Fraunhofer IPM

Fraunhofer Institute for Physical Measurement Techniques IPM

Annual report 2021/2022

Measuring • Monitoring • Optimizing

Annual report 2021/2022

Measuring · Monitoring · Optimizing

Quality Management
ISO 9001

"We make industrial processes more ecological and at the same time more economical."

Great scope for innovation
Spotlight on the forestry and timber sector

Dear customers, dear partners,

Around a third of Germany is covered by forest. Forests provide both an invaluable natural habitat and an important economic asset, with over 70,000 businesses in the forestry and timber sector achieving an annual turnover in excess of 120 billion euros. Nevertheless, many technological innovations have passed the forestry sector by. But change is underway – and Fraunhofer IPM has been playing an active part in bringing it about. Measurement technology and digitalization can help us to better conserve, protect and make use of the forest!

Integrated and distributed sensor technology enables us to gather data on the state of our forests, and our Gas and Process Technology Business Unit has been developing the required sensors. Based on this data, we can identify which measures are needed to preserve the forest ecosystem – even in the face of climate change. Laser scanners mounted on drones enable the precise mapping of forest and subsoil from the air, while researchers from our Object and Shape Detection Business Unit use artificial intelligence to analyze this measurement data. This creates a valuable data base to underpin forestry management planning.

Timber industry logistics benefit from marker-free log tracking using the "Track & Trace Fingerprint" method developed by our Production Control Business Unit. And thanks to innovative fine particulate air filters, the emissions from thermally utilized timber have been significantly reduced. These filters, which are electrostatic, self-cleaning and powered by waste heat, are being developed by our Thermal Energy Converters Business Unit. What's more, our home base of Freiburg and the surrounding Black Forest is an ideal setting to put the forest on the agenda: Since the 1980s, the forest sciences degree course offered by the University of Freiburg has been one of the most popular courses, and the region is connected to the forest in many ways in both science and industry.

We are enthusiastic about applications such as these, and they perfectly reflect our mission: *Fraunhofer IPM stands for applied research. We develop extremely fast, accurate and robust measurement technology and systems to make industrial processes more efficient, enabling our clients to minimize their use of energy and resources while maximizing quality and reliability. Fraunhofer IPM makes processes more ecological and at the same time more economical.*

This mission comes to life in all of our projects, four of which are presented in this Annual Report: "Mass production of individualized products with 100 percent control", "3D cable and line infrastructure surveying for building pits", "Sensor technology for safe hydrogen handling" and "Switchable heat pipes to regulate cooling". Each and every one of these projects contributes to the more efficient use of resources, quality assurance and sustainability. And let's not forget our revenue share derived from industry contracts, which – at around 40 percent – is comparatively high and proves that economy and ecology are not a contradiction in terms.

Sounds interesting? Then why not follow what we do! We have over 2500 social media followers and newsletter subscribers. In 2021, more than 1000 people took the opportunity to discuss very specific topics with our experts in one of our twelve online forums. Maybe you would like to check them out and also discover something new. And last but not least, don't miss the wealth of information on our website.

Hopefully see you soon!

Yours,

Karsten Buse

Prof. Dr. Karsten Buse, Director

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Fraunhofer
Fraunhofer

Overview Fraunhofer IPM

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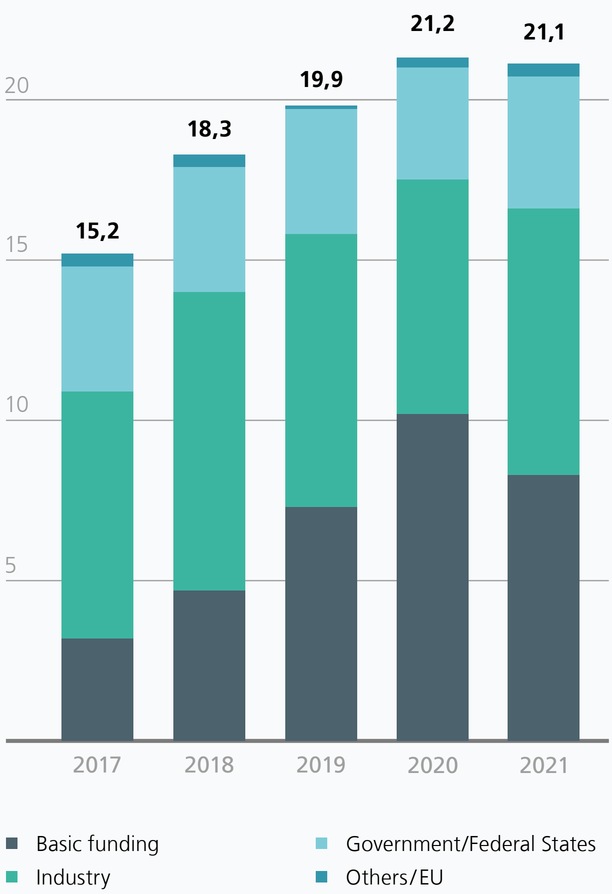
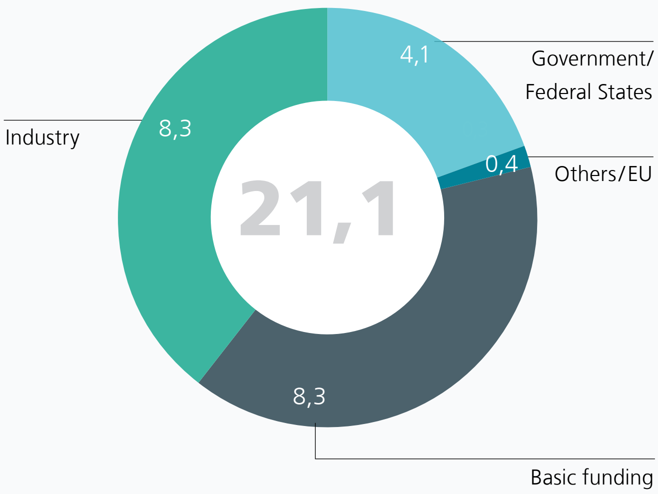
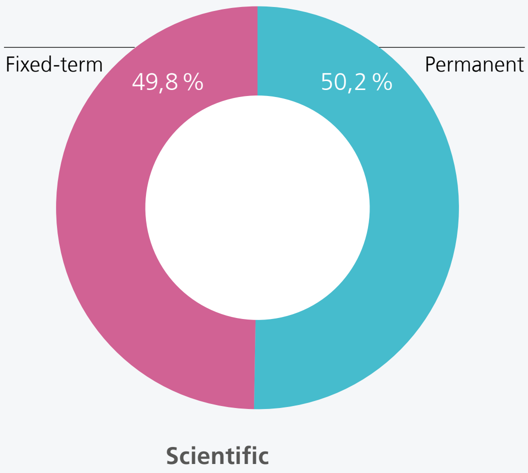
Development Operating budget in million euros

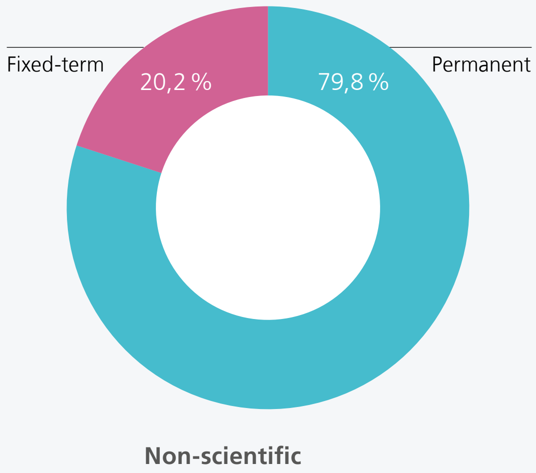


Operating budget 2021 in million euros

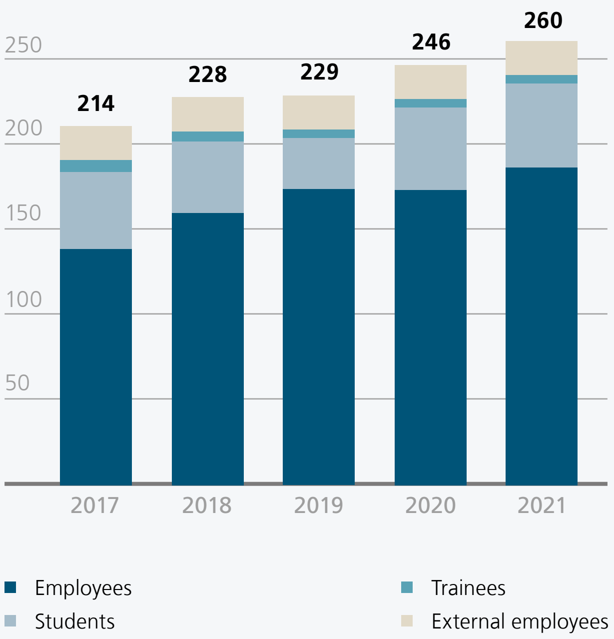


Staff under the terms of the Collective Agreement for the Public Service TVöD
Percentages of fixed-term/permanent contracts of employment 2021

