. We simply cannot find enough people to cover the required distances using traditional on-foot inspection. The staff shortage is driving a shift toward new technologies and automation.

What requirements must measurement technology meet today to remain competitive?

It must meet the existing field benchmarks: speed, sensitivity, detectability. And it must be compliant. Ultimately, what counts is that measurements are properly documented and officially recognized.

Where is development headed? What can we expect next?

Photoacoustic measurement systems allow for a more compact design, enabling a shift from vehicle-based systems toward portable, handheld devices. In the longer term, additional gases such as NH_3 may become relevant, and with increasing time pressure and rising documentation requirements, we will eventually see autonomous systems like drones.

Do you have a motto that guides you?

Innovation is the only driver. You have to be willing to take risks and get enough things right so that you can also afford to fail.

Thank you very much for talking to us!



Project Manager Dr. Johannes Herbst (left) talking to Volker Heimburger.

Business units

Working for our customers

Hands-on: testing electrocaloric material systems on a material test bench.

Overview Production Control

“Measuring as fast as manufacturers produce: our contribution to greater efficiency, quality, and sustainability.”

Prof. Dr. Daniel Carl, Head of Department

We develop optical systems and imaging processes to inspect surfaces and take measurements of complex 3D structures in the active production line. The aim: To ensure processes are controlled and therefore more efficient. Our systems are so fast and so accurate that areas of contamination or even the smallest defect can be detected at high production speeds and classified in real time. In fact, when combined with (marker-free) individual component tracking and tracing technologies, our optical sensors and measurement systems have the potential to make 100 percent reliable real-time production control a reality—in many cases for the very first time. This assigns them a role as enabling technology for the implementation of modern production strategies against the backdrop of the fourth industrial revolution.

A wide range of methods is used, including infrared reflection spectroscopy, fluorescence methods, and digital holography. We combine these with very fast, low-level image and data processing and intelligent handling, for example, for 360°-component inspection in free fall or 3D measurement directly in machine tools. Our customized measuring systems are used in a wide range of industries, from forming technology in the automotive sector to quality assurance for medical devices and electronics.



Optical sensors and imaging processes



Customized systems



Data collection and interpretation in real time

Our groups and focus areas

Optical Surface Analytics

- Element analysis in complex multilayer systems and liquids
- Analysis of filmic coatings and contaminations
- Detection and classification of particulate contaminations

Inline Vision Systems

- Surface inspections and dimensional accuracy checks for semi-finished products and components
- Inspection of long products for surface defects and straightness
- Marker-free component identification in production and via mobile app

Geometrical Inline Measurement Systems

- Precision measurement of functional surfaces on active production lines
- Full-surface, imaging 3D measurement of workpieces directly on the machine tool, on robots, and on coordinate measuring machines with one and the same system
- Rapid dynamic 3D deformation measurements



We work together perfectly, just like the mechanical, optical, and electronic components that make up our systems.”

Highlights Production Control

Projects • Innovations • Events

We successfully launched and completed many exciting projects in the field of Production Control in 2025. Here are some of them.

MIAME / SWAP projects

Digital holography for robots and coordinate measuring machines

Our digital holographic sensors are increasingly being used in multi-axis gantry systems and robots. Now, they are also employed in a fully cordless configuration in a coordinate measuring machine.

Digital multi-wavelength holography is a powerful and fast method for measuring the surface topography of components with high precision. At Fraunhofer IPM, we have been gradually refining this method over the past few years, making it faster and more accurate, enabling better data processing and making it compatible with a wide range of carrier systems. The newest version of the digital holographic sensor HoloTop NX is not much bigger than a food can and can be installed on

machine tools or industrial robots. The corded sensor comprehensively measures coin-sized objects in less than a second, generating up to 90 million 3D points. This allows components to be measured with sub-micrometer accuracy inline. Researchers have recently managed to integrate the digital holographic sensor in a completely cordless configuration into a coordinate measuring machine (CMM). Their work builds on the results of two Fraunhofer projects, MIAME and SWAP.

Their extremely high accuracy makes CMMs the gold standard for assessing the dimensional accuracy of components. CMMs typically use tactile measurement, in which a probe is moved over the component surface along three axes by a high-precision positioning system, measuring the coordinates of individual points. Fraunhofer IPM operates one of the most accurate CMMs on the market. Until

recently, the device was used to verify the accuracy of our holographic measuring systems, but more recently we started using it as a carrier system for a digital holographic sensor. HoloTop NX was wirelessly integrated into the CMM through the SENMATION sensor exchange system. The integration comes with major advantages: The extremely precise calibration of CMMs enables high-precision referencing of optical measurements.

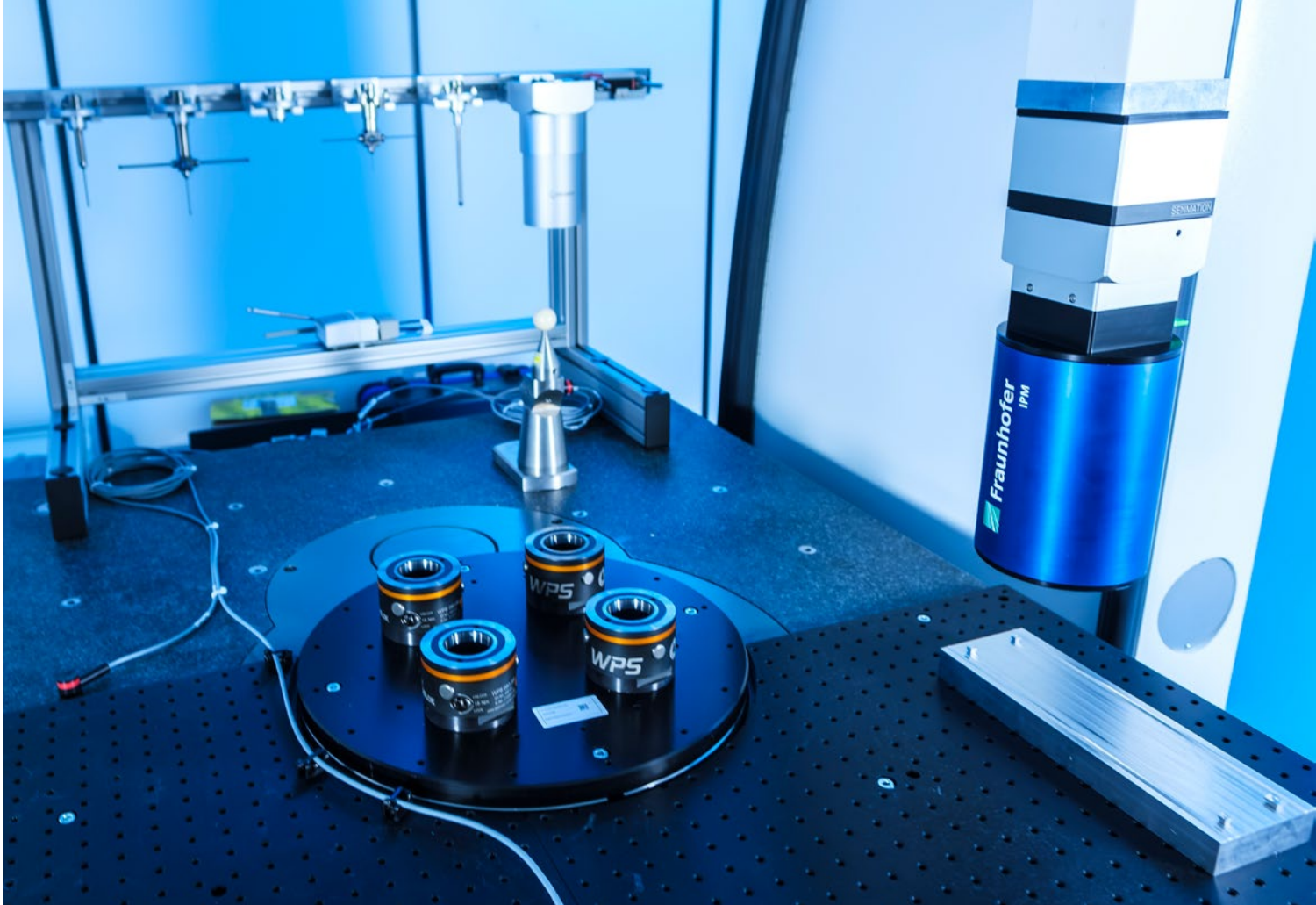
Due to its higher speed and greater point density, the digital holographic sensor outperforms tactile measurement methods, making it a valuable optical add-on. In a comparative measurement on a test component measuring 30 × 7 cm², the HoloTop NX generated more than 1.4 billion 3D measurement points in eight minutes, while the CMM recorded 360 measurement points in 18 minutes at maximum accuracy. Rather than providing a single

point with coarse lateral resolution, the holographic measurements delivered a continuous surface profile of the specimen, achieving a comparable accuracy of less than 1 µm. This allows critical areas of component surfaces to be measured efficiently across the full surface, while the tactile system measures locations that were previously inaccessible to optical sensors. Such points are typical of many safety-critical precision components in the fields of aerospace, automotive and medical technology. In the future, digital holographic surveying should also be used

here. The researchers have already developed the first optical probes and mirror optics, enabling the sensor to measure the specimen from various angles and distances thanks to its extended working range.

MIAME (Micrometer on Meter) and SWAP (Heterogeneous, workload-optimized robot teams and production architectures) projects, funded by the Fraunhofer-Gesellschaft (Prepare project, lead project)

HoloTop NX, integrated into the Leitz Infinity coordinate measuring machine. The zero-point clamping system allows the specimens to be positioned accurately and effortlessly.



Coil-Twin project
Marker-free position tracking on a coil

A camera-based system provides precise position and process data for continuous materials, establishing the foundation for tracing defective sections throughout the entire production chain.

Cold rolling, coiling and uncoiling, skin-passing, and oiling—technical strips such as car body sheets or electrode foils undergo multiple processing stages before being cut and further treated. Inspection systems monitor the surface quality, coating, oiling, roughness and cleanliness of the strips at multiple stages throughout the production process. In break-bulk production, parts recognized as defective can be easily sorted out, while for continuous materials, defective sections must be identified and removed in subsequent processing steps. But how can a defect be located once it has been detected on a strip stretching for kilometers? The issue of position measurement on continuous material has not yet been adequately resolved. In practice, meter-long sections of strip are often generously discarded because the exact position of a minor defect cannot accurately be determined.

In the Coil-Twin project, launched in November 2025, we are developing a marker-free method for position measurement on continuous materials. The goal is to enable the assignment of process data to a specific position on the coil or a previously cut section of the strip—with an accuracy of just a few millimeters. By



generating a digital twin of the strip, the method facilitates efficient quality assurance and adaptive process control. Based on the Track & Trace Fingerprint technology developed at Fraunhofer IPM, which was originally designed for marker-free identification of break-bulk goods, the method leverages the unique surface structure of the material as an identifying feature. This has already been achieved even on finely polished surfaces.

To determine the position on continuous material, a camera repeatedly captures the strip surface during production. A digital fingerprint is then generated of each high-resolution image, which is stored in a database along with the position and process data. If the strip section is scanned again later, the corresponding fingerprint can be retrieved from the database by running a comparison, along with its position

and associated process data. High belt speeds and harsh production conditions pose significant challenges for accurate position measurement.

New algorithms are being developed for real-time image data processing, using parallel-computing graphics cards. To capture high-resolution images even with a vibrating strip, the researchers employ, for the first time, a method that eliminates the need for mechanical focus tracking. Tilting the camera sensor according to the “Scheimpflug” principle, which is used in photography, achieves a greater depth of field, ensuring that at least a part of the image plane remains in focus regardless of the strip’s actual position.

The aim of the project is to develop and integrate a demonstrator into a coil system and test it under real-world conditions

A camera-based system enables the reliable identification of defective sections detected during production even at a later stage.

in collaboration with our project partner Fraunhofer IGP. The technical implementation is supported by more than a dozen industrial companies.

Coil-Twin (Digital twin for continuous material through marker-free position measurement) project, funded by the Federal Ministry for Economic Affairs and Energy (Industrial Collective Research, IGF), coordinated by the European Research Association for Sheet Metal Working

[More about Track & Trace Fingerprint](#)

Star Track project
Position determination: micrometer precision from a great distance

In laser-based inertial confinement fusion, precise position measurement of the fuel capsules remains an unresolved challenge. A spectrally coded sensor may provide a solution for target tracking.

In December 2022, the US National Ignition Facility (NIF) reported a breakthrough in nuclear fusion: For the first time, laser-based inertial confinement fusion produced more energy than the input from the lasers. While this achievement proves the physics is possible, scaling the process to power plant operation requires substantial advances—not least in measurement technology.

During the NIF experiment, 192 lasers were focused on a single fuel capsule precisely positioned in a reactor chamber. For future power plant operation, however, around ten capsules per second would need to be ignited and injected into the reactor at high speed and accurately aligned with the lasers in both space and time. During the Star Track project, we developed a novel optical position measurement technique capable of determining the trajectories of objects with dimensions comparable to typical fusion targets, with high precision.