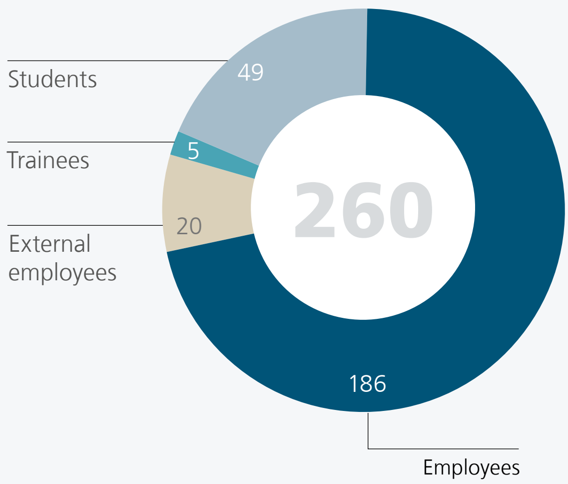




Development Number of employees



Employees 2021



MANAGEMENT

Director
Prof. Dr. Karsten Buse

Deputy Director
Dr. Daniel Carl

EXECUTIVE ASSISTANTS AND PUBLIC RELATIONS

Head of Communications and Media
Holger Kock

Research
Dr. Rosita Sowade

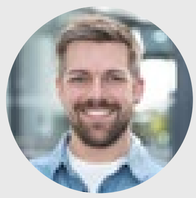
Organizational Development
Dr. Heinrich Stülpnagel

ADMINISTRATION AND IT

Head of Administration
Wolfgang Oesterling

Administration
Sabine Gabele

Information and Communications Technology
Gerd Kühner



Human Resources
Manuel Mak

TECHNICAL SERVICES

Head of Technical Services
Clemens Faller

Mechanics and Construction
Thomas Hinrichs

Facility Management
Clemens Faller

PRODUCTION CONTROL Page 26

Head of Department

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 38

Head of Department

Prof. Dr. Alexander Reiterer

Mobile Terrestrial Scanning

Dr. Philipp von Olshausen

Airborne and Underwater Scanning

Dr. Christoph Werner

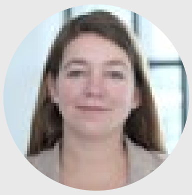
Smart Data Processing and Visualization

Prof. Christoph Müller

GAS AND PROCESS TECHNOLOGY Page 48

Head of Department

Prof. Dr. Jürgen Wöllenstein



Integrated Sensor Systems

Dr. Marie-Luise Bauersfeld

Spectroscopy and Process Analytics

Dr. Raimund Brunner

Thermal Measurement Techniques and Systems

Martin Jägle

Nonlinear Optics and Quantum Sensing

PD Dr. Frank Kühnemann

THERMAL ENERGY CONVERTERS Page 58

Head of Department

Dr. Olaf Schäfer-Welsen

Caloric Systems

Dr. Kilian Bartholomé

Thermoelectric Systems

Dr. Olaf Schäfer-Welsen

Advisory Board Keeping us on track

Our highly qualified Advisory Board guides and supports us in shaping our strategic direction and future goals. In 2021, Dr. Lutz Aschke took over as chair of the board from Dr. Manfred Jagiella, who had served as board member for six years including five as chair. We also welcomed new board members Sebastian Bannert and Dr. Mirko Lehmann.

Chairman

Dr. Lutz Aschke
Carl Mahr GmbH & Co. KG

Members

Sebastian Bannert
Robert Bosch GmbH

Hanna Böhme
Freiburg Economic Tourism and Trade Fair Agency (FWTM)

Stephanie Busse
DB Netz AG

Dr. Mathias Jonas
International Hydrographic Organization

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

Dr. Mirko Lehmann
Endress+Hauser Flowtec AG

Claus Mayer
Ministry of Economics, Labour and Housing in Baden-Württemberg

Prof. Dr. Andreas Nüchter
Julius-Maximilians-Universität Würzburg

Dr. Volker Nussbaumer
Volkswagen AG, Group Charging GmbH

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

"The professional highlights from the institute are also an inspiration for the members of the Advisory Board in their own daily lives."

Dr. Lutz Aschke
Chairman of the Advisory Board

Investments 2021

2021 was another year of substantial investment. By investing in our modern technical infrastructure, we ensure we are best placed to support our customers with top-class research.

Coordinate measuring machine

How accurate are the measurements taken by our 3D holographic systems? Most industrial companies check accuracy against reference topography measurements from tactile coordinate measuring machines (CMMs). CMMs produce high-precision measurements and are considered the gold standard in dimensional measurement technology. To determine the accuracy of the measurements generated by our holographic systems, in 2021 we invested in the most accurate CMM currently available on the market – the Leitz Infinity 12.01.6. The system is already in operation, housed in a temperature-controlled room where vibration levels are kept to an absolute minimum.

Technical Center for Quantum Magnetometry

In 2021, work began on our "Technical Center for Quantum Magnetometry". This 30 m^3 cube-shaped magnetically-shielded room will be operational from autumn 2022. Large enough for people to stand in, it will be used for developing quantum magnetometers and testing out related applications.

Continuous-wave laser light source

Thanks to a continuous-wave laser light source which is tunable over a wide spectral range, we can now characterize the dispersion characteristics of the lithium niobate waveguides produced here at the institute over a wide spectrum, from visible to mid-infrared.

Material processing system using ultra-short pulsed laser (in-house construction)

A system developed at the institute now allows us to "write" optical waveguides using an ultra-short pulsed laser system. Pulse energy, pulse repetition rate and polarization are all manually adjustable and the laser pulses can be focused using various lenses. The workpieces are positioned with sub-micrometer precision over a span of several centimeters.

Semi-automatic wafer bonding system

The institute has invested in a new wafer bonder for bonding lithium niobate on SiO_2 wafers. The system's bonding tools are designed to prevent contamination of the wafers during the bonding process. Once bonded, the resulting wafer stacks provide the base material for the institute's very own fully-mechanized manufacturing process for thin film lithium niobate.

Test environment for fluorescence laser scanners (in-house construction)

We are now able to demonstrate the inline capability and performance of our fluorescence laser scanners for lubricant film measurements to our customers in a realistic test environment, which has been designed to replicate conditions in a production facility. This demonstration environment is used to test new developments and finished systems, and also to calibrate devices to new metal blanks or lubricants.

Wind LiDAR

We have invested in a 3-channel LiDAR module which will be used to develop a wind LiDAR system for contactless wind-speed measurements. The module has three telescopes for 3D wind measurements with a high spatial and temporal resolution, and can measure over distances of up to 50 meters.

Upgrade for evaporation coating system

Our evaporation coating system (BAK640) has been given a new lease of life by replacing all of the control components, as well as the high-voltage power supply and the vacuum-measuring devices. The layer thickness monitoring, gas flow regulation and media supply components have also all been upgraded or replaced. Metal and even optical layers can now be vacuum-coated in multi-layer packages in a process monitored using an oscillating crystal. Processes using reactive gas are also possible and the system has been expanded to enable the coating of 8" substrates.

Professorships Universities & Universities of applied sciences

Fraunhofer IPM maintains connections with the University of Freiburg in the form of three associated professorships and one lectureship. Through the close university connection, we can draw on the latest results from basic research in our project work. Since 2019, the institute has also been cooperating with the Furtwangen University of Applied Sciences as part of the Fraunhofer-University Cooperation Program.

UNIVERSITY OF FREIBURG

Department of Microsystems Engineering – IMTEK

Laboratory for Optical Systems

Prof. Dr. Karsten Buse
www.imtek.de/laboratories/optical-systems

Research foci
- Nonlinear optical materials
- Optical whispering gallery resonators
- Miniature solid-state lasers
- Optical frequency converters (optical parametric oscillators OPO)
- Frequency combs
- Fast tuning of laser frequencies
- Integrated optics

Laboratory for Gas Sensors

Prof. Dr. Jürgen Wöllenstein
www.imtek.de/laboratories/thin-film-gassensors

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

Department of Sustainable Systems Engineering – INATECH

Chair for Monitoring of Large-Scale Structures

Prof. Dr. Alexander Reiterer
www.inatech.de/alexander-reiterer

Research foci
- Inspection and monitoring of objects and 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

FURTWANGEN UNIVERSITY

The Department of Microsystems Engineering of the University of Freiburg is right next door.

Faculty of Digital Media

Professorship of Computer Graphics

Prof. Christoph Müller

https://www.hs-furtwangen.de/en/faculties/digital-media

Research foci

- Real-time 3D visualization for industrial and medical applications
- Interactive visualization solutions for measuring technology
- Photorealism in real-time computer graphics
- Software engineering in 3D computer graphics
- Synthetic training data for AI-based image classification

Magazine Briefly reported

Online Forum

Here to stay

It is less than two years since we launched our virtual event program "Fraunhofer IPM Online Forum", but in that time we have already hosted over 15 events.

We first introduced our virtual events back in 2020 as a way to ensure that expert knowledge continued to be shared between science and industry during the pandemic. From the very beginning, the online events proved extremely popular, often attracting over 100 participants per event. Today, the Online Forum is a firm fixture in our events calendar. We continue to organize regular online events, each one dedicated to a specific discussion topic from the world of measurement and inspection technology. Immediately after each event, we also organize informal break-out rooms where participants can discuss specific questions in a smaller group. Details of upcoming events can be found on our website and in our newsletter.

Energy Efficiency Award

Award-winning system delivers zero-carbon heating

Work on the new Fraunhofer IPM premises in the north of Freiburg was completed in 2020. When designing the site, one of the key objectives was to ensure it was as sustainable as possible. A key element of this was to connect the site to a smart system utilizing local heat from nearby industrial premises. This local heating network was the brainchild of Badenova Wärmeplus GmbH & Co. KG and its software partner Mondas GmbH and has since been recognized with the highly-regarded Energy Efficiency Award.

From very early on in the planning process, Fraunhofer IPM knew that it wanted to install a low-temperature heating system at its new site, in order to maximize energy efficiency. That decision soon paid off, because it made connecting to the local heating network simple. All that was needed was to establish a direct interface with the building technology. Today, all the offices, laboratories and conference rooms at the site benefit from zero-carbon heating.

Thanks to a connection to the local heating network, Fraunhofer IPM now benefits from zero-carbon heating.

9. Gas Sensor Workshop

Record turnout

Our Gas Sensor Workshop on March 18, 2021, saw a record turnout, with more than 150 participants from industry and research tuning in online. The four-hour workshop included seven specialist presentations on technological trends in the area of gas sensors. One of the topics covered was hydrogen measurement technology. Representatives from Infineon and Dräger also gave a talk on sensors for measuring CO_2 levels. And other presentations looked at concepts for mobile selective nitrogen-oxide measurements in combustion engines and a dual-frequency comb spectrometer. After the talks, participants and speakers were invited to continue the conversation in informal break-out rooms.

The workshop concluded with a virtual laboratory tour. The next Gas Sensor Workshop is planned for March 16, 2023. The event will provide the first opportunity for the gas sensor community to take an in-person tour of the new laboratories acquired by Fraunhofer IPM in 2020.

Top right: All the girls taking part in the Girls' Day event were sent a CO_2 sensor kit in advance.

Girls' Day goes online

STEM – it's a woman's world too

How do machines learn? And how high does the CO_2 level have to get before we need ventilation? These were the two key questions on the agenda at our national Girls' Day event in 2021. The girls aged between 12 and 15 were split into two groups, and then tasked with building a CO_2 sensor and training their own neural network. They all thoroughly enjoyed the challenge and really got stuck into the task, asking lots of questions about our research activities at Fraunhofer IPM. The event was the first Girls' Day to be held online and it proved a real success, since girls were able to attend from all over Germany – from Hamburg to Munich – unlike previous events which have mostly attracted girls from the local area.

"

It was really fun and I learned so much!"

Mia, age 13

Prof. Dr. Alexander Reiterer (center) accepted the AI prize from the Baden-Württemberg Minister of Economic Affairs, Dr. Nicole Hoffmeister-Kraut (right), on behalf of the team.

AI Champions Baden-Württemberg

Infrastructure planning goes digital

What has been used to pave the road? Where are the trees, streetlights and garbage cans? All this information, and more can be found on a smart map for infrastructure planning. Thanks to a new AI-based tool from Fraunhofer IPM, these smart maps are now much easier to produce. The tool automatically analyses 3D measurement data from areas undergoing development and integrates this data into digital maps. It has proven so effective that in July 2021, Baden-Württemberg Minister of Economic Affairs, Dr. Nicole Hoffmeister-Kraut, named Fraunhofer IPM "AI Champions Baden-Württemberg" for their work developing the software. Digital maps are now standard practice for BIM-compliant infrastructure planning. However, producing these maps is an extremely complex and time-consuming task, because until now all the measurement data had to be input manually. This new AI-based tool cuts the time required to produce these maps from several weeks to just a few days.

The AI-based object classification technology developed by the team at Fraunhofer IPM uses a combination of traditional object recognition, based on geometry and characteristics, and deep learning methods from the field of machine learning. The underlying artificial neural network is trained using a training data set that has been specifically developed for infrastructure planning and is the only one of its kind in the world. It includes more than 30 types of object classes including different times of day, different seasons and different lighting conditions, as well as regional differences.

Prof. Dr. Alexander Reiterer, Head of Department

"When developing AI-based data interpretation technologies, our expert understanding of the quality of 3D measurement data is a real asset."

Youtube Video
Award Ceremony

Introducing Software developers at Fraunhofer IPM

Three different people. Three different departments. One job. Or should that be three jobs? Dominik Störk, Dominic Pietz and Christian Lutz all develop software for our measurement systems. But each of them is based in a different department. Is the software development process the same for them all? And what motivates them as developers? We decided to find out...

Dominik Störk

Object and Shape Detection

"I've been working here at the institute for more than ten years. Initially, I was more involved with the hardware end, developing and calibrating sensors. But over the years, I've taken on more software development, in particular looking at deep learning which has become a big part of my work. Our customers, for instance, need data for their construction planning work, but they don't want to take 3D measurements of everything. They just need to know where the electricity pylons and phone masts are, where the manhole covers are, and where the parked cars are.

One of my biggest professional achievements was working on a project with Deutsche Telekom. It was the first project with an industrial partner where we used our usual survey vehicles but also designed the whole process chain – data acquisition, interpretation and use – to run in the cloud. It was an enormous challenge. Every project is a creative process and there's always lots to learn, especially when you're working together with a customer.

My job is really varied; I do a bit of everything, from project management right through to programming. Automated data analysis is a fast-moving area and big research focus at the moment."

Dominic Pietz

Gas and Process Technology

"I am based in the Gas and Process Technology department but also frequently work on cross-departmental projects. My job is all about software/hardware co-design. In other words, I build the bridge between the physical measurement system and the user interface.

My work has required full commitment right from day one. My first project was a very special one, which saw us develop a measuring device for researching light-sensitive proteins in plants. I had to be able to do it all, from programming the hardware, to interpreting and processing the data, to designing the graphics to display the data.

One of the projects I'm working on at the moment is for a gas detection system, which we're planning to present at a trade fair. I'm responsible for programming one of the user interfaces. Customers are looking for solutions that are simple and intuitive to use, and this focus on user-friendliness is something we're seeing more and more. I get a real kick out of working on projects directly with customers. It's so much more satisfying to build a system that will ultimately be used, than a program that you're just working on in the background."

Christian Lutz

Production Control

"We develop optical sensors and systems for inspecting components and functions, and my job is to develop the right software to do this. Image processing is a key element of most of our work. Our customers provide us with catalogs of error categories and example images, and we then write software to check the components against these catalogs and decide which of them pass or fail.

I currently particularly enjoy working on inspecting components in free fall. Our aim is to develop a piece of cross-project software that can be broken down into modules and adapted for specific use cases. I really like the variety of projects we work on and the different challenges they pose. With every project we develop new customized solutions, many of which push the limits of what we previously thought possible.

It's also extremely satisfying to work on projects with real-world applications. I'm so proud when I see our systems and software in action – checking for dimensional accuracy, defects or contamination – as tiny components with delicate microstructures or meter-long metal blanks rattle through our customers' machinery in a matter of seconds."