The measurement requirements for practical reactor operation are extremely demanding. The system must determine the position of an object only a few millimeters in diameter, moving at a velocity of

up to 400 m/s, from several meters away, with an accuracy of 25 µm and a repetition rate of 10 Hz.

The team drew inspiration from chromatic confocal distance measurement and extended the method to allow lateral object detection over greater distances. In chromatic-confocal distance measurement, the position of a target is encoded using broadband spectral information. Three discrete laser light sources in the red, green and blue spectral ranges encode the target’s position, which is then determined from the reflected light by identifying the color-specific focal planes. Initial laboratory experiments with a prototype sensor yielded promising results. Future research aims to improve measurement accuracy to the single-digit micrometer range, which is essential for generating precise control signals for laser alignment. Beyond fusion applications, this high-precision measurement technique has potential in other industrial contexts, such as robotics.

Star Track (Spectrally coded target tracking in laser-based inertial fusion) project, funded by the Ministry of Economic Affairs, Labor, and Tourism of the State of Baden-Württemberg (VwV Invest BW—Praxisprints program)

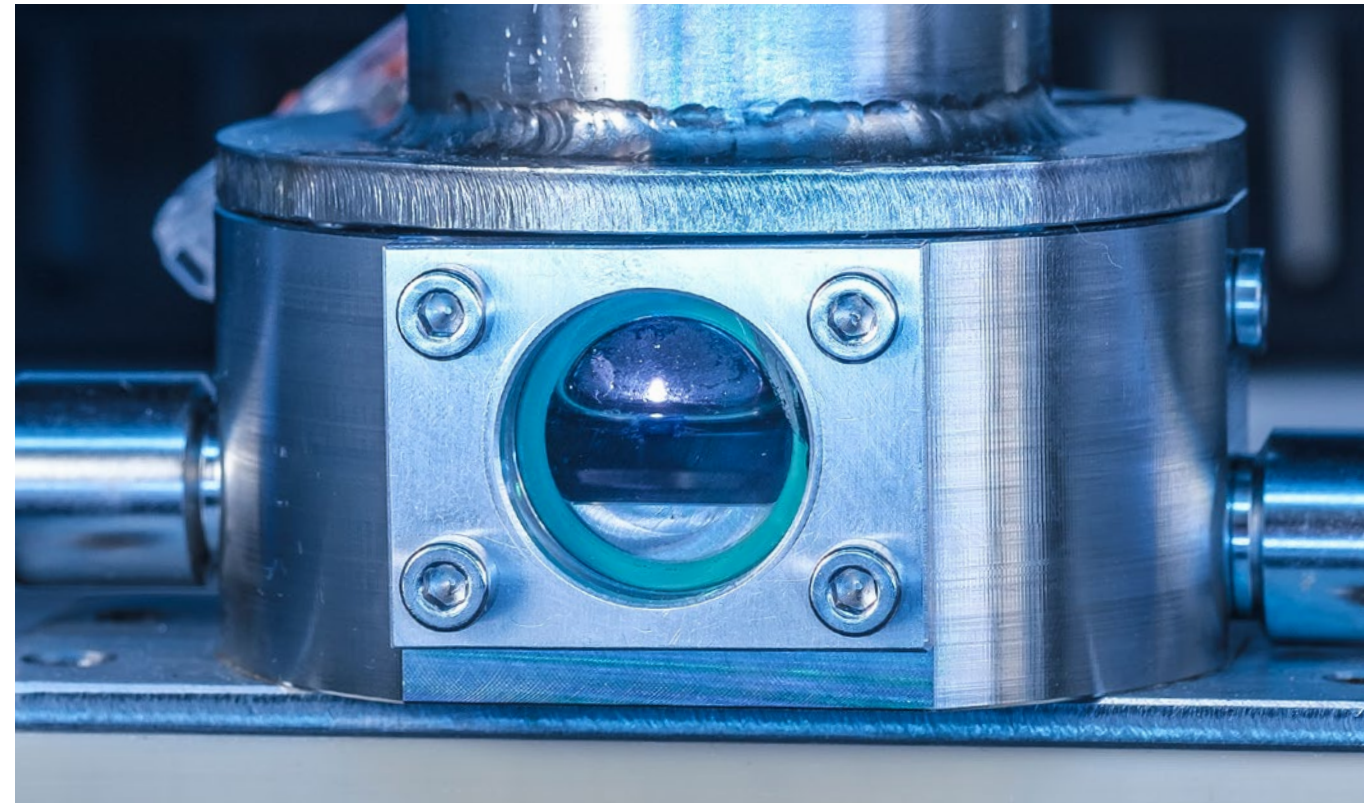
LiMO-Praxis project

Enhancing efficiency in direct lithium extraction

A LIBS-based inline monitoring process has been developed to regulate direct lithium extraction (DLE). The process has been proven effective in both laboratory and initial field tests.

Direct lithium extraction (DLE) from geothermal brine offers the dual benefit of generating clean energy while recovering critical raw materials. During DLE, lithium—often referred to as “white gold”—is extracted from a liquid via adsorption and desorption. This process allows lithium to be extracted as a byproduct, for instance, during geothermal heat generation or hydraulic fracking in natural gas extraction. Compared to the conventional evaporation method, DLE is faster, more efficient and more environmentally sustainable. Consequently, major lithium-producing countries, such as Chile, are shifting to DLE. For Europe, and Germany in particular, exploiting the vast domestic lithium reserves hidden in geothermal brines, such as those in the Upper Rhine Rift, could be transformative. Without these reserves, the EU’s strict targets for strategic raw material independence cannot be met.

During the LiMo project and its follow-up, the LiMo-Praxis project (completed in 2025), an inline monitoring approach for DLE was developed and successfully tested in collaboration with the Karlsruhe



Institute of Technology. The method uses laser-induced breakdown spectroscopy (LIBS), where a short-pulse laser generates a plasma from a small brine sample. Spectroscopic analysis of the plasma provides quantitative, real-time information on elemental composition, enabling the control of the sorption and desorption processes, enhancing extraction efficiency. In contrast to ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy), which requires controlled laboratory conditions for sampling and dilution, the LIBS method allows direct measurement under real-life process conditions. Laboratory

and field test measurements using the LiVision system confirmed that accurate measurements are possible even at the high temperatures and pressures typical of the extraction process.

Looking ahead, the DLE method is expected to play an important role in battery recycling. The LIBS approach (patent pending) can quantify not only lithium but also other elements such as sodium, potassium or magnesium, allowing comprehensive monitoring of the recycling process with a single measurement method.

LiMO-Praxis project, funded by the Ministry of Economic Affairs, Labor and Tourism of Baden-Württemberg (Invest BW—Praxisprints)

Measurement cell of the LiVision system for DLE:
The sensor accurately measures the lithium content in brine during extraction in real time.

“

We measure the lithium content inline, directly in the brine, enabling real-time control of the extraction process.”

Dr. Carl Basler, Project Manager

Focus on product authentication and traceability

Origify from Bosch demonstrates how close collaboration between research and industry can transform an idea into a commercially viable product.



The idea originated in 2008 with a simple question: Can the unique surface texture of industrial components be used for subsequent identification in large batches without applying physical markers? The concept was initially tested on Bosch spark plugs and works as follows. A high-resolution camera captures an area of the component surface, and an in-house developed algorithm digitizes the surface features and stores the data alongside a unique identifier in a database. For subsequent identification, the process is repeated and the data compared to the

database entries. In industrial production, this approach not only enables component authentication but also allows inexpensive, mass-produced parts to be traced without additional costs while linking production data to individual components.

From industry applications to consumer goods

Feasibility studies already confirmed the concept's viability back in 2009. Nearly a decade later, we tested the technology

in a Bosch plant for particle sensors. The result was a 99.8 percent recognition rate across more than 50,000 components, achieved under realistic production conditions. Oliver Steinbis, a project partner at the time, was impressed and wanted to take things one step further. Having recognized the potential of marker-free tracing and product authentication technology, he turned his attention to the consumer goods market. However, the challenges posed by consumer applications were very different from those of industrial use. Proof of principle had been

demonstrated under controlled conditions using a high-resolution industrial camera with precisely positioned and illuminated components. For widespread authentication uses—for example, via smartphone in any given location—the technology needed to be more robust against variations in exposure, camera angle, device model and even wear on component surfaces. Fraunhofer IPM took on these challenges, while Bosch invested in exclusive, continuous development for smartphone and cloud integration. Thus, Bosch secured its leadership in marker-free

identification with an algorithm that is now considered the world leader in this field.

Origify: Real-time authentication via smartphone

After years of development, Bosch Secure Authentication GmbH was finally founded in 2025 and Origify was commercially launched. Origify uses the image-based technology developed by Fraunhofer IPM to verify the authenticity of luxury goods,

Real or fake? Upon very close inspection, product surfaces are as unique as a fingerprint. With the Origify app, consumers can verify a product's authenticity based on its surface characteristics. At the heart of the technology is an algorithm developed by Fraunhofer IPM.

pharmaceuticals, banknotes and other security prints. In January 2026, company founders Florian Hachenberger and Oliver Steinbis presented Origify at CES, a technology trade show in Las Vegas.

From project to strategic partnership

From the initial project in 2008 to the establishment of Bosch Secure Authentication in 2025, the development teams at Fraunhofer IPM and Bosch have maintained a close partnership. "This strategic collaboration is founded on mutual trust," says Oliver Steinbis, now the company's CTO. Daniel Carl, who has been involved since the project's inception, emphasizes the continued emotional investment: "It is simply important to us that Origify succeeds." Fortunately, the successful cooperation has continued long after the company was founded. Fraunhofer IPM will continue to monitor and support Origify's development to ensure its adaptation to new device technologies and evolving business models.



In this partnership, our role is that of an extended workbench and an external part of the Origify team."

Prof. Dr. Daniel Carl, Head of Department

Origify and the fight against product piracy

Pharmaceuticals, watches, shoes, wines, car tires, and visas—according to the OECD, counterfeit trade accounts for approximately 2.5 percent of global trade volume. The consequences for companies and consumers are significant and range from financial loss and health and safety risks to a damaged brand image. With Origify, Bosch Secure Authentication addresses this challenge by enabling authentication based on a product's natural surface texture without adding additional markers such as codes, labels or chips. Bosch Secure Authentication GmbH was founded in 2025 as a wholly owned subsidiary of Robert Bosch GmbH and is part of the Bosch Group.

How does Origify work?

The concept and the underlying technology were developed in cooperation with Fraunhofer IPM. The basic idea is the biometrics of things: This means that, upon very close inspection, each product surface exhibits unique features, much like a fingerprint. For authentication, a product's surface features are captured by a camera and are analyzed by an algorithm. The data are then digitized and stored as a tamper-proof bit sequence in the cloud. Verification can be carried out via the Origify smartphone app or a stationary camera system, with real-time comparison against database entries.

[Bosch Secure Authentication GmbH](#)

Production Control | Trade fairs & events

Participation

all about automation
February 25–26, 2025, Friedrichshafen
EDIH Südwest Stand

43. EFB Colloquium on Sheet Metal Processing
May 6–8, 2025, Stuttgart
Own booth

Control
May 6–9, 2025, Stuttgart
Fraunhofer Business Unit Vision booth

SKZ: Composite barrier foils
July 1–2, 2025, Würzburg
Symposium

IPFA 2025
International Symposion on the Physical and Failure Analysis of Integrated Circuits
August 5–6, 2025, Malaysia

parts2clean
October 7–9, 2025, Stuttgart,
Fraunhofer Business Area Cleaning booth

Quantum Effects
October 7–8, 2025, Stuttgart
QuantumBW (Fraunhofer) stand

Space Tech Expo Europe
November 18–20, 2025, Bremen
Own booth

43rd Conference on Materials Testing
November 27–28, 2025, Dresden
Presentation

In-house events

Online forum on production control
January 1, 2025
3D-Geometry & roughness

April 9, 2025
Imaging deformation measurement—highly accurate and dynamic

Industry workshop on production control
September 25–26, 2025
New optical inline methods: 3D surface | coating | purity

Planned for 2026

EUROGUSS
January 13–15, 2026

New Space Acceleration Days
February 4–5, 2026

GM Innovation Day
February 18, 2026

Clean event
April 23, 2026

Future Lab Black Forest (Zukunft.Lab.Schwarzwald)
May 21, 2026

all about automation
August 26–27, 2026

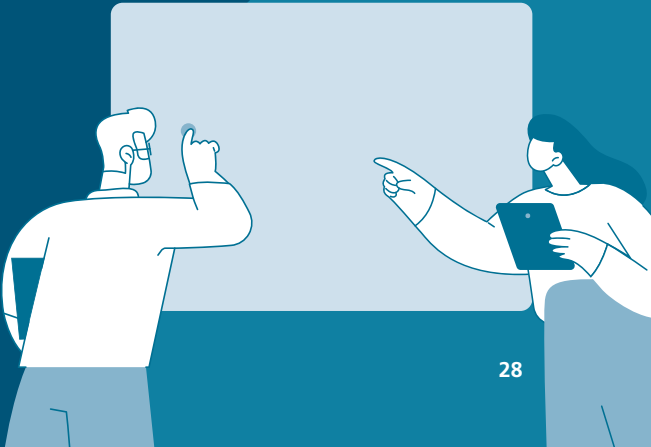
Arnold IT Systems Technology Day
July 16, 2026

Specialist screw conference HS Offenburg
September 22–23, 2026

SEMICON Europa
November 10–13, 2026

EuroBLECH
October 20–23, 2026

Space Tech Expo Europe
November 17–18, 2026



Overview Object and Shape Detection

“Automated capture and processing of 3D data: our contribution to the digitalization of infrastructure and the environment.”