Interview HÜBNER Photonics

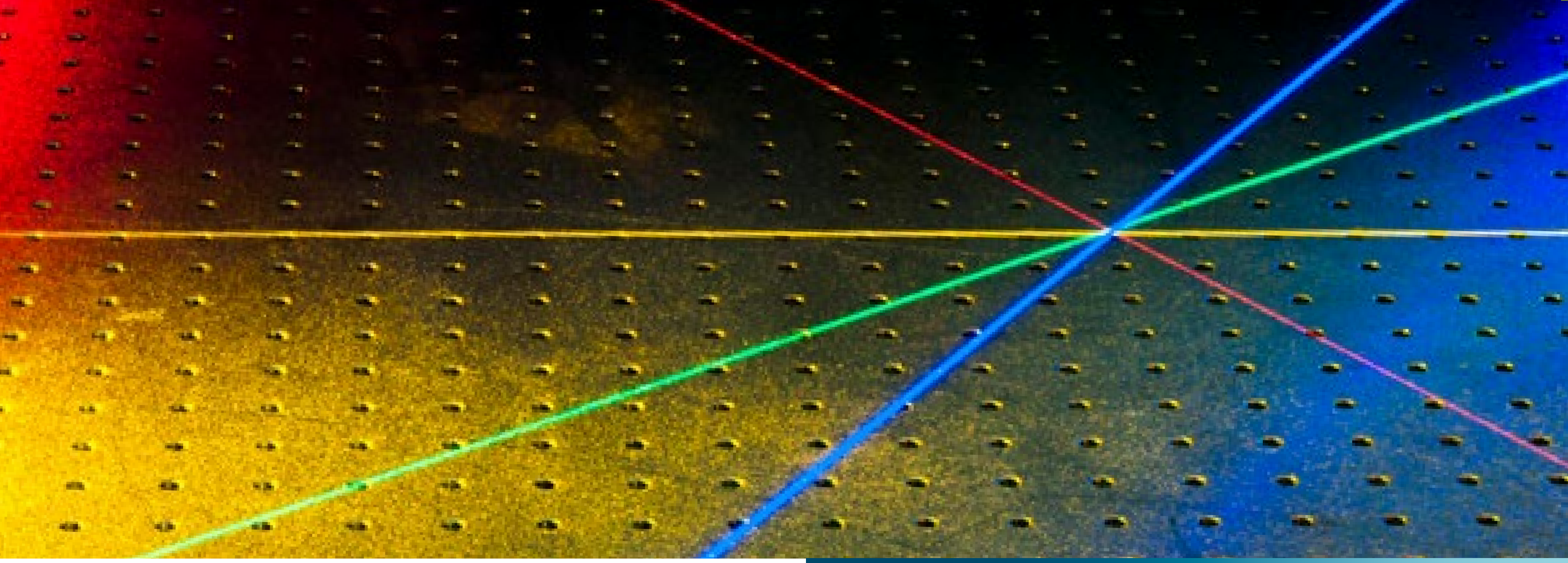
"By working together with Fraunhofer IPM, we are able to develop new products much faster."

HÜBNER is a world-leading supplier of folding bellows and gangway systems for buses, trains and planes. So how did it get involved in the photonics sector?
Korbinian Hens: It's quite simple really; we wanted to diversify our business. HÜBNER is the world leader in its core market, which is a real privilege. But it's also a problem, because it meant the company's growth was limited by the size of the market. Our move into photonics was a clear strategic decision. We wanted to move into the high-tech space, so that we could open up brand new market segments and grow our company outside of our core business. There was just one challenge: We didn't have the necessary technological expertise. Back in 2006, HÜBNER therefore teamed up with Fraunhofer IPM and started developing terahertz systems. In 2012, we also began working with Fraunhofer IPM to develop a novel tunable laser system, which ultimately became the C-WAVE. Both prototypes received a Prism Award at the Photonics West conference in 2014, and that's when we really took things up a gear.

Korbinian Hens is a physicist and currently COO and R&D Manager at HÜBNER Photonics. He is responsible for the development, production and servicing of photonics products at the company site in Kassel.

In other words, those two awards marked the birth of Hübner Photonics?
Yes, you could say that. We had successfully developed the technology, but now we needed to make it commercially viable. Once again, we looked for a partner with the strengths we needed and at the end of 2015 we acquired Swedish laser specialists COBOLT AB. The new HÜBNER Photonics division was born out of this acquisition in 2016.

How has your close collaboration with Fraunhofer IPM helped you on this road?
Our partnership has changed and evolved a lot over the years. No one at Hübner knew anything about photonics when we embarked on the very first C-WAVE project. But we knew we wanted to look more closely at certain technologies with the help of Fraunhofer IPM. Back then, we were running development projects without having a single member of in-house staff with any expertise in technologies such as lasers. Over the years, we have of course built-up whole teams of people to look after these products and continue to develop them in future. Nonetheless, Fraunhofer IPM is still very much part of the picture. Their input is especially important when it comes to fundamental principles and basic research. By working together with Fraunhofer IPM, we are able to develop new products much faster. Here at HÜBNER, we come at projects more from the customer perspective. Our strengths lie in developing user interfaces, software and electronics, as well as adapting products to specific customer use cases. Fraunhofer IPM's



Tunable: In the C-WAVE laser system (below), the desired laser wavelength can be set specifically and easily over a wide range.

strengths lie in basic research, materials and optical design. That said, everything is very closely intertwined. It's a fluid partnership with no hard divisions. Thanks to our external research and development work with Fraunhofer IPM, we always have our finger on the pulse, as well as having the opportunity to test out the latest technologies and incorporate them into our in-house projects. It's a partnership between equals built on an open exchange of information – and that's the key to its success. A traditional customer-supplier relationship would simply not work.

What are your criteria when deciding whether or not to team up with an external partner to develop a new product?
Speed is often a key factor for us. We obviously have our own in-house development teams, and we like to use these resources wherever possible because it means we can keep the development process moving forward. However, it is equally, if not more, important that we have an in-depth understanding of all aspects of the systems we're developing – and that's where external partners such as Fraunhofer IPM come in. By working together, we can turn new technologies into commercially viable products in a much shorter timescale.

HÜBNER Photonics

HÜBNER Photonics develops and manufactures high-power lasers and terahertz systems. With a staff of around 100, it is the smallest of the three divisions of Hübner GmbH & Co. KG. In total, the Hübner Group employs around 3500 employees at 25 sites around the world, and in 2020 the group generated sales of around 450 million euros.

More info at: **www.hubner-photonics.com**

What are the ingredients for successfully breaking into a new market?
There's always a bit of guesswork involved. You never know exactly what to do. But I honestly think that success has a lot to do with people. Take Reinhard Hübner for example: It takes a really open mind and amazing foresight to take over your father's company (which he has built up over several decades) and then suddenly announce: "I'd like us to diversify and try something completely different – new markets, new products, different technologies." And having made this decision, it takes real trust to say: "OK, let's give it a go," and put your money where your mouth is. That's not something everyone can do. I honestly believe this bold decision was the spark that set everything else in motion. Plus, you obviously need a little luck along the way and the good fortune to bring the right people on board. That's what we had and together we've achieved our goal.

Thank you very much for talking to us, Mr. Hens.

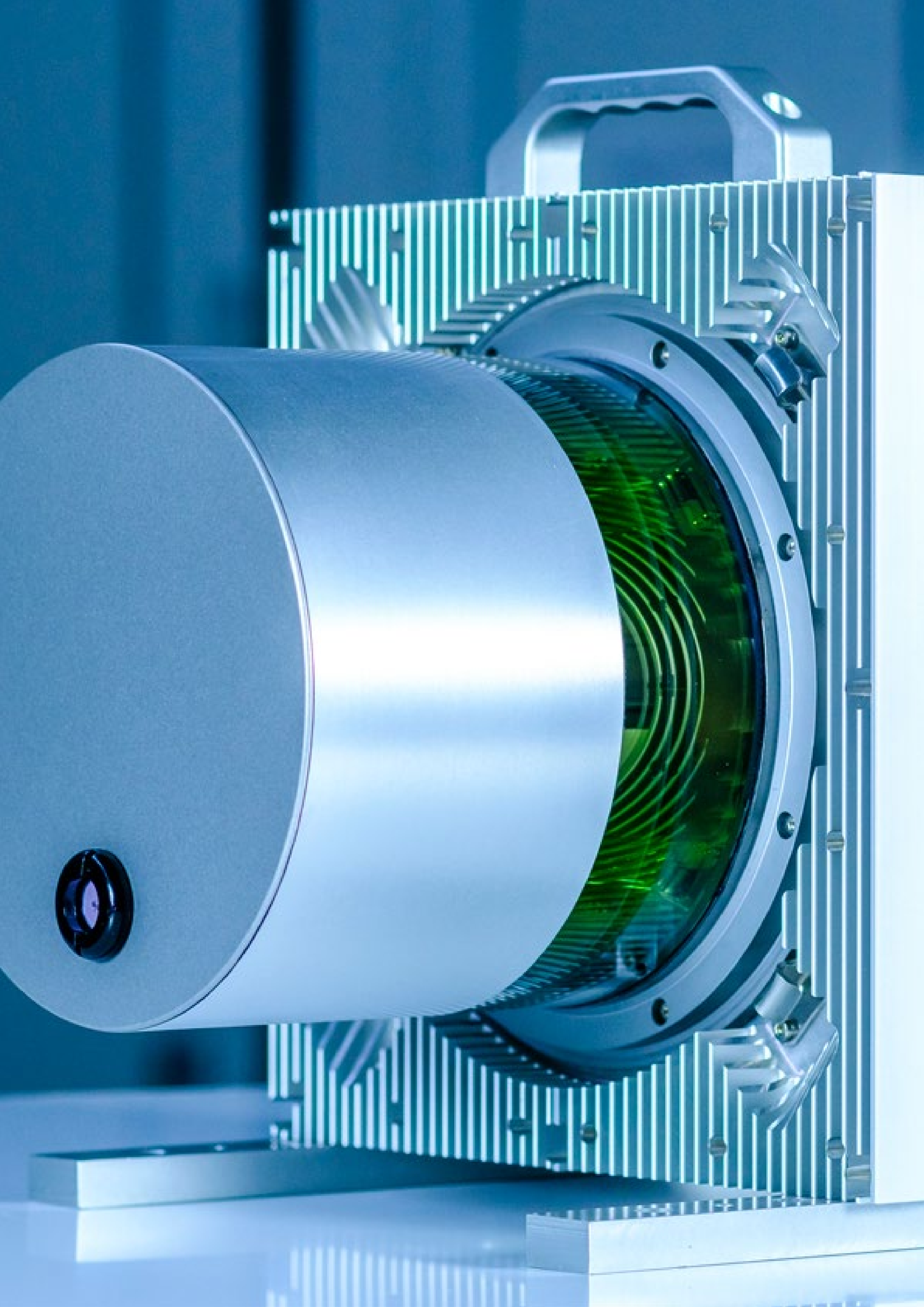
"

Our move into photonics was a clear strategic decision. We wanted to open up new market segments."