Prof. Dr. Alexander Reiterer, Head of Department

We develop customized measurement systems for the optical monitoring of infrastructure objects and large structures. Our services cover the entire 3D data process chain—from automated mapping, referencing, and analysis to the visualization of the geometry and position of objects.

Our robust LiDAR systems, along with custom lighting and camera systems, capture the environment from moving platforms, three-dimensionally with extreme speed and precision. Typical measuring ranges extend into the hundred-meter range. Measured data is evaluated in a fully automated process by dedicated software. For the analysis, we employ techniques from the field of artificial intelligence (AI), such as deep learning. Our measurement data forms the basis for the digitized planning and maintenance of civil infrastructure.



Fast, precise and robust sensors



Miniaturized measurement systems



Data analysis software

Our groups and focus areas

Mobile Terrestrial Scanning

- Systems for mobile mapping vehicles
- Systems for regularly circulating vehicles
- Sensor and data fusion for complete systems

Mobile Railway Measurement Techniques

- Systems for measurement trains
- Systems for regular trains
- Sensor and data fusion for complete systems

Airborne and Underwater Scanning

- Systems for unmanned aerial vehicles
- Systems for underwater applications
- Signal analysis for demanding measurement environments

Autonomous Measurement Robotics

- Adaptation of sensors to be applied in robotic systems
- Integration of complete robotic systems
- Realization of cooperative systems

3D Geodata Analytics

- AI-based semantic segmentation of 2D and 3D data
- Real-time visualization of spatial data
- Creation of synthetic measurement data
- Platform-independent systems



We calibrate our laser scanners in the laboratory to get them ready for real-life applications on railways and roads, for example.”

Highlights Object and Shape Detection

Projects • Innovations • Events

We successfully launched and completed many exciting projects in the field of Object and Shape Detection in 2025. Here are some of them.

Stackable Scanner project

Flexible LiDAR system for mobile platforms

The Mobile Precise Scanner MPS, our latest development in laser scanning, is the first mobile mapping system to employ the time-of-flight method for high-precision measurements.

Our LiDAR sensors for mobile 3D environment detection rank among the most powerful globally. The Mobile Precise Scanner MPS developed as part of the Stackable Scanner project completed at the end of 2025, introduces a particularly compact, lightweight, yet

high-performance profile scanner to the portfolio. With a measuring range that exceeds 100 meters and a scan rate of 300 Hz, the MPS establishes new standards for mobile mapping. Weighing approximately 4 kilograms, the LiDAR system can be deployed on road or rail vehicles for infrastructure status assessments or mounted on autonomous robotic platforms for indoor applications. Its very high scan rate ensures dense point clouds even at elevated driving speeds, while the 360° scan angle and high resolution even enable detection of narrow structures such as signs or overhead lines.

A key innovation of the MPS introduced by the development team is its modular

design. Multiple scanners can be stacked on top of each other to increase point density for demanding measurement tasks, with central components such as the arithmetic logic unit shared between the sensors. The mechanical design eliminates the need for individual calibration.

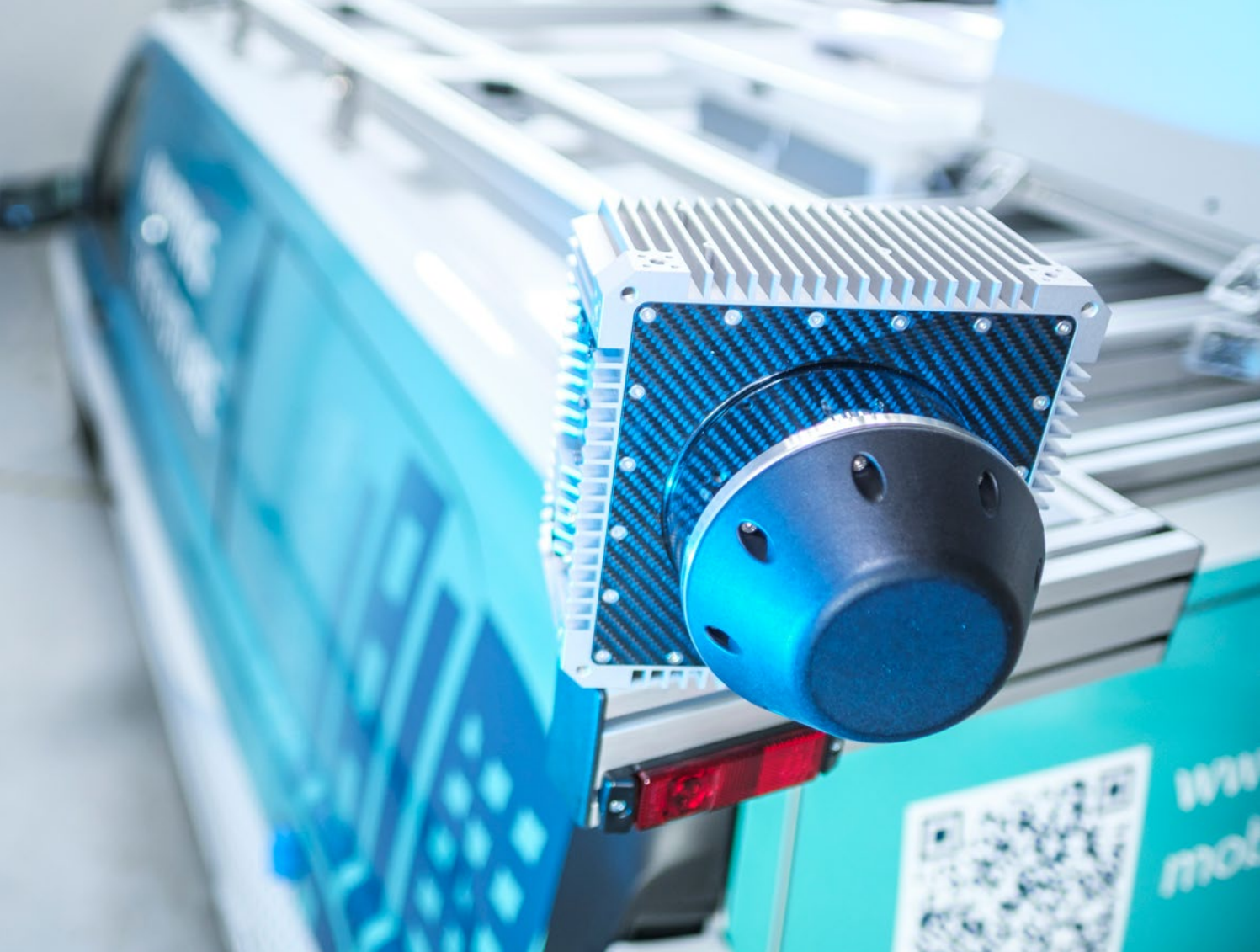
Unlike previous profile scanners, which relied on phase-shift measurement methods for high-precision measurement, the MPS uses time-of-flight (ToF) technology. Advances in light sources, detectors, signal converters, electronics and processing units now allow sub-millimeter precision, surpassing the accuracy of earlier systems. ToF offers additional advantages, including the ability to measure distances

exceeding 100 meters and a compact system design. Data processing has also been enhanced: The full echo sequence of each laser pulse is analyzed, enabling reliable detection of multiple echoes (full waveform signal processing). This means that objects can also be detected through vegetation or fencing, for example. The MPS can be equipped with cameras, GNSS receivers and an inertial measurement unit (IMU), providing universal

functionality as a stand-alone system. Interfaces are available for integration into existing mobile mapping platforms. Test measurements with the MPS commenced in early 2026.

Stackable Scanner project, funded by the Fraunhofer-Gesellschaft (SME project)

Our latest LiDAR sensor is approximately the size of half a shoe box and can be mounted on a variety of carrier platforms.



ECHO project

Compact railway measurement system based on innovative signal processing

A LiDAR system designed for installation on passenger and freight trains is intended to enable high-resolution monitoring of railway overhead lines.

Defects in overhead lines account for approximately one third of disruptions in rail traffic. One key contributing factor is long maintenance intervals, which are primarily driven by cost. Maintenance requires specialized measuring trains that cost several million euros, as well as trained personnel and complex operational planning. As a result, secondary routes are often only inspected every few years. As part of the ECHO project, which began in early 2026, a compact, laser-based contact wire inspection system is being developed for use on regular trains. The system is designed to measure contact wire wear with an accuracy greater than 0.5 mm and determine the referenced position of the overhead line with an accuracy greater than 2 cm, at travel speeds of up to 100 km/h.

The system is based on a novel signal processing approach, involving the full analysis of LiDAR echoes. Conventional systems typically determine distance based on the propagation delay of the primary reflection of a laser pulse. In contrast, the new approach analyzes the entire amplitude profile, i.e., the temporal evolution of the reflected laser pulse. Using this full-echo evaluation and a sampling rate of up to

five billion measurements per second, detailed information on both the spatial position of the contact wire and its residual thickness can be derived. This approach offers significant advantages. The system eliminates the need for cameras and complex illumination setups, enabling a compact and energy-efficient design. Recent advances in processor technology make this possible by digitizing the electrical detector signals at extremely high rates so that the intended five billion measurements per second can be processed in real time within the measurement system. Defects are detected and classified, and the resulting data are transmitted via a 5G network to a central database while the train is in motion. The project's goal is to develop a demonstrator that will be tested under real operating conditions in the final project phase in 2028, in collaboration with Freiburger Verkehrs AG.

The ECHO project (Measurement of the contamination and geometry of overhead rail lines by analyzing the echo of laser pulses) project, funded by the Fraunhofer-Gesellschaft (SME project)



By analyzing the entire LiDAR signal, we can avoid using cameras.”

Dr. Kira Zschiesche, Group Manager

Hydrography: Pramuka Field Work 2025

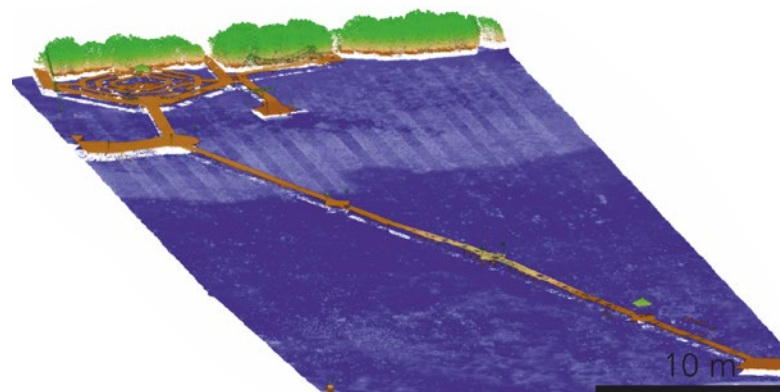
High-resolution 3D modeling of underwater structures

A team of researchers from Germany and Indonesia evaluated the performance of our underwater LiDAR systems, ULi and ABS, during field measurements in Indonesia.

As economic use intensifies and environmental concerns grow, the mapping of seabeds, coastal zones and marine ecosystems is becoming increasingly important. In the fall of 2025, a joint research team from HafenCity University Hamburg (HCU) and the Indonesian Institut Teknologi Bandung conducted a field campaign to assess sensor technologies and measurement methods for underwater and bathymetric surveys in Indonesian waters. In addition to sonar and photogrammetric sensors, we deployed our advanced LiDAR technologies, the Underwater LiDAR System ULi and the Airborne Bathymetric Laser Scanner ABS. During the week-long research mission, extensive measurements were carried out in the waters surrounding

Pramuka island. The island offers favorable conditions for underwater surveys, with water clarity reaching depths of up to 12 meters.

Laser-based measurement techniques are gaining increasing importance in underwater applications. The ULi enables a significantly more accurate detection of underwater objects compared to conventional sonar systems. The ABS allows high-resolution bathymetric measurements from the air. The LiDAR data complement traditional acoustic and camera-based measurements and, owing to their high spatial resolution, provide the basis for generating detailed 3D models of underwater structures. In this campaign, the ULi and ABS systems acquired by HCU were deployed simultaneously for the first time, enabling concurrent LiDAR-based data acquisition of the same scene from both underwater and airborne perspectives. The fused data is expected to further enhance overall data quality. The data obtained during the field measurement will be merged with satellite data and integrated into a publicly accessible data

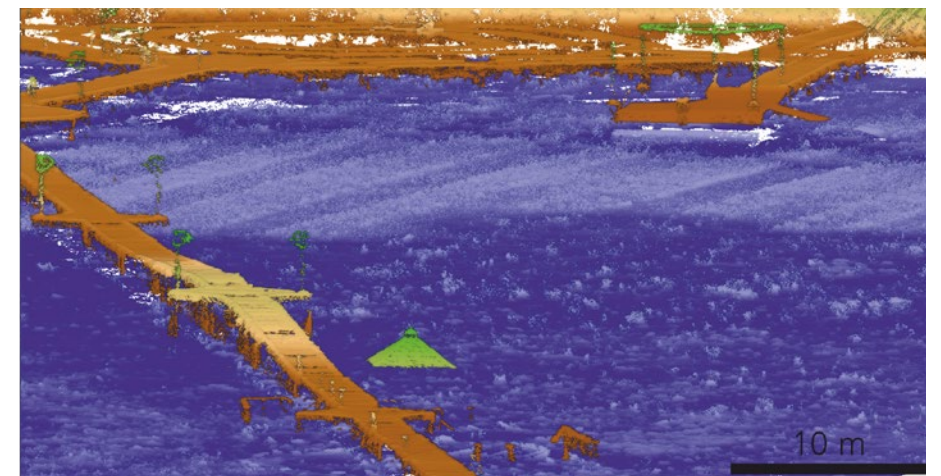


The Airborne Bathymetric Laser Scanner flies over the coastal region of Pramuka.

model, with the aim of contributing to the advancement of global hydrographic standards. HCU has since acquired an additional ABS system, which enables simultaneous and efficient surveying of bodies of water using multiple coordinated systems with automatically adapted measurement parameters.

[Video](#)

The LiDAR system generates a high-resolution image of the underwater topography.



SatCalVal project

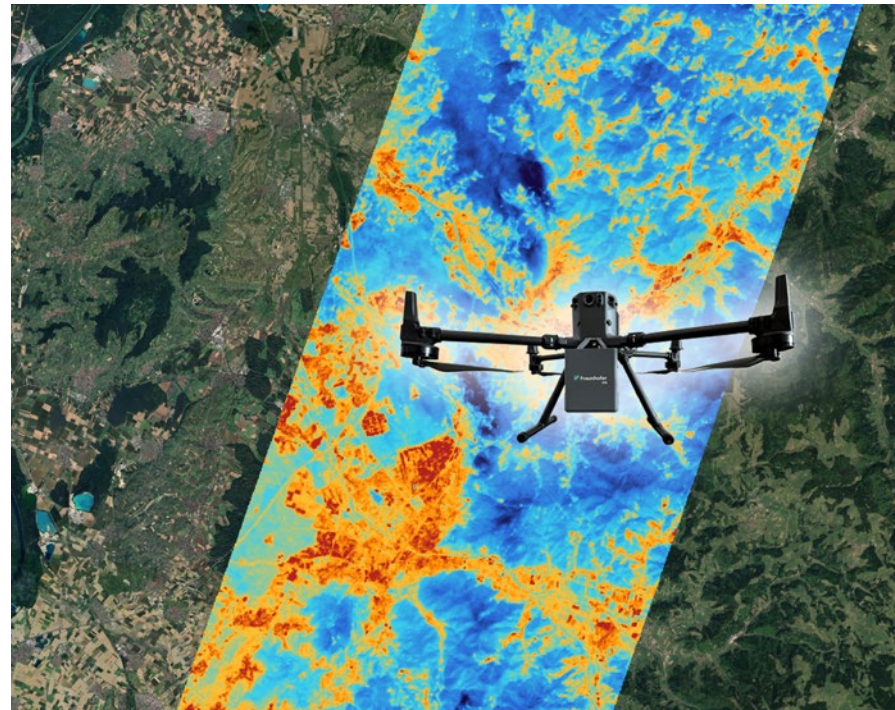
Data for data: UAV-based validation and calibration of thermal satellite data

A drone-based measurement system provides reference temperature data for thermal satellites. The system optimally adapts flight routes according to satellite data acquisition and can operate fully autonomously when necessary.

Numerous thermal satellites orbit the Earth, providing data on its surface temperature. These data form the basis for climate models and weather forecasts and are also used for planning and decision-making by stakeholders such as farmers, urban planners and energy plant operators. With spatial resolutions having been reduced to several tens of meters per pixel, high-precision reference measurements are required to validate and calibrate satellite data, thereby improving their accuracy and reliability. In the SatCalVal feasibility study, researchers at Fraunhofer IPM, in cooperation with constellr GmbH, developed a drone-based measurement system for acquiring reference temperature data during satellite passes.

The Airborne Reference Temperature System ART uses a pyrometer with an accuracy of up to 0.5 K to determine surface temperatures of water, soil, sand or asphalt. Flight patterns are optimized to improve the accuracy of the mean reference temperatures corresponding

to individual satellite pixels at the time of the satellite pass. The compact and lightweight measurement system can be integrated into different UAV platforms and is also available as a fully autonomous “drone-in-a-box” solution. In this configuration, the system operates completely autonomously and is controlled from a drone hangar for takeoff, execution of predefined measurement routines and landing. This enables reference measurements during satellite passes even in remote or difficult-to-access areas. The ART system can be deployed in stationary or mobile configurations, for example, on road vehicles or vessels. System parameters—including measurement area, flight pattern, sensor parameters and maximum wind speed, as well as data retrieval and remote camera inspection—are configured via a web interface. This enables self-sufficient and low-maintenance operation.



The resolution of thermal satellite images is in the range of several tens of meters per pixel. An autonomous drone system provides precise data for validating and calibrating the satellite.

“

With the drone-in-a-box solution, thermal data and other satellite data can be automatically validated and calibrated.”

Dr. Dominik Merkle, Group Manager

Focus on autonomous sensor systems

Autonomous measuring robots with adaptive sensors increase mobile mapping efficiency and improve data quality.

The digitalization of planning and maintenance processes requires increasingly precise and up-to-date environmental data. At the same time, field measurements should be as efficient as possible and ideally not require specialist personnel. Autonomously operating intelligent sensors address the continuously increasing demands associated with mapping projects and inspection tasks.

Adaptation at sensor level—enabled by real-time data

Since 2024, the Autonomous Measurement Robotics research group has been working on the development of autonomous robotic systems for 3D data acquisition. The objective is to develop multisensor systems that operate with a high degree of independence and can perform measurements in environments

that are difficult to access, hazardous, or too extensive for conventional manned platforms. A wide range of carrier platforms are employed, including drones, unmanned ground vehicles (UGVs), trolleys, autonomous underwater vehicles (AUVs) and robotic quadrupeds. Depending on the specific measurement task, both commercial and in-house-developed sensors—including LiDAR systems—are integrated. Parameters such as wavelength, measurement distance, measuring range and resolution are optimized for each application.

Real-time environmental data are the prerequisite for autonomous operation. Software for real-time data processing is always an integral component of all autonomous measurement systems, as it enables verification of data quality and completeness during acquisition. Localization, mapping and navigation are all

based on environmental data. Autonomous navigation of the robotic platforms is achieved using Simultaneous Localization and Mapping (SLAM) methods, which remain functional even in harsh and dynamic environments.

Depending on the level of autonomy, user-friendly tools are required to enable efficient, safe and convenient operation of the sensor systems, including remote control. The research group is working on human-machine interaction solutions that provide comprehensive control, safety and assistance functionalities. Fully autonomous solutions are also already in operational use. For example, the Airborne Reference Temperature System (ART), used for the validation and calibration of thermal satellite data, can be deployed as a fully autonomous “drone-in-a-box” system.



Flexible sensor selection and selective measurement

When monitoring infrastructure, transportation routes, or mapping large agricultural and forested areas, achieving both a wide measuring range and high resolution is a fundamental requirement as well as a trade-off. Large areas do not always need to be captured with the highest possible resolution in their entirety. Effective solutions to this challenge include selective data acquisition, flexible sensor selection and iterative measurement strategies. In the future, intelligent and adaptive sensor

systems will be capable of autonomously determining which areas require closer inspection. Measurement data will be evaluated in real time, allowing critical regions to be identified and investigated in a targeted manner, for example, by activating specific sensors or adjusting platform speed or flight altitude.

Iteratively capturing structures

This approach is particularly advantageous in the aerial inspection of large structures like bridges or dams. Continuous

Autonomous platforms such as this robot dog make it possible to fully map even hard-to-reach environments. Using AI, we ensure the necessary data quality in real time.

high-resolution measurement generates excessive data volumes without highlighting anomalies efficiently. To achieve better efficiency in data collection, we use an iterative approach, where the sensors start by recording a structure with a lower

resolution in order to identify possible defects. If anomalies such as cracks are detected during the semantic image analysis, the system will adapt its trajectories and sensor parameters to capture the relevant areas in high resolution, enabling precise determination of crack dimensions. This approach allows for compact drone systems, reducing regulatory constraints and safety risks while enabling deployment with fewer operational restrictions.

A robot-assisted sewer inspection system developed as part of the FlexiSKan project follows a similarly selective and adaptive approach. In addition to a LiDAR scanner, the system employs a panoramic camera to achieve continuous and complete environmental coverage, replacing conventional pan and tilt cameras. Measurement data are evaluated in real time. That way, the travel speed can be reduced to improve image quality upon detection of a defect. Laser-based 3D speed measurement further enables high-precision positioning in enclosed, homogeneous environments, where low-texture surfaces limit the effectiveness of SLAM approaches based on visual odometry. Beyond sewer inspection, potential applications include the inspection of pipelines, shafts, chimneys, tunnels and mines.

Our Underwater LiDAR System ULi is currently being developed into an autonomous system capable of independently mapping underwater structures from an AUV. It is designed to use 3D position and intensity data for Active Simultaneous Localization and Mapping (A-SLAM), enabling real-time data evaluation and

dynamic adjustment of sensor parameters such as scan patterns or measurement distance, for example, under conditions of high turbidity. For the Airborne Bathymetric Laser Scanner ABS, research focuses on automated flight path planning based on Collaborative Active SLAM (AC-SLAM), involving multi-stage surveys of target areas. The objective is to achieve complete coverage while dynamically adapting the altitude to environmental conditions such as water turbidity.

Advances in AI-based learning approaches, particularly reinforcement learning, will increasingly enable sensor systems to autonomously adjust measurement parameters. In the future, such systems may also incorporate knowledge from Extended Reality (XR), providing access to extensive contextual information about the measurement object.



The autonomy of these systems is the key to measurement tasks that were previously impossible.”

Dr. Dominik Merkle, Group Manager

Object and Shape Detection | Trade fairs & events

Participation

Bau
January 13–17, 2025, Munich
Fraunhofer Building Innovation
Alliance booth

INTERGEO
October 7–9, 2025, Frankfurt
Own booth

Space Tech Expo Europe
November 18–20, 2025, Bremen
Own booth

Planned for 2026

AF-Verteidigung und Sicherheit in Deutschland
January 3–5, 2026

New Space Acceleration Days
February 4–5, 2026

OI Oceanology International
March 10-12, 2026

digitalBau
March 24–26, 2026

INTERGEO
September 15–17, 2026

InnoTrans
September 22–25, 2026

Space Tech Expo Europe
November 17–19, 2026

In-house events

Arnold IT Systems Technologietag
July 15, 2025, Freiburg
Workshop



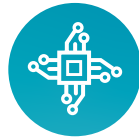
Overview Gas and Process Technology

Developing customized sensor systems and energy converters: our contribution to greater efficiency, safety and sustainability

Prof. Dr. Jürgen Wöllenstein, Head of Department

We develop and manufacture measurement and control systems for gases and liquids to fit our clients' briefs. In our research and development, we rely on a range of different technologies—from spectroscopic methods for gas analysis and energy-efficient gas sensors to thermal sensors and quantum magnetometers for flow metering. Our robust sensors and systems are used wherever short measurement times, high accuracy, and reliability are required, no matter how extreme the conditions. They are employed in exhaust gas analysis, process measurement technology, as much as in environmental, energy, and medical technology.

We also develop, design and assemble systems capable of pumping, converting, transferring and controlling heat. We research new heat dissipation and temperature control concepts based on heat pipes and Peltier elements, as we also work on caloric heat pumps.



Miniaturized sensors and systems



Spectroscopy methods



Thermal sensors



Cooling with caloric systems

Our groups and focus areas

Integrated Sensor Systems

- Development and processing of gas-sensitive materials
- Photoacoustic gas sensors
- Micro-optic infrared components
- Miniaturized gas sensor systems

Spectroscopy and Process Analytics

- Laser spectroscopy for gas detection
- Remote gas detection
- Raman spectroscopy
- Evaluation methods

Thermal Measurement Techniques and Systems

- MEMS and MOEMS
- Thermal measurement systems and IR detectors
- Simulation of physical processes
- Peltier cooling and thermal management
- Structural, thermal and electrical analytics of components and materials

Caloric Systems

- Heating and cooling without harmful refrigerants
- Development of magnetocaloric, elastocaloric and electrocaloric systems
- Simulation of thermal processes
- Development and characterization of heat pipes for thermal management
- Quantum magnetometry for non-contact flow metering



We measure flow non-invasively and accurately using quantum sensors.”