Korbinian Hens

Business units

Working for our customers



Overview Production Control

Efficient production control requires measurement technology that can keep pace with high-speed manufacturing lines – and that's precisely where we come in.

Our Production Control business unit develops optical systems and imaging processes for inspecting surfaces and taking precision measurements of complex 3D structures on active production lines. The aim: To ensure processes are controlled and therefore more efficient. Our systems are so fast and so accurate that even the smallest defect or area of contamination can be detected on a high-speed production line 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 digital holography, infrared reflection spectroscopy and fluorescence methods, with fast, low-level image and data processing. They can also be customized to suit different customer use cases, including for forming technology in the automotive sector and for quality assurance in the production of 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
- Analysis of filmic coatings and contamination
- Detection and classification of particulate contamination

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

Geometric Inline Measurement Systems

- Precision surveying of functional surfaces on active production lines
- 3D surveying of workpieces directly on the machine tool
- Rapid dynamic deformation measurements

"We develop customized measurement and inspection systems for a changing production landscape."

Dr. Daniel Carl, Head of Department

Highlights Production Control

Projects · Innovations · Events

Track & Trace Fingerprint is the first marker-free method for component tracking and tracing.

Component tracking and tracing

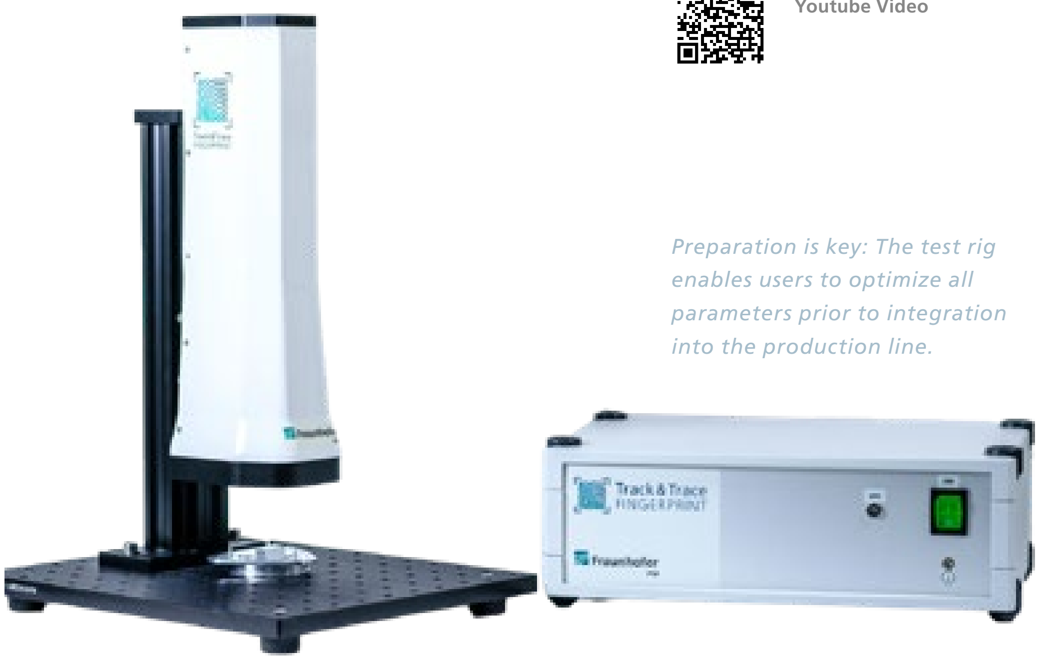
Test rig for Track & Trace Fingerprint

Our Track & Trace Fingerprint technology for marker-free component tracking and tracing has already been successfully implemented in industrial production facilities. Gone is the need for an additional marker for tracking purposes; instead the technology uses the component's existing surface microstructure as its distinctive marker. Camera systems generate the images of the components needed for identification during the procuction process and then generate a characteristic bit sequence (or fingerprint) for each component. A number of factors must be considered when positioning the camera on the production line, including the mounting space, the handling systems, the rate of production, the environmental conditions, the amount of components in circulation and, of course, the component surface itself. The camera system and software parameters can also be adjusted to optimize component recognition.

The newly developed Track & Trace Fingerprint test rig provides a quick and simply way for users to test all these parameters and get their set-up just right, using a few dozen real-life components. Industry customers can also borrow or purchase a test rig for feasibility studies. The Fraunhofer IPM team is always on hand to support customers when commissioning our Track & Trace Fingerprint technology, adjusting the system to their specific production environment and ultimately integrating the system into their production line.

Track & Trace Fingerprint Youtube Video

Preparation is key: The test rig enables users to optimize all parameters prior to integration into the production line.



DiGeBaSt project

Marker-free log identification

Wood is a valuable and sustainable raw material, but only if our forests are managed cost-effectively and ecologically. As part of the DiGeBaSt research project (Digitalization of Felled Logs), Fraunhofer IPM and its partners are developing a marker-free procedure for identifying logs and trunk sections, which they hope will provide the basis for a comprehensive digital control system for the forestry industry.

Instead of using numbering tags to label felled trees, logs could in future be identified using the unique structure of their cut surface, in much the same way as we use fingerprint recognition. This system would enable us to trace individual logs from the point that they are felled right through to when they are surveyed at the sawmill. Camera images of the cut surfaces are converted to a simple bit sequence, and the logs can then be tracked by comparing this data with later images of the same cut surface and the corresponding bit sequence. The ID data for the logs is also linked to additional geographical data and other relevant information and stored in the cloud for future reference. This means that in future, even if logs are mixed up during the felling process, it will be possible to identify the wood belonging to different forest owners without any risk of counterfeiting. And this, in turn, will ensure that payments for the timber are transparent, even in collective marketing scenarios.

Funded by the German Federal Ministry of Education and Research (BMBF) (Digital GreenTech program)

GUmProDig project

Digital processes for energy-efficient production of lightweight components

Fraunhofer IPM has developed a measurement system for quality control and component tracking and tracing that has the potential to make the production of lightweight components more energy efficient. In today's production facilities, the vast majority of lightweight components are produced using power-hungry machining techniques. But if they switched to forming processes, manufacturers could cut their CO_2 emissions by 50 percent. To make this viable, however, they need an inline-capable measurement technique to ensure that stringent manufacturing tolerances continue to be met when using a cold forming process.

In spring 2021, Fraunhofer IPM and its research partners launched the GUmProDig project (Holistic digitalization of the forming process), with the aim of developing a solution to this exact problem: A free-fall inspection system capable of checking the geometric dimensional accuracy and surface quality of every individual component with micrometer precision. The unique surface structure at a pre-defined position on each part is also recorded, so that it can be used as a fingerprint for later component tracking and tracing. In other words, specific quality characteristics can be assigned to individual components. The digital measurement data can also be fed into self-learning systems in order to optimize production facilities. These systems have been developed by the researchers based on machine-learning techniques.

Funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the Technology Transfer Program Lightweight Construction (TTP LB).

The structure of the cut surface is like a fingerprint which can be used to identify the logs.

Forming solutions for lightweight components: Free-fall inspection system for quality control and component tracking and tracing

We measure bipolar plates with micrometer precision during the cold forming process.

SPOT project

Spotlight on surface defects and contamination

Tiny particles and the smallest of defects on the surface of a component can have a big impact; they can prevent the component from working correctly or even disrupt downstream processing steps. Until now, defects and contamination have been identified using visual inspection or by rinsing the component and analyzing the rinsing fluid. Both these quality control options are extremely cumbersome. However, thanks to an optical inline measurement system developed by Fraunhofer IPM and its partners as part of the SPOT project (System for Adaptive Photonic Surface Testing with Image Analysis Functionality Capable of Learning in Combination with a Cleaning System), it will soon be possible to identify and classify particles and defects on metallic parts during the production process itself.

Thanks to the measurement data generated by the system, the production process can be corrected immediately, for instance by adjusting some of the cleaning system parameters. When developing the optical recognition technology, the research team opted to use camera technology with adaptive light field control. By optimizing the lighting selection for each component surface, ensuring that defects and particles on the component can be safely inspected irrespective of its geometry or reflective property. This is essential for the AI-based image analysis to function correctly and be capable of learning across different component geometries and surface properties.