Highlights Gas and Process Technology

Projects • Innovations • Events

We successfully launched and completed many exciting projects in the field of Gas and Process Technology in 2025. Here are some of them.



SuperPile project

Thermopile detectors for use at high temperatures

Thermopile detectors based on gold-nickel superlattice structures are being developed for continuous operation at temperatures exceeding 200 °C.

Temperature is a key parameter for the efficiency and control of many industrial processes. Thermopile detectors,

especially those based on antimony (Sb) and bismuth-antimony alloys (BiSb), are already used for contactless, high-precision temperature monitoring in industrial environments. However, they are only applicable up to an ambient temperature of 200 °C. Many industrial settings require substantially higher temperatures for processes such as heat treatment or drying. Although silicon-based thermopiles can withstand such high temperatures, they do not achieve sufficient measurement accuracy. During the SuperPile

project, initiated in 2025, we are collaborating with three industrial partners to develop new thermopile sensors capable of operating at high temperatures while performing highly sensitive measurements over extended periods. At Fraunhofer IPM, our work focuses on developing a new thermopile chip as the core element of thermopile detectors.

Thermopiles are thermal radiation sensors that measure temperature through the thermoelectric effect. The detector

directly converts absorbed thermal radiation into a voltage signal that is proportional to the temperature. The quality of the materials used in the thermocouples is critical to measurement sensitivity. For the first time in an industrial application, Au-Ni superlattice structures are being employed, building on recent publications that demonstrate the outstanding thermoelectric properties of gold-nickel alloys. This nanoscale layer system will now be realized for the first time in MEMS architecture, with the individual

layers deposited onto silicon substrates by sputtering. As a part of SuperPile, the manufacturing process technology for the thermopile chips is being developed, as well as the material system and chip design.

The SuperPile (superlattice-based thermopile sensors for continuous use at elevated temperatures) project is funded by the German Federal Ministry of Research, Technology and Space (KMU-innovative program), with VDI Technologiezentrum GmbH as project sponsor

Thermopile sensors enable high-precision temperature measurements. They are produced on wafers. A novel material has been developed to enable the sensors to withstand extreme temperatures in industrial environments.

Druide project

Colorimetric sensors monitor air filters in fuel cells

Cost-effective colorimetric gas sensor systems can detect filter breakthroughs in real-time, enabling demand-driven filter maintenance.

Polymer electrolyte fuel cells generate electricity by using supplied hydrogen and oxygen from the ambient air. Air pollutants can block the platinum-coated catalyst surface of the cells, resulting in decreased performance and service life. Multistage gas and particle filters are used to prevent this. To avoid filter breakthroughs, the filters are replaced at regular intervals—regardless of their actual wear and tear. In the Druid project, which was completed in mid-2025, we worked with smartGAS Mikrosensorik GmbH and DataPhysics Instruments GmbH to develop a colorimetric sensor system for the real-time condition monitoring of gas-absorbing filters to detect filter breakthroughs. Thus, in the future, the filters will only need to be replaced once the filter quality is no longer sufficient.

Colorimetric sensors detect gases selectively, can be produced at low cost and require little energy. Upon contact with the target gas, a chemical reaction occurs that causes a color change, which can be read with the naked eye or by means of a detector. If unwanted gas molecules pass through the cathode filter in a fuel cell, the color of the sensor surface changes—depending on the gas, the corresponding dye reacts by changing its color. The

team at Fraunhofer IPM was tasked with synthesizing gasochromic dyes for the target gases carbon monoxide, carbon dioxide, the nitrogen oxides NO and NO₂, ammonia and the sulfur-containing gases H₂S and SO₂. The dyes were characterized in the laboratory using a UV/Vis spectrometer. In collaboration with DataPhysics, inks were developed for an inkjet printing process that can be printed on glass substrates. Project partner smartGAS built a multi-channel demonstrator of the sensor system that was successfully tested in the laboratory.

The Druid (Printed, colorimetric gas sensors for monitoring filter breakthroughs in PEM fuel cells) project was funded by the German Federal Ministry of Research, Technology and Space (Program: SME-innovative)



For each target gas we identified a specific dye, printed it onto a substrate, and tested it.«

Ina Seiberlich, Project Manager

PyroCO project

Gas tightness of pyrotechnic seat belt pretensioners: fast laser spectroscopy for hot gas temperature determination

Direct absorption spectroscopy can be used to measure very short concentration peaks of the fire gas carbon monoxide during the ignition of pyrotechnic seat belt pretensioners.

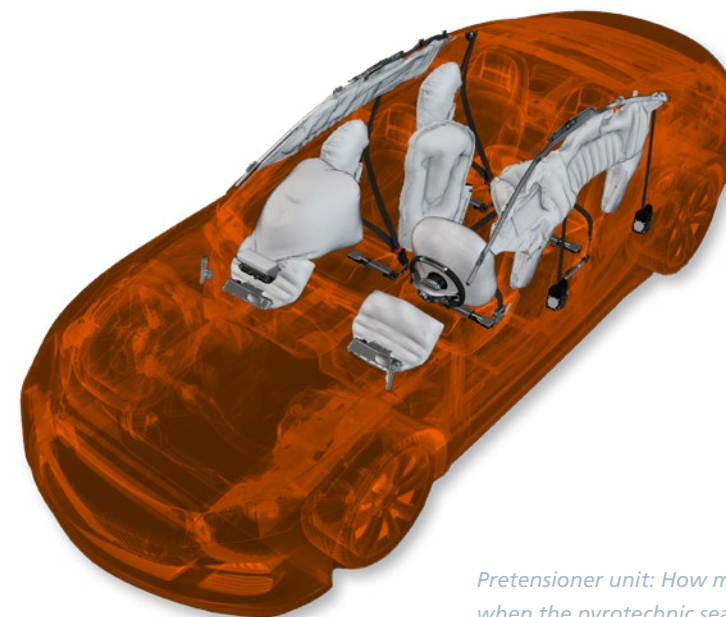
In the event of a vehicle collision, a small ignition charge is typically triggered within milliseconds to activate pyrotechnic seat belt pretensioners. Many seat belts have this feature, and as with any safety-critical technology, the technology itself must be safe by design. This raises the question of how CO emissions relate to gas temperature when pyrotechnic seat belt pretensioners are ignited. ZF Lifetec, one of the world's leading suppliers of vehicle safety systems, develops gas-tight seat belt pretensioning systems and commissioned us to investigate this relationship.

In an initial study, a high-speed thermal imaging camera operating in the mid-infrared range was used to characterize the spatial and temporal behavior of temperature and gas leakage. For these measurements, the pretensioners were tested under conditions where significant gas

leakage was deliberately induced upon ignition of the propelling charge. However, the gas temperature could not be conclusively determined with the camera, as the emissivity of the gas was unknown and the temporal resolution of the camera was insufficient. As part of the PyroCO project, the team adopted a laser spectroscopic measurement approach to determine both gas temperature and CO concentration directly after ignition. The measurements were optimized primarily for temporal resolution, enabling analysis of the gas cloud generated upon ignition in the sub-millisecond range. Spectra were recorded and analyzed at a measurement rate of 10 kHz.

CO detection was performed using tunable laser spectroscopy in an open-path

configuration. The emission wavelength of an interband cascade laser was tuned to a characteristic pair of absorption bands of the CO molecule in the mid-infrared at 4.8 µm (2060 1/cm). The distinct temperature characteristics of the absorption bands enabled simultaneous determination of both CO concentration and gas temperature from the absorption spectrum, covering a temperature range of approximately 200 °C to 1,500 °C. The laser spectroscopic measurements were used to validate the camera-derived values. This approach may enable the quantitative, spatially resolved characterization of the temperature profile of any escaping gas in the future.



Pretensioner unit: How much CO escapes when the pyrotechnic seat belt pretensioner ignites? Measurements with a laser spectrometer provide a reliable answer.

Spin-off: Quirie GmbH

Researchers introduce electrocaloric cooling systems to the market

The start-up Quirie aims to transform the established market for cooling systems with their development of a solid-state heat pump based on electrocaloric materials.

Founded in January 2026, Quirie GmbH is a Fraunhofer IPM spin-off that is the result of more than ten years of research and development in the field of caloric cooling systems and heat pumps. Led by founder Dr. Kilian Bartholomé, the team focuses on electrocaloric technology, which uses temperature changes in solid materials induced by applied electric fields to create cooling circuits. There are strong indications of the disruptive potential of caloric cooling technologies. Caloric heat

pumps have the potential to operate more efficiently than conventional compressor-based systems, which reach a maximum of 50 percent of the thermodynamically achievable efficiency. In contrast, the theoretical efficiency of caloric systems exceeds 80 percent, which would save 40 percent in operating power. Additionally, these systems do not require environmentally harmful refrigerants, involve significantly reduced maintenance requirements and have the potential for lower production costs in the long term.

The ultimate cost and performance of electrocaloric systems depend greatly on the heat transfer between the electrocaloric material and the heat exchangers. To address this challenge, the research group developed and globally patented a novel concept for latent heat transfer in recent years. In their approach,

electrocaloric components are integrated into a heat pipe system, enabling high pump frequencies and consequently very high power densities. This core innovation positions the company competitively with respect to alternative system concepts for caloric cooling systems. Beginning in spring 2026, Quirie employees in Freiburg will focus on the development of cooling systems for switch cabinet air conditioning and laser cooling. Based on these initial niche applications, electrocaloric systems are expected to be further developed for commercial refrigeration and subsequently for the consumer market. As part of the ELCH (electrocaloric heating and cooling) project, the company will receive funding from the EXIST research program of the Federal Ministry for Economic Affairs and Energy until the end of 2026 to support development activities.



In May, Quirie's founding team led by Dr. Kilian Bartholomé (left) and Dr. Christian Vogel (second from right) moved into their laboratory and office facilities at the Haid industrial park in Freiburg.



Our core innovation and key competitive advantage is our patented heat pipe heat transfer concept.”

Dr. Kilian Bartholomé, Group Manager and founder

Focus on trace gas sensors

Resonant photoacoustics opens up new possibilities for the precise measurement of even the smallest gas concentrations.

Accurately measuring very small gas concentrations is crucial for climate protection, safety technology and industrial process monitoring. Fraunhofer IPM has unlocked the potential of a physical effect that has been known for over a century with the development of resonant photoacoustic sensors. Our photoacoustic sensor systems are extremely sensitive, fast, compact, robust and cost-effective, thus setting global standards.

Photoacoustics is fundamentally transforming trace gas sensor technology. When a gas sample is irradiated with light at a suitable wavelength, specific gas molecules absorb the light. The absorbed energy is proportional to the number of gas molecules. As the energy is converted into heat, the pressure increases, generating sound waves—an effect first described

by Alexander Graham Bell in 1880. The modulation of the light source is a key requirement for detection. Periodically turning the light on and off causes a rhythmic pressure increase that produces a measurable acoustic signal. Since the signal is directly proportional to the concentration of the target gas, it can be used for gas analysis.

The principle appears simple, but implementation is challenging. The resulting sound levels are extremely low, and, until recently, the signal-to-noise ratio has made it difficult to use this method for demanding measurement applications. Our research teams applied both a systematic understanding of the effect and technological creativity to develop the photoacoustic principle into a robust, highly sensitive and fast measurement technique.

The idea of the acoustic resonator

The real breakthrough came with the idea of using the measuring cell itself as an acoustic resonator. Each measuring cell geometry has its own natural frequency at which it resonates most strongly. When the modulation of the light beam is matched precisely to this frequency, the weak photoacoustic signal produces an amplified and clearly defined resonance sound. This dramatically boosts sensitivity, making the measurement stable and precise. However, the amplification is only useful if the resonance frequency remains constant. Temperature changes, pressure variations and different gas compositions alter the acoustic behavior and therefore shift the optimal frequency. Solving this challenge was essential to making the technology practicable.

Resonance tracking: the key to stable resonance

Our team developed a patented method for stabilizing the resonance frequency, known as resonance tracking. A second light source, typically an LED, selectively illuminates the wall of the measuring cell. The absorbed radiation generates a sound wave which is used by the electronics to determine the current resonance frequency. The modulation frequency of the primary measurement light source is continuously adjusted so that the acoustic cell constantly remains in resonant operation. This innovation solves a fundamental problem in photoacoustics by ensuring that the sensor remains optimally matched to the resonant frequency—regardless of environmental conditions. This enables

measurements in the ppb range, with response times under one-third of a second, using a small, robust and energy-efficient setup.

High-performance measurement without optical complexity

Unlike established laser-based systems that rely on sensitive optical resonators, resonant photoacoustics uses durable and geometrically robust acoustic structures. Optical systems are sensitive to vibrations, contamination and temperature drift, while acoustic resonators are largely immune to these influences. This creates the foundation for cost-effective, compact, field-ready devices with high measurement quality. Its properties make this technology particularly suitable for

This photoacoustic SO₂ sensor monitors the aging of SF₆ insulating gas directly inside the transformer.

mobile and industrial applications where fast response times and low maintenance requirements are critical.

Methane monitoring in the field—reliable at 50 km/h

The LDEM 2000 system for detecting methane leaks, which was developed by Fraunhofer IPM in collaboration with Schütz GmbH Messtechnik, demonstrates the high performance of this technology. The sensors of the LDEM 2000 are integrated into a measurement vehicle



and detect methane concentrations in the ppb range while driving at speeds of up to 50 km/h. The extremely short response time prevents measurement gaps even in cases where a leak leaves only a narrow, diluted gas trace. The system operates reliably under real-world conditions such as vibrations, humidity, dirt and shifting winds, meeting the demanding requirements of gas grid operators, which supports the rapid implementation of the new EU Methane Regulation.

[Interview with Volker Heimbürger,
Managing Director at Schütz Messtechnik
\(pp. 20–21\)](#)

Monitoring critical energy infrastructure

Monitoring high-voltage systems constitutes another important application of photoacoustic sensors. In high-voltage systems, the formation of even the smallest amount of SO₂ is indicative of aging insulating gas SF₆. Until recently, detection required manual sampling followed by laboratory analysis. With the resonant photoacoustic SO₂ sensor, developed at the institute, direct and continuous measurement is now possible. The sensor is sufficiently compact to be integrated into a transformer; it operates on battery power for years and achieves a detection limit of approximately 10 ppb. This opens up new possibilities for predictive maintenance and significantly increases operational safety in the energy sector.

A tool for climate protection and industry 4.0

Thanks to its easy integration, great robustness and exceptional performance, resonant photoacoustics has strong potential for many more applications: environmental monitoring, industrial measurement, emissions-related process control and safety technology in complex facilities. The global market for trace gas analysis is growing steadily—and Fraunhofer IPM is establishing itself as a technological leader.



Resonant photoacoustics is a game changer in gas sensor technology because it enables measurements that were previously considered technically or economically unattainable.”

Prof. Dr. Jürgen Wöllenstein, Head of Department

Gas and Process Technology | Trade fairs & events

Participation

Sensor+Test
May 6–8, 2025, Nuremberg
Own booth

Quantum Effects
October 7–8, 2025, Stuttgart
Quantum BW (Fraunhofer) booth

Space Tech Expo Europe
November 18–20, 2025, Bremen
Own booth

In-house events

11th Gas Sensor Workshop
March 20, 2025, Freiburg

**International Meeting on
Chemical Sensors IMCS**
June 22–26, 2025, Freiburg
Conference chair and management

Planned for 2026

New Space Acceleration Days
February 4–5, 2026

Sensor+Test
June 9–11, 2026

**Global Flow Measurement
Workshop**
September 29–October 1, 2026

Quantum Effects
October 6–7, 2026

Hydrogen Technology World Expo
October 20–22, 2026

Space Tech Expo Europe
November 17–19, 2026

**Photonics BW Weiterbildungs-
seminar Quantensensorik**
November 26–27, 2026



Overview Photonic Systems

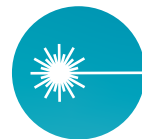
Customized laser wavelengths using frequency conversion: our contribution to advancing sensors and optical measuring methods

PD Dr. Frank Kühnemann, Head of Department

Lasers are an indispensable tool for measurement technology and many other fields. However, the wavelength required are often not available off the shelf. We use nonlinear optical frequency conversion methods to produce customized wavelengths for a number of application areas. These methods primarily involve converting single-frequency continuous-wave laser light, the conversion efficiency and frequency stability requirements of which are particularly high.

Our services range from customer-specific nonlinear optical crystals for frequency conversion to the development of production-ready optical parametric oscillators prototypes for OEM laser manufacturers.

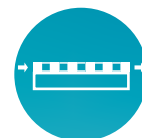
The light sources developed by Fraunhofer IPM are used in various fields, including quantum technology, nanophotonics, digital holography, Raman spectroscopy, fluorescence microscopy and the production of micro-optical diffraction elements.



Laser light sources



Photonic quantum sensors



Waveguides

Our groups and focus areas

Nonlinear optics and quantum sensors

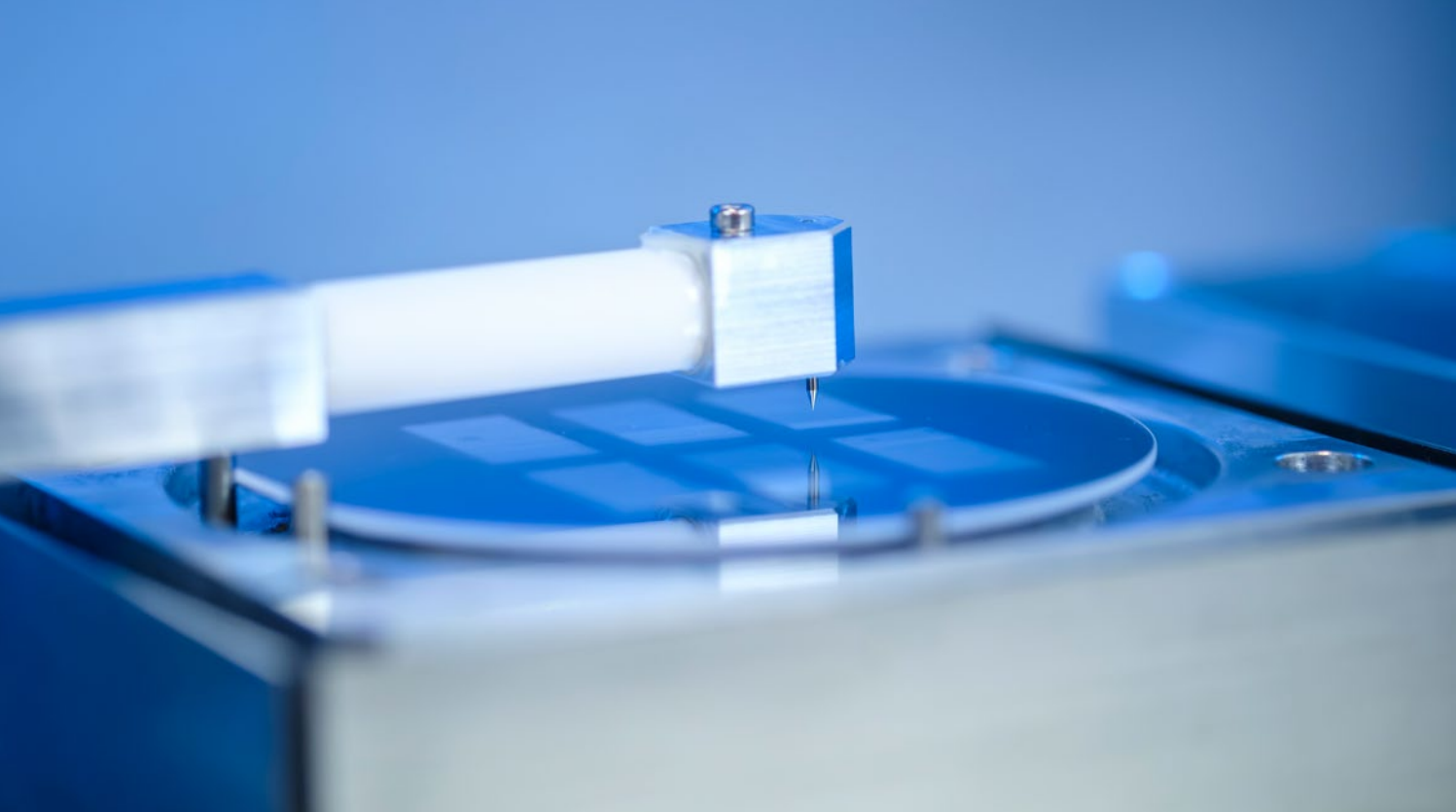
- Nonlinear optical frequency conversion: turnkey modules for producing customized wavelengths and for infrared measurement technology
- Component development: Maskless poling of crystals for quasi-phase matching, waveguides for efficient frequency conversion

We meticulously check the quality of our optical materials.”

Highlights Photonic Systems

Projects • Innovations • Events

We successfully launched and completed many exciting projects in the field of Photonic Systems in 2025. Here are some of them.



Kallipol project
Flexibly structuring lithium niobate—no need for a photomask

Thanks to a maskless process for poling lithium niobate crystals, special poling patterns can be produced quickly, flexibly, and in high quality—as individual pieces or small series.

Many applications in measurement technology, analytics, quantum technology, and photonics require wavelengths for which no suitable lasers are currently available on the market. Frequency conversion using nonlinear optical materials offers a solution. Crystals such as lithium niobate (LiNbO₃) must be specially structured for this purpose. A targeted, spatially periodic reversal of the crystal's spontaneous

polarization ("periodic polarization") determines which nonlinear optical process is supported and ensures high conversion efficiency. The resulting crystals, such as periodically poled LiNbO₃ (PPLN), form the basis for custom-made light sources across a very wide wavelength range, from the visible to the mid-infrared.

The traditional production process for PPLN crystals is complex. A separate photomask is required for each new poling pattern, and exposure processes must take place in a cleanroom. This way, entire wafers can be poled within seconds, making it an efficient procedure for the mass production of identical PPLN crystals. However, when it comes to research, development, one-offs, or small series, this process is too slow, expensive, and

inflexible. Another issue is the fact that some special poling patterns cannot be produced using a photomask.

In the Kallipol project, which was completed in 2025, Fraunhofer IPM worked with the University of Freiburg to develop a maskless poling process that addresses precisely this issue: Instead of exposure via a photomask, a tungsten tip is moved over the surface, creating the desired poling pattern directly into the lithium niobate crystal. A high voltage is applied between the tip and a planar metallic bottom electrode. This creates a well-localized micrometer-range domain inversion right below the tip. By moving the charged tip across the surface, domain lines can be serially written into the crystal. To ensure high-quality poling results, the electrical poling

current is monitored and controlled.

The advantages lie in the wide range of possibilities. With serial writing, we can create domain structures that are not possible to achieve using a mask, such as fan outs or radial patterns. The process can also be used to produce high-quality poling on wafers with nonhomogeneous properties. Moreover, without a mask, very quick design changes are possible. This is extremely important when developing new structures or poling new materials. The minimum periodicity is about 6 µm. Lithium niobate and lithium tantalate crystals from sub-millimeter to multi-millimeter thicknesses and formats from single chips to 3-inch wafers can be processed. The process is compatible with stoichiometric, MgO-doped, and

congruently melting lithium niobate. This opens up new avenues for research groups and industrial partners to develop new photonic components.

A tungsten tip writes the desired poling pattern directly into the material—flexibly and without the need for time-consuming mask production.

“

We write poling patterns directly into the crystal—fast, flexibly, and maskless, thereby shortening development cycles and creating greater design flexibility for nonlinear optical components.”

Dr. Simon Herr, Project Manager

MirCoSens project

Infrared lasers for tomorrow's laboratory analytics

A waveguide-based mid-infrared laser source was designed to provide precise, fast, and cost-effective tunable light for the analysis of minute fluid samples.

Many molecules reveal their identity in infrared light. Spectral signatures that are crucial for gas and fluid analysis are found particularly in the mid-infrared range. Especially when analyzing fluids, very broad spectral ranges must be covered. The standard measurement technique that is applied is Fourier transform infrared spectroscopy (FTIR spectroscopy) using thermal emitters. This technique reaches its limits, however, when it comes to highly absorbent samples. One possible solution is to use laser light sources, but these are only slowly catching on because of the specific requirements they have to meet. They must cover a wide wavelength

range and be quickly tunable in their wavelength, while the linewidth requirements are significantly lower than they are in gas analytics.

In the MirCoSens project, we are working together with SI Stuttgart Instruments GmbH and CLADE GmbH to develop a new laser platform specifically designed to meet the requirements of fluid analysis. The goal is to develop a broadly tunable light source for industrial applications that is more compact and cost-efficient than existing solutions. Target specifications include a wavelength range of 975 to 3800 nm, a spectral bandwidth below 2 cm⁻¹ and a tuning speed of up to 20 nm/ms.

The project builds on a concept developed by SI Stuttgart Instruments for pulsed optical parametric oscillators based on fiber-feedback technology, which enables particularly rapid wavelength tuning. The goal is to develop this further by shifting the frequency conversion from a lithium

niobate bulk crystal to a customized lithium niobate waveguide. This means that fewer components and moving parts are required while the efficiency of the frequency conversion increases, reducing pump capacity, size, cooling requirements, and costs. In this project, researchers at Fraunhofer IPM are developing buried waveguides for frequency doubling and the generation of mid-infrared light. The team uses its expertise in the laser-based fabrication of waveguides, periodic poling of wafers, and processing of non-linear-optical substrates.