Funded by the German Federal Ministry of Education and Research (BMBF) (Computer-Aided Photonics program)

AKS-Bipolar project

Quality assurance for key fuel cell components

Bipolar plates (BPP) are a vital component of fuel cell systems. In fact, modern fuel cell stacks can contain anywhere up to 600 of them. To date, graphite BPP have dominated the market, because attempts to manufacture these components from thin metal blanks or metal foil have frequently been hampered by surface defects or deviations in dimensions. Such defects can cause difficulties during installation, or prevent the fuel cell from functioning correctly. Nonetheless, metallic BPP do have certain advantages: They are cheaper to produce and can also be processed at lower thicknesses, which is a key requirement for the automotive sector.

Together with its partners at the University of Stuttgart, Thyssenkrupp System Engineering and Chemische Werke Kluthe, Fraunhofer IPM sets out to develop an inspection system which is supposed see metallic BPP produced as standard. The system is based on a digital-holographic 3D sensor, which inspects the components thoroughly and with micrometer precision during the cold forming process. The aim of the project, entitled the AKS-Bipolar project (Active Process Control in the Series Production of High-Precision Embossed Bipolar Plates), is to create a comprehensive simulation tool chain, including a digital twin of the forming process, on the basis of which recurring production problems can be numerically recorded and systematically resolved.

Funded by the German Research Foundation and the Fraunhofer-Gesellschaft (Trilateral Transfer project)

In the spotlight: Thanks to the adaptive light field, defects can be easily assigned to specific categories.

SiBoF project

Identifying multidrug-resistant bacteria on-site

As the number of multidrug-resistant pathogens grows, it becomes all the more important that, wherever possible, bacterial infections are treated using a targeted antibiotic for the bacterium in question. To work out which antibiotic to use, we first need to analyze the bacterial genome. Until now, the task of identifying the correct antibiotic has fallen to medical laboratories. However, as part of the SiBoF project (Signal Boosters for Fluorescence Assays in Molecular Diagnostics), Fraunhofer IPM and LMU Munich have developed a test platform, which, within less than an hour, can automatically identify the pathogen directly at the point-of-care, e. g. at a doctor's surgery.

At the heart of this patented system is a miniaturized high-resolution fluorescence microscope, developed by Fraunhofer IPM. This microscope detects single DNA molecules which bind to the binding sites primed for specific pathogens on a microfluidic chip. The DNA molecules are detected using fluorescence markers. In order to amplify the optical signals of these markers, the researchers have adopted a new method, which uses antennas, developed by LMU Munich and consisting of nanometer-sized metal particles, to concentrate the light in a tiny region and enhance the optical field. Because of this, time-consuming chemical amplification via polymerase chain reaction (PCR) is no longer required.

Funded by the German Federal Ministry of Education and Research (BMBF)

The team presented a demonstrator of the compact, portable test platform at MEDICA 2021.

A single DNA molecule is all that is needed to identify the pathogen."

Dr. Benedikt Hauer, Project Manager

"We want to ensure that electronics last longer."

Dr. Markus Fratz, Project Manager

Scientific publication: Digital holography in production. An overview. Light. Adv. Manuf. 2, 15 (2021)

LongPower project

Holographic inspection system for power electronics

Electrical waste presents an enormous challenge for both people and the environment. All too often, entire devices are thrown away simply because a single component is faulty. As part of the LongPower research project (Holographic Inspection System for the Development and Series Production of High-Performance Electronics), researchers from Fraunhofer IPM and the Department of Microsystems Engineering (IMTEK) at the University of Freiburg have developed a technology that can identify faulty electronic components during the production process. The hope is that this technology will prevent these faulty components from being installed in devices and therefore reduce the number of devices that fail prematurely.

The project partners have also conducted research into the IGBT (insulated-gate bipolar transistor) chips used in many power electronics. When exposed to high thermal load, these chips will warp, often by just a few micrometers, but even these tiny changes can cause the electronics to fail. The researchers have therefore designed a demonstrator system for quality control purposes which enables manufacturers to detect these tiny deformations. The chips are first exposed to a thermal load using a heating system developed by IMTEK. They are then inspected using a digital-holographic process developed by Fraunhofer IPM, which generates fast, temporally resolved imaging measurements and is capable of detecting even the smallest of deformations. A follow-on project entitled Longpower 4.0 is now planned to develop an inspection system that is suitable for use in industry and performs 100 percent reliable quality assurance checks.

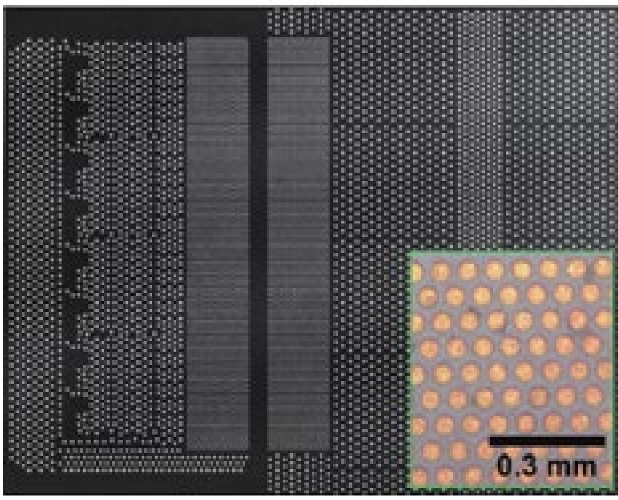
Funded by the Sustainability Center Freiburg (LZN)

Quality control for microstructures

3D measurement system for chip production

The latest generation of microchips contain many hundreds of thousands of electrical contacts. Every individual chip assembly is connected to the contacts on the printed circuit board using a soft soldering process, which requires sub-micrometer precision to ensure the electrical contacts function correctly and reliably.

The HoloTop digital-holographic 3D-inline measurement system is the first to enable manufacturers to measure the exact height of every single solder joint during the production process. In spring 2021, the team from the Geometric Inline Measurement System Group began testing the technology on the production lines of the world's largest semiconductor manufacturer, Intel Corporation. Measurement technologies for use in the chip production industry must meet extremely stringent standards. The high-speed nature of the production lines means that measurements must be taken within a fraction of a second. And the wide dynamic range between the highly reflective solder and the rough dark-colored substrates presents an additional challenge for optical measurement systems. The HoloTop system uses the latest generation of digital-holographic 3D-sensor camera technology to overcome all these challenges and deliver 100 percent reliable quality control measurements with sub-micrometer precision for the chip production industry. It is the most accurate HoloTop system ever put into practice in industry.



Microstructure of a ball grid array captured using the 3D sensor: The ball grid array contains many hundreds of thousands of solder joints for electrical contacts. The inset shows an enlarged section of the structure.

RE-USE project

Extremely-thin coating for better recycling rates

Packaging for sensitive products such as food and pharmaceuticals are multilayer systems consiting of a mix of materials (including different polymers and functional layers) which make it extremely problematic to recycle. To address this problem, four Frauenhofer Institutes have joined forces as part of the RE-USE project (Recyclable Functional Packaging for the Food and Pharmaceutical Industry Based on ultra-thin Barrier Layers) to develop nanometer-thin barrier layers, which will enable packaging to be made from a single material in future. The amount of secondary material applied to the base polymer is so small that the packaging can be easily recycled as a mono-material.

To ensure these "super barriers" meet the necessary quality standards, Fraunhofer IPM is developing an inline-capable solution, which can thoroughly check (and also regulate) the thickness and composition of the barrier layers during the manufacturing process. This technology relies on the characteristic spectral properties of the different coatings in the infrared region. By shining an infrared light onto the coating at an angle, the system can detect the spectral signature of both the layer itself and the substrate. These spectral characteristics can then be interpreted to give information about the thickness and chemical composition of the different layers.

Funded by the Fraunhofer-Gesellschaft (PREPARE project)

Sensitive products are often packaged using compound materials; however, equivalent packaging made from mono-materials is much easier to recycle.

F-Scanner for optimized aluminum forming

With their lower weight and higher resistance to corrosion, aluminum auto bodies have some significant advantages over their steel counterparts. The problem is that it is more difficult for manufacturers to monitor the forming processes for aluminum blanks than for steel ones. Aluminum is comparatively brittle and its hard oxide layer leads to increased tool wear. As a result, dry lubricant has to be applied to the blanks' surface prior to forming. How well the lubricant is distributed and how thickly the coating is applied has a significant impact on the result of the forming process.

A US automotive manufacturer recently introduced four of our F-Scanners to help it monitor this lubricant application process. The four identical fluorescence measurement systems were developed in 2021 and installed on the company's production line in spring 2022. Two of the F-Scanners are positioned on either side of the metal blank, where they map how the lubricant is dispersed across a width of two meters. These measurements are performed with millimeter-range spatial resolution at a feed rate of up to 2.5 m/s. Each of the scanners uses a laser beam to scan the blank surface at a rate of 400 lines per second and detect varying strengths of the fluorescence signal depending on the distribution of the lubricant. This process generates 160 million data points per second, which in turn produce a comprehensive, high-resolution map of lubricant distribution for each individual blank.