To produce the waveguides, local changes to the refractive index are written into the bulk material with an ultrashort pulse laser, creating "depressed-cladding" waveguides—no cleanroom process needed. These waveguides enable rapid prototyping and are well suited for high-power applications due to the good thermal dissipation properties of the bulk material. While lithium niobate waveguides are already established in near-infrared applications, their use in the mid-infrared range remains an active area of research. Some preliminary tests at Fraunhofer IPM have demonstrated waveguiding up to 3.2 μm; the project aims to extend this range to longer wavelengths by adapting the structural parameters.

These new waveguides are primarily intended for bioanalytical applications in the 3 to 4 μm wavelength range. Project partner CLADE GmbH is contributing its expertise in fluid analysis. The targeted wavelength range is difficult to access using the conventional FTIR method due

to strong water absorbance. Higher-brilliance laser-based measurements could enable access to this area and provide additional information on protein structure, hydration, folding, denaturation, and aggregation. This is particularly relevant for the pharmaceutical and biotechnology sectors, given the growing need to characterize biomolecules quickly, precisely, and only using very small sample volumes.

The MirCoSens project thus combines three areas of expertise: Fraunhofer IPM's waveguide technology, SI Stuttgart Instruments GmbH's laser and systems technology, and CLADE GmbH's bioanalytics. Next to fluid analysis, other conceivable applications of the new laser platform include gas analysis, environmental monitoring, wafer processing, photonic integrated circuits, quantum research and quantum cryptography.

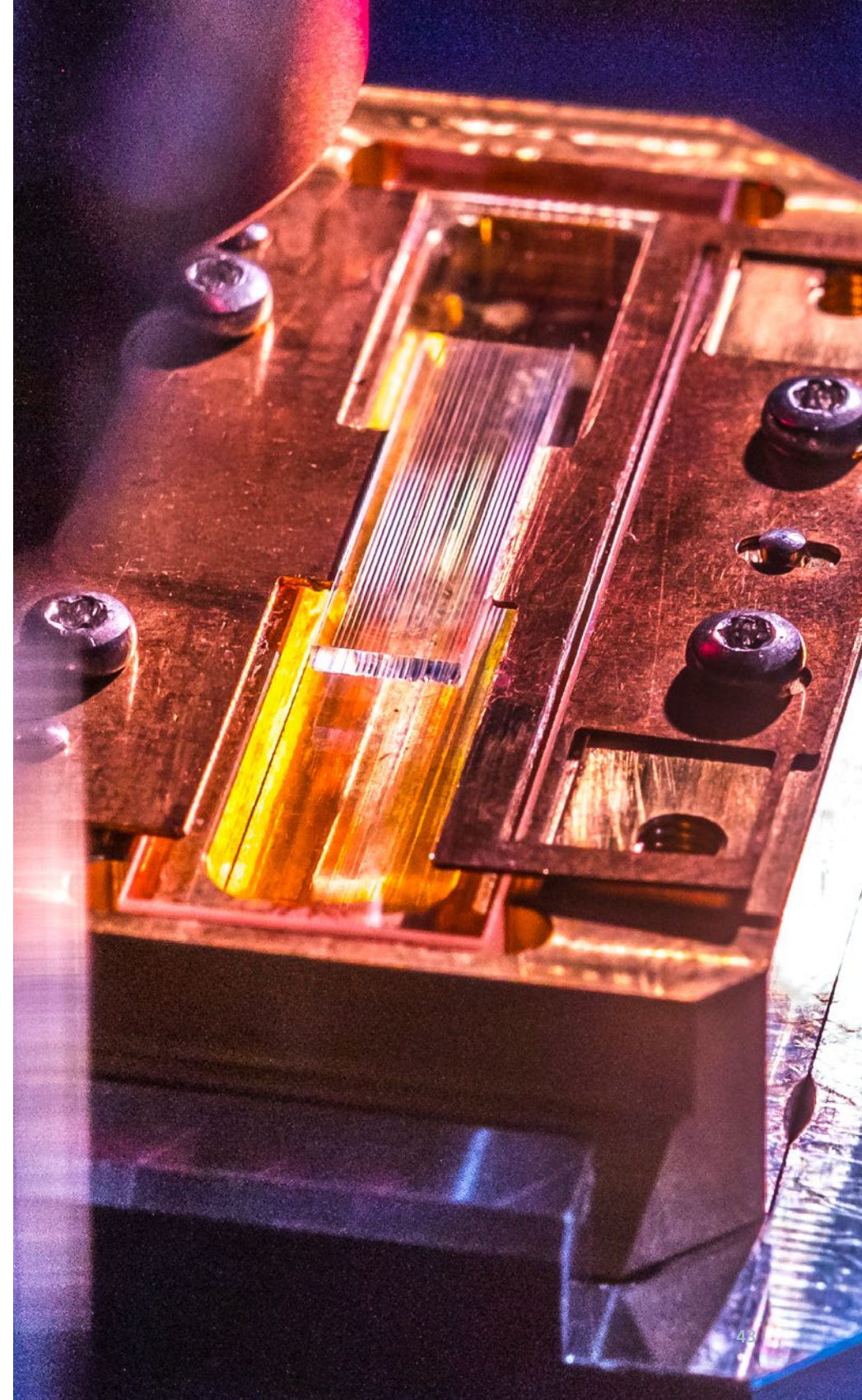
The MirCoSens project (waveguide-based mid-infrared laser source for fluid analysis), funded as part of the KMU-innovativ Photonics and Quantum Systems Program

Buried waveguides (visible here as fine lines in the transparent LiNbO₃ chip) are suitable for efficient frequency conversion in the mid-infrared range.



Our goal with waveguide-based frequency conversion is to develop more compact, cost-effective mid-infrared laser sources and open up new applications in bioanalytics."

Dr. Chiara Lindner, Project Manager



Focus on optical materials

Optical materials must meet ever-increasing demands. To this end, we measure the absorption levels in glass, crystals, and coatings at minute levels.

The development of powerful lasers and optical systems is pushing the boundaries of what is required from materials. High-power laser systems, precision optics, and quantum and medical technology are placing ever-increasing demands on transparent materials and optical coatings. Something that appears flawless to the naked eye can cause problems when it's exposed to high laser power. Tiny absorption losses lead to local heating, thermal lenses, deformation, or long-term damage. As optical systems become more powerful, the question of how pure, homogeneous, and resilient their components are becomes increasingly critical. Fraunhofer IPM develops and applies highly sensitive photothermal measurement methods that can be used to detect even extremely low absorptions in bulk materials and optical coatings.

For bulk absorptions, depending on the wavelength and the material, we achieve detection limits in the range of 10^{-4} to 10^{-6} cm^{-1} and for coatings down to 10^{-7} .

Small losses, big impact

Optical materials are often considered high quality if they transmit or reflect light with minimal loss. In high-performance applications, however, this view is too simplistic. Impurities in the range of just a few parts per million (ppm) can determine whether a lens remains permanently stable or drifts, ages, or is damaged during operation. Anti-reflective (AR) and highly reflective (HR) coatings, lenses, mirror blanks, and transparent materials, such as those used in laser systems, are particularly critical. Fraunhofer IPM offers

both service measurements for supply chain quality control and customized measurement systems. The measurement portfolio includes AR and HR coatings, as well as lenses and mirror blanks. The spatial resolution is $50 \text{ }\mu\text{m}$ transversal and $700 \text{ }\mu\text{m}$ lateral.

Heat as a measurement signal

The measurements are primarily based on photothermal common-path interferometry (PCI), a method that uses a pump-probe technique. An intense continuous pump beam is directed at a sample, creating a local heating effect in the area where the material absorbs light. This heating changes the refractive index and influences a crossing, weaker probe beam. The resulting refraction and

diffraction effects are proportional to the sample's absorption and can be measured by a lock-in technique. As the sample is moved along the z-axis through the laser beam's interaction zone, spatially resolved PCI data is generated that provide values for both bulk and surface absorption.

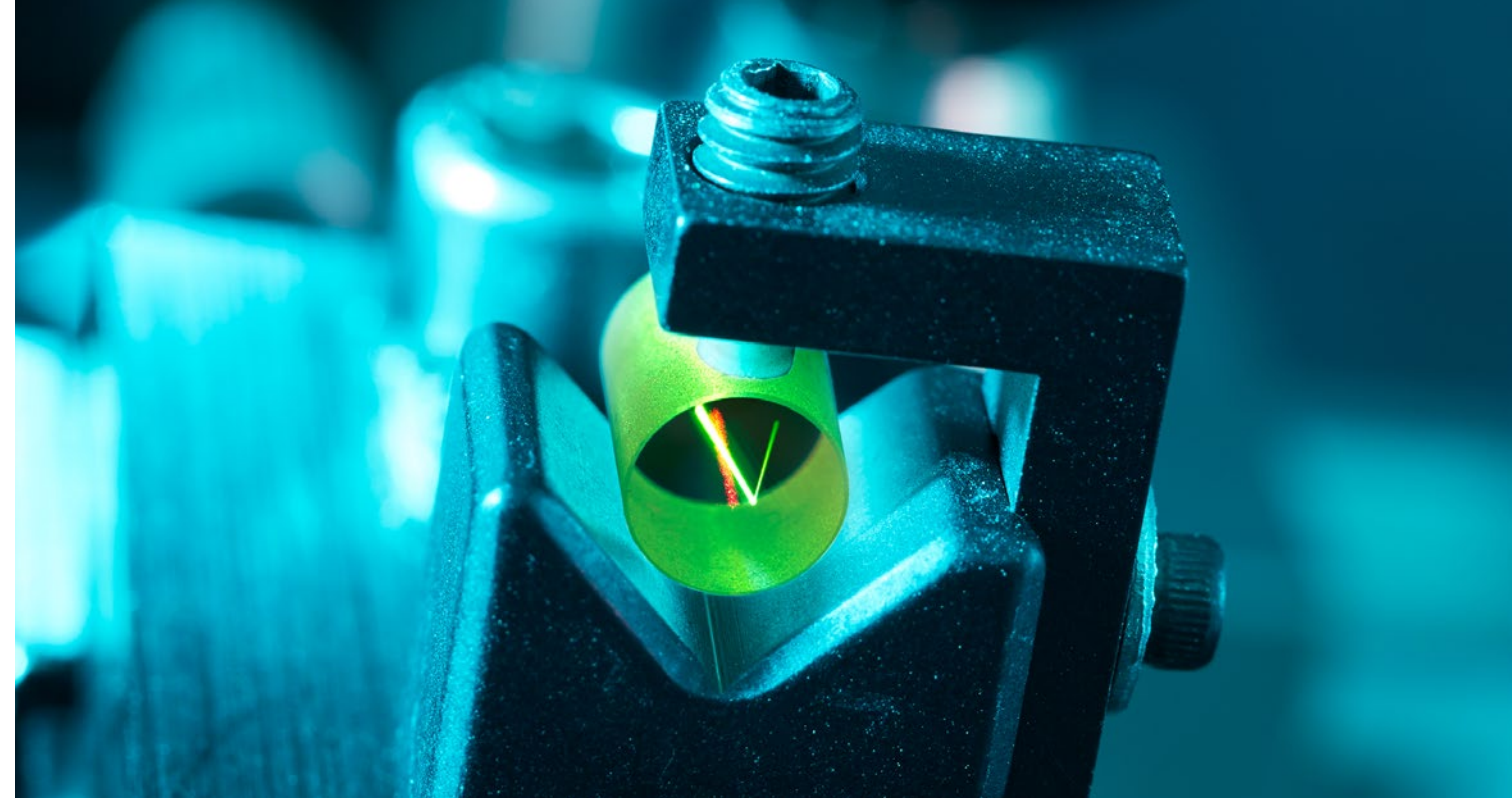
For testing, laser powers 100 to 1000 times lower than those used in actual operation are sufficient. Rather than simply measuring how much light has been absorbed in the material, this elegant principle makes visible the tiny heat trace that absorbed light leaves behind in the material. Absorption is thus understood not only as a loss variable but also as a local quality feature: Where is heat generated? At what depth? In which part of the material? At what wavelength? These are the questions that determine

the reliability, service life, and performance of modern optical systems.

Tunable light for full spectra

Traditionally, highly sensitive absorption measurements are performed at fixed laser wavelengths—preferably in the range of the future application. Fraunhofer IPM takes this principle one step further by combining PCI with continuously operating optical parametric oscillators (OPO) developed at the institute. These tunable pump sources enable absorption spectra that cover a wide wavelength range. This not only enables the determination of individual values but also the recording of spectral fingerprints of materials and components. The OPO-based laser light sources cover measurement

In photothermal common-path interferometry, a pump beam is directed into the sample; absorption of light induces local heating, which changes the refractive index and consequently affects a crossing probe beam.



ranges in the visible, near-infrared, and mid-infrared regions and can therefore often provide information on the origin of interfering absorption, such as metallic contamination or residual moisture during production.