"The F-Scanner is the only system in the world that performs spatially resolved measurements of lubricant thickness during production."

Dr. Alexander Blättermann, Group Manager

Four F-Scanners are in operation at a US automotive manufacturer, where they are being used in forming processes to monitor the application of dry lubricant to metal blanks.

Production Control | Trade Fairs & Events

parts2clean

Leading International Trade Fair for
Industrial Parts and Surface Cleaning
October 5–7, 2021

Measurement systems for 100-percent reliable automated quality control of surfaces using a range of imaging processes for detecting and quantifying particulate and filmic contamination (F-Scanner, F-Camera, F-Camera mini)

Forum lecture by Dr. Alexander Blättermann, optical surface analytics
Rapid fluorescence imaging – detecting filmic contamination across areas measuring just a few mm² to several m²

Medica

Trade fair for medicine
November 15 –18, 2021

Platform for point-of-care diagnostics: Identifying pathogens from a single DNA molecule using a high-resolution fluorescence microscope with optical antenna to amplify the signal

Fraunhofer Vision seminars

"3D measurement technology" seminar
with practical element
November 10 –11, 2021

Expert talk by Dr.-Ing. Tobias Seyler, Geometric inline measurement technology
Digital holographic 3D measurement technique for multi-axis systems

Online Forum on production control

In 2021, we held eight online forums as part of our virtual event series:

- Measurement technology for precision surfaces, January 27, 2021
- Measurement technology for material and component inspections, February 24, 2021
- Marker-free component tracking and tracing, March 17, 2021
- Component inspection in free fall, April 21, 2021
- Particle measurement technology, May 12, 2021
- Detecting and quantifying filmic contamination, June 23, 2021
- Track & Trace Fingerprint – a decentralized solution, July 21, 2021
- Measuring component deformation in real time, September 29, 2021

Events in 2022

Control 2022
International Trade Fair for Quality Assurance
May 3 –6, 2022

drinktec 2022
World's Leading Trade Fair for the Beverage and Liquid Food Industry
September 12 –16, 2022

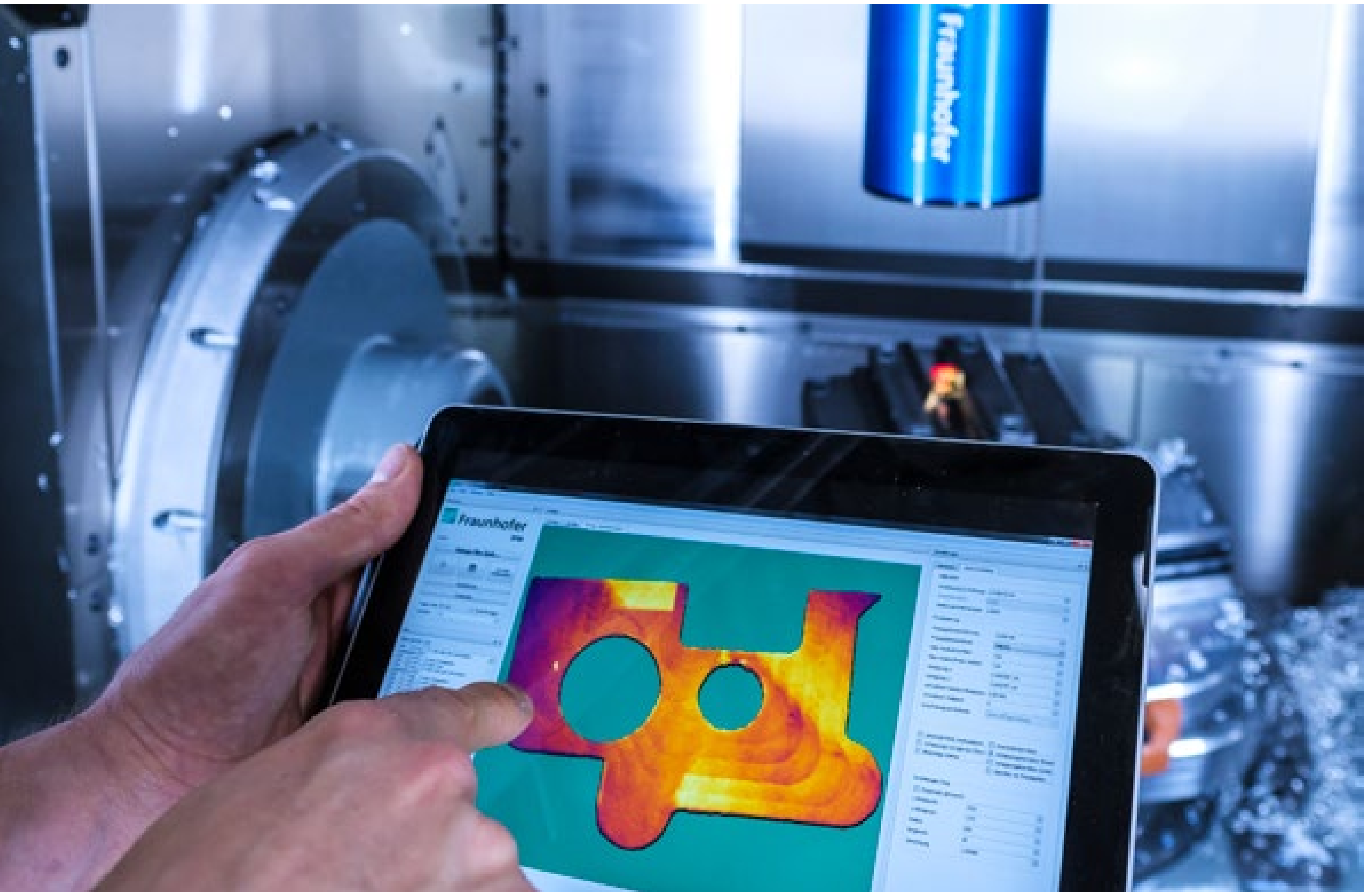
parts2clean
Leading International Trade Fair for Industrial Parts and Surface Cleaning
October 11 –13, 2022

Fraunhofer Vision: Technology Days
October 19 –20, 2022

EuroBlech
International Sheet Metal Working Technology Exhibition
October 25 –28, 2022

Focus Custom mass production

As production processes evolve, flexible and innovative solutions are required for the complete quality control of the future.



Measurements with micrometer precision: Our digital-holographic measurement system inspects precision components while they're still in the machine tool.

As it stands, production and assembly processes follow a strict workflow. But the world of industrial production is set to change, with processes being digitalized and products being customized more and more. Batch Size 1 is not uncommon. With so much being made to measure, quality control needs to move beyond the realms of random sampling.

New challenges – new approaches

When it comes to production and quality assurance, one thing is clear: We need new technological approaches. But is there a way to make production flexible and autonomous without having any knock-on effects on efficiency and quality? This question is at the heart of the work we're doing within our Production Control business unit. And our systems are already providing significant added value when it comes to handling, traceability and quality assurance within production processes.

Custom components – custom tracking and tracing

When working on highly specific products within the likes of the medical or automotive sectors, the standards for documentation are very high and fault tolerance is minimal. Full traceability is required all the way back to the start of the value chain – and customization is important here too. Fraunhofer IPM has developed its Track & Trace Fingerprint method in response to this need, allowing for traceability of individual products without markers. A fast, camera-based reading system is the key component. It generates a high-resolution image of the microstructure of the component surface. The image data is then used to generate a numerical identification code, providing each component with its own digital signature. All the data from the production and quality assurance processes can be matched to the component's digital twin in a central database. This fingerprint is generated so quickly that the data can be assigned at the rate of production, meaning there is no risk of slowing down the production process.

Flexible inline quality assurance

Checks on semi-finished and finished products pose another challenge. Inline-capable measurement systems are a basic requirement whenever all functional surfaces need to be fully inspected. Digital-holographic measurement techniques developed by Fraunhofer IPM make it possible to take highly accurate measurements in the most challenging conditions – even on the production line or in a machine tool. A sensor that takes comprehensive measurements can be used for workpieces in a processing machine – directly at the hollow shaft taper interface, where they'll already be held in place for processing. It delivers millions upon millions of individual points in a matter of seconds, with repeatability down to the sub-micrometer. This comes with major advantages. There is less chance of faults occurring because the workpieces don't need to be set up multiple times and the measurement time is much shorter compared to the cumbersome process involved with coordinate measuring machines. Quality and efficiency are improved as a result

Research with other Fraunhofer Institutes

We're contributing our expertise in custom component traceability and full inline checks to the Fraunhofer SWAP lighthouse project, for example. The aim of the project is to optimize production processes so they are running at full capacity and flexibility, by combining modular units in different swarms of tools, machines, measurement and test equipment, and vehicles. One strand of the project is focused on combining component handling, identification and inspection. The idea is for mobile robotic systems to pick individual components, automatically identify them using Track & Trace Fingerprint, and fully inspect them using measurement systems installed on the mobile platform. Components are then moved on to the next station. In the future, individual components are set to be able to make their way through the production process on their own, with fully automated quality control being performed on all components in a final step within the production line.