Understanding coatings, not just evaluating them

Spectral PCI measurements are particularly valuable for highly reflective dielectric coatings consisting of multiple layers with different refractive indices. Their absorption is usually specified as a single value for the entire layer stack. A tunable pump source, on the other hand, allows an absorption spectrum to be recorded. If the wavelength is varied beyond the high-reflectivity range, the electric field distribution within the layer stack changes. This makes the absorption visible at different depths and in different material contributions, which opens up a new analytical perspective.

Quality control and component development

In quality control, knowing that a coating is absorbing is often not sufficient. The decisive factor is what proportion of the material is responsible, whether the loss occurs in the substrate, on the surface, or in the layer system, and how the absorption changes across the wavelength. This is why Fraunhofer IPM offers scientific measurement evaluations and customized measurement systems to support industrial partners when it comes to quality control and the development of new optical components.



Our measurement techniques make even minute absorptions visible, enabling more robust optical materials, better coatings, and more reliable laser systems.”

PD Dr. Frank Kühnemann, Head of Department

Photonic Systems | Trade fairs & events

Participation

- Laser World of Photonics**
June 24–27, 2025, Munich
Fraunhofer-Gesellschaft booth
- Space Tech Expo Europe**
November 18–20, 2025, Bremen
Own booth
- 845. WE-Heraeus Seminar**
»Sensing with Quantum Light«
December 7–9, 2025
Seminar management

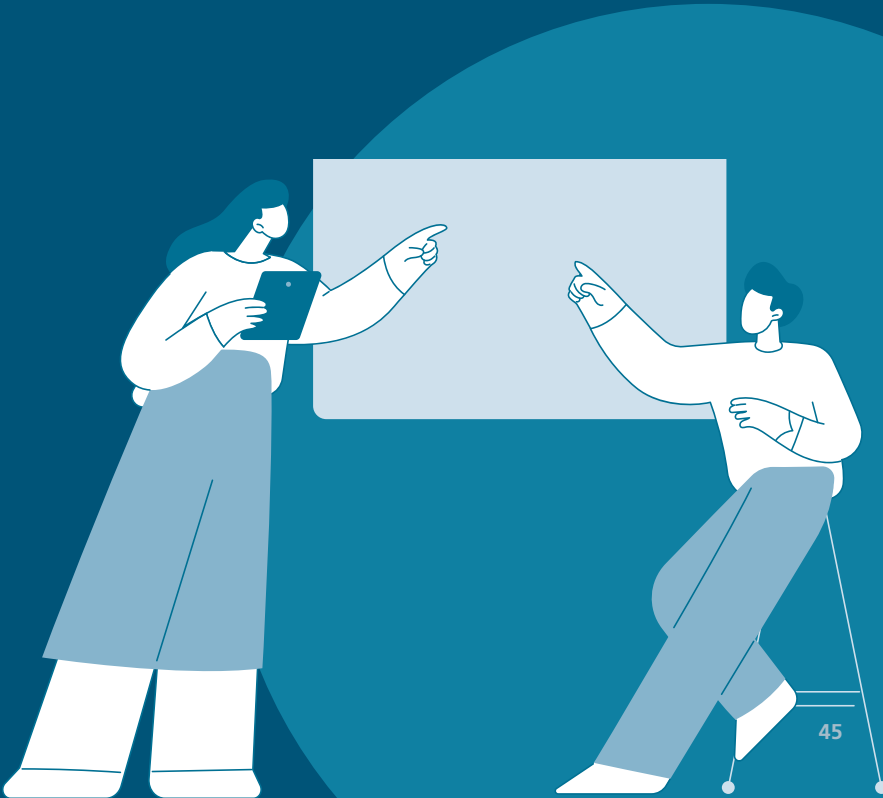
In-house events

- Photonics BW Weiterbildungsseminar Quantensensorik**
November 27–28, 2025
(Joint event)

- Planned for 2026**
SPIE Photonics West
January 20–22, 2026

- New Space Acceleration Days**
February 4–5, 2026

- Photonics BW Weiterbildungsseminar Quantensensorik**
November 26–27, 2026





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More highlights from 2025.

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Generating a highly uniform magnetic field inside the magnetically shielded room of the n2EDM experiment
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Adolf Thies GmbH; Institut für Mikrosensoren, -aktoren und -systeme IMSAS; Fraunhofer-Institut für Physikalische Messtechnik IPM (Hrsg.)
KOGAST: Wartungsarme Schadstoff-Detektion mit kolorimetrischen Gas- und adaptierten Streulicht-Feinstaubsensoren
Final report; Reporting period: 01.01.2023 – 31.12.2024
Freiburg/Brsg., 2025, 29 pp.

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[Freiburg, Univ., Diss., 2025]
Shaker Verlag. Gas Sensors 18 (2025)

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[Freiburg, Univ., Diss., 2025]
Shaker Verlag. Gas Sensors 19 (2025)

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doi:10.6094/UNIFR/274897

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Bimetallic Au-Pd catalyst on mesoporous Co3O4 for sensitive detection of combustible gases
[Freiburg, Univ., Diss., 2025]

Poku-Agyemang, K. N.; Reiterer, A. [Reviewer]
Multi-Data Fusion for 3D Reconstruction of Bridges
[Freiburg, Univ., Diss., 2025]
doi:10.6094/UNIFR/273642

Rathmann, L.; Reiterer, A. [Reviewer]
UAV-borne Dual-Wavelength Laser Scanner for Concurrent Snow Grain Size and Snow Depth Mapping
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Yassine, H.; Wöllenstein, J. [Reviewer]
Photoacoustic Sensors for the Detection of Sulfuryl Difluoride and Water Vapor
[Freiburg, Univ., Diss., 2025]

Large-scale projects 2025 Funded by the public sector

Throughout 2025, our scientists worked on seven publicly funded research projects with a total budget of over one million euros for Fraunhofer IPM.

EIKaWe Electrocaloric heat pumps
Funding: Fraunhofer-Gesellschaft (Flagship project)
Duration: 10/1/2019–02/28/2025

FMD-QNC Research Fab Microelectronics Germany (FMD) –
Module Quantum and Neuromorphic Computing (QNC)
Funding: Federal Ministry of Research, Technology and Space
(BMFTR), project management agency: VDI/VDE-IT
Duration: 12/1/2022–12/31/2025

Bau-DNS Comprehensive process for sustainable, modular and
circular building refurbishment
Funding: Fraunhofer-Gesellschaft (Flagship project)
Duration: 1/1/2023–12/31/2026

MultiLambdaChip Optically integrated multi-wavelength
laser system for holographic 3D surface inspection in industrial
quality assurance
Funding: Federal Ministry of Research, Technology and Space,
project management agency: VDI-Technologiezentrum GmbH
Duration: 10/1/2023–9/30/2026

SMArtCool Elastocaloric heat pumps for efficient air conditioning
Funding: Federal Ministry for Economic Affairs and Energy,
project management agency: Jülich (PtJ)
Duration: 12/1/2024 – 11/30/2027

FlexiScan Flexible sewer inspection system
Funding: Fraunhofer-Gesellschaft (PREPARE project)
Duration: 2/1/2025 – 1/31/2028

ELCH Electrocaloric heating and cooling
Funding: Federal Ministry for Economic Affairs and Energy
(EXIST research transfer)
Duration: 6/1/2025 – 11/30/2026

Network Our partners

We are actively involved in groups, specialist organizations and networks within the Fraunhofer-Gesellschaft, nationwide and worldwide.

Fraunhofer-Verbund Light & Surfaces

The Fraunhofer Group for Light & Surfaces brings together the Fraunhofer-Gesellschaft's scientific and technical expertise in the areas of laser, optical, measurement and surface technology. With around 1,900 employees, the association works together to solve complex technological issues for the industry and economy with application-oriented solutions. But the Fraunhofer institutes are not only innovation partners for the industry. They also work to produce new generations of scientific and technical experts. In cooperation with the local universities, the young scientists at the Fraunhofer institutes form a bridge between academic research and the industry.

Chairman of the group is Professor Karsten Buse, the central office is headed by Dr. Heinrich Stülpnagel (Fraunhofer IPM).

light-and-surfaces.fraunhofer.de/en

Fraunhofer-Gesellschaft

- Fraunhofer Group for Light & Surfaces
- Fraunhofer Agriculture and Food Industry Alliance
- Fraunhofer AVIATION & SPACE
- Fraunhofer Building Innovation Alliance
- Fraunhofer Business Area Cleaning
- Fraunhofer Business Unit Vision
- Fraunhofer Transport Alliance

Germany

- AMA Association for Sensors and Measurement
- Arbeitskreis Prozessanalytik der GDCh und DECHEMA
- Cluster Fuel Cell BW
- CNA Center for Transportation & Logistics – Neuer Adler e. V., Cluster Bahntechnik
- Competence Center for Applied Security Technology e. V. (CAST)
- Deutsche Forschungsgesellschaft für Oberflächenbehandlung e.V. (DFO)
- Deutsche Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V. (DGPF)
- Deutsche Hydrographische Gesellschaft e. V. (DHyG)
- Deutsche Physikalische Gesellschaft e. V. (DPG)
- Deutsche Thermoelektrik Gesellschaft e. V. (DTG)
- Deutscher Hochschulverband (DHV)
- Deutscher Kälte- und Klimatechnischer Verein e.V. (DKV)

- Europäische Forschungsgesellschaft für Blechverarbeitung e.V.
- Forum Angewandte Informatik und Mikrosystemtechnik e. V. (FAIM)
- Forum Luft- und Raumfahrt Baden-Württemberg e.V. (LR BW)
- Gesellschaft Deutscher Chemiker e. V. (GDCh)
- Green City Cluster Freiburg
- Innovationsnetzwerk Gesundheit (Bayern Innovativ)
- Innovationsplattform Magnetische Mikrosysteme INNOMAG e.V.
- microTEC Südwest e. V.
- Nano-Zentrum Euregio Bodensee e. V. (NEB)
- netzwerkdraht e.V.
- Photonics BW e. V. – Innovationsnetz Optische Technologien und Quantentechnologien
- Strategische Partner – Klimaschutz am Oberrhein e. V.
- VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA)
- VDSI – Verband für Sicherheit, Gesundheit und Umweltschutz bei der Arbeit e. V.
- Wissenschaftliche Gesellschaft Lasertechnik und Photonik e.V. (WLT)

International

- European Thermoelectric Society (ETS)
- International Thermoelectric Society (ITS)
- Optica (formerly OSA)

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft, headquartered in Germany, is one of the world’s leading organizations for applied research. Since its founding as a nonprofit organization in 1949, Fraunhofer has held a unique position in the German research and innovation ecosystem. With nearly 32,000 employees, the research organization operates 75 institutes and legally independent research units across Germany. The Fraunhofer-Gesellschaft plays a major role in innovation by prioritizing research on cutting-edge technologies and the transfer of results to industry to strengthen Germany’s industrial base and for the benefit of society as a whole.

Fraunhofer’s primary customer base consists of large and medium-sized companies that utilize its expertise to boost their competitiveness with new technologies. For years, Fraunhofer has been one of the most active patent applicants in both Germany and Europe. Its extensive international patent portfolio is the basis for technology transfer through research projects, spin-offs and licensing. Moreover, Fraunhofer addresses societal goals in key technology sectors through interdisciplinary and international partnerships in specific markets. Examples include developments in microelectronics, artificial intelligence (AI), quantum computing, healthcare, the circular economy, new materials, energy systems, critical infrastructure security and defense.

Fraunhofer is an attractive and established partner in publicly funded joint projects with industry partners. The Fraunhofer-Gesellschaft is also instrumental in strengthening Germany’s innovation and industrial base and ensuring its viability. Its activities create jobs in Germany, increase public-sector investments, give companies competitive edges and foster public acceptance of advanced technology. International partnerships with leading research partners and companies around the world ensure direct contact with the most influential research communities and economic areas.

Fraunhofer’s annual business volume is €3.6 billion, €3.1 billion of which is generated by contract research—Fraunhofer’s core business model. Unlike other public research organizations, base funding from the German federal and state governments is merely the foundation for the annual research budget. This serves as the basis for groundbreaking precompetitive research that will become important for the private sector and society in the years ahead. Fraunhofer’s distinctive feature is its large share of industry revenue, guaranteeing close collaboration with the private sector and industry and the consistent focus of Fraunhofer’s research on the market. In 2024 alone, industry revenue accounted for €867 million of its total budget. Fraunhofer’s research portfolio is augmented by competitively

acquired public-sector funding, pursuing the right balance between public-sector and industry revenue.

Highly motivated employees are the most important factor behind Fraunhofer’s success. The research organization therefore fosters an environment that encourages independent thinking, creativity and goal-driven work. It supports career development in both research and industry by providing targeted programs for professional and personal development.

The Fraunhofer-Gesellschaft is a recognized nonprofit organization named after Joseph von Fraunhofer (1787–1826), a Munich-based scholar who enjoyed equal success as a scientist, inventor and entrepreneur. His legacy continues to inspire the organization’s spirit of innovation to this day.

[fraunhofer.de/en](https://www.fraunhofer.de/en)

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*Making-of: Our colleague Jannis
Gangelhoff dived into the test
pool for the cover picture.*



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