Production optimization with AI

Machine learning is key here. The quality control results are assigned to each component's digital twin to act as the base data required to analyze and optimize the production process. These insights can be applied to other product variants by means of transfer learning. Over the long term, a machine learning model can be applied to any process, without the need to start from scratch for each individual production line.

"We're on a mission to fully inspect every component as part of the production process."

Dr. Daniel Carl, Head of Department

Fraunhofer Group Production Lighthouse Project SWAP

Overview Object and Shape Detection

The automation of 3D data collection and processing is our contribution to the digitalization of our environment.

Our Object and Shape Detection business unit is focusing on the entire process chain for the automated mapping, referencing, interpretation and visualization of the geometry and position of infrastructural objects. We develop measurement systems, mainly laser scanners, and custom lighting and camera systems for mapping objects and shapes three-dimensionally with extreme speed and precision – mostly from moving platforms. Typical measuring ranges are between a few centimeters to hundreds of meters.

Measured data is evaluated in a fully automated process and interpreted by specially developed software. To this end, we employ techniques from the field of artificial intelligence (AI), such as deep learning. Data that is processed and visualized for specific applications provides a sound basis for planning, which is particularly important where infrastructure is concerned, for instance.

Fast, precise and robust sensors

Miniaturized measurement systems

Data interpretation software

Our groups and focus areas

Mobile Terrestrial Scanning

- Rail systems
- Road systems
- Systems for meteorological applications

Airborne and Underwater Scanning

- Systems for unmanned aerial vehicles
- Systems for underwater applications
- Systems based on low-cost and consumer products

Smart Data Processing and Visualization

- Real-time visualization of spatial data
- Creation of synthetic measurement data
- Flexible function libraries
- Platform-independent systems

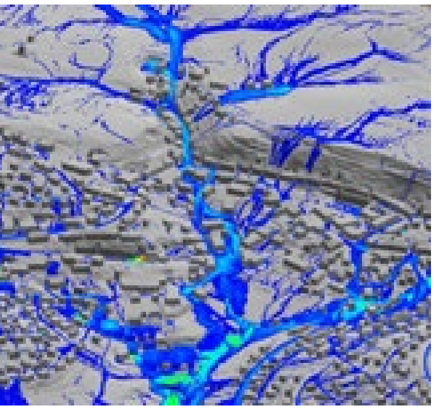
"We cover the entire process chain for 3D data collection."

Prof. Dr. Alexander Reiterer, Head of Department

Highlights Object and Shape Detection

Projects · Innovations · Events

AI helps us to simulate heavy rainfall.



The flow depth, rate, and direction of heavy rainfall can be simulated in a 3D micro model.

3D-HYDRA project

Heavy rainfall: 3D micro models as basis for flood maps

What risks does heavy rainfall pose for a specific area? Flow simulations generated using 3D models calculate flood dynamics and can be used to run risk assessments and develop protective concepts. As it stands, simulations tend to be based on image data typically gathered using aerial cameras and analyzed in half-meter sections. But it's not precise enough to reveal the finer structural details of the terrain, which can't then be incorporated into forecasts.

Laser scanners attached to drones are a more effective source of data because they also pick up the details of typical urban features like walls, pavements, facades and underpasses. And yet it's far from easy to analyze the 3D point clouds generated by a scanner. As part of the 3D-Hydra project, Fraunhofer IPM is working with industrial partners to develop AI-based object recognition that uses data gathered on drone flights to automatically generate 3D micro models including metadata. AI-based algorithms are used to transfer the data to a streamlined 3D model as well as to analyze and semantically enrich it. The 3D models are set to speed up the generation of flood risk maps and improve their accuracy.

Funded by the Ministry of Economic Affairs, Labor and Tourism of Baden-Württemberg (AI innovation competition)

DVW e.V. winter lecture series

Who's afraid of artificial intelligence?

Artificial intelligence is creeping into more and more aspects of our lives and routines. And it now has an important role to play in geodesy too. Our colleague Prof. Dr. Alexander Reiterer explained the potential of using AI in this field in an online guest lecture as part of the winter lecture series organized by the German Association for Geodesy, Geoinformation and Land Management (DVW e.V.) back in December.

During his session called 'Measuring the world – can Artificial Intelligence do a better than people?', he discussed the huge volumes of data to be processed, complex learning algorithms and the current state of the art. Using the example of analyzing mobile mapping data with AI, he explained how measurement data can be processed quickly and reliably using artificial intelligence. He also looked at the prospect of machine learning methods becoming a standard development tool to make people's work easier in future.

AI-based modeling is set to help better protect people and infrastructure in cities against extreme weather conditions.

I4C project – intelligence for cities

AI toolbox to help cities in face of climate change

Extreme weather conditions – including heat waves, heavy rainfall and storms – hit social and commercial centers in towns and cities particularly hard. Within the scope of the I4C project, Fraunhofer IPM is working with Fraunhofer ISE, the University of Freiburg and other partners to research AI-based approaches to construction project planning and risk prevention with the climate crisis in mind. Taking the city of Freiburg as an example, the team working on the project is developing an AI-based process chain that will improve the predictions made about risks, covering every step from collecting and analyzing data to running environmental impact assessments and taking specific action. The starting point is a 3D model of the city that can be linked to weather forecasts and climate simulations. Bringing in machine learning, the model can be used to identify groups of people, trees and buildings that are most vulnerable to certain extreme weather conditions. The AI toolbox will make it possible to assess local environmental risks in future – even identifying at-risk buildings – and will deliver the data required to adapt construction project plans to account for those risks.

Funded by the Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) ("AI lighthouse projects for the environment, climate, nature and resources" initiative)

GOSAIFE project

Road safety with AI

Navigation systems guide road users safely to their destination, with congestion and other dynamic situations being factored into planned routes. But something has always been missing – road safety information. The kinds of risks posed by road damage and dangerous crossings are not recognized. The goal of the GOSAIFE project completed in 2021 was to add this aspect to existing navigation systems using artificial intelligence (GOSAIFE project, AI-based safety assistant for navigation systems).

We joined forces with three partners on this project to develop a demonstrator system that collects and analyzes road traffic data. This data is collected by our MUM mini mobile mapping system. An artificial neural network goes on to analyze the GPS-referenced data and automatically identifies potentially dangerous objects and situations. The risk score determined on the basis of that data can be fed into navigation applications and potential hazards can be shown on a map.

Funded by the Ministry of Economic Affairs, Labor and Tourism of Baden-Württemberg (AI innovation competition)

"

AI will just be another tool in our toolbox in future."

Prof. Dr. Alexander Reiterer, Head of Department

COGNAC Fraunhofer lighthouse project

Multispectral camera detects plant condition

What condition are the plants and soil in? Are the plants at risk of pests and diseases? Is the soil rich enough in nutrients? For centuries, answers to these typical agricultural questions have been based on sound judgment and experience. The COGNAC (Cognitive Agriculture) project has brought together eight Fraunhofer Institutes to work on technology designed to digitalize and automate agriculture.

As part of this project, Fraunhofer IPM has been developing a measurement system that can detect the condition of plants and their height from the air. Three cameras installed on a UAV platform take up to five images per second. The images taken by the 12 megapixels RGB camera and two 5.5 megapixels monochrome cameras are much more detailed than the images taken by any other system already available on the market. They provide insights into plant health, with a LiDAR sensor also measuring the height. Farmers can respond to any stunted growth revealed by the measurement data before it's too late. The prototype of the camera system weighing just 650 grams was tested in 2021 and the measurement results were promising. With the project scheduled to end in fall 2022, the main objective now is to optimize the LiDAR module, which needs to be able to work effectively even when it's foggy or raining. A GNSS positioning system is also due to be integrated.

The Gas and Process Measurement Technology business unit has created a laser-based spectrometer for high-precision measurements of low concentrations of N_2O at ground level within the context of the COGNAC project.

Funded by the Fraunhofer-Gesellschaft (Lighthouse project)

Plant conditions and growth are detected from the air by cameras and LiDAR – with more precision than ever before.

MuSe3D project

High in the sky: monitoring vegetation from the air

Woodland, marshland, and agricultural land are all being thrust into the spotlight by the climate crisis. The best way to monitor the condition and vegetation of these large areas is from the air, but the size and weight of most of the systems available make it difficult to gather data in this way. As part of the MuSe3D project (focusing on multispectral and 3D monitoring of vegetation by UAVs), Fraunhofer IPM partnered up with Remote

Sensing Solutions GmbH and others to develop a compact, lightweight camera system for drones, which can be used to take multispectral images and map 3D geometries in a short space of time for this very purpose. The integrated software allows for data to be analyzed and classified too. Over the past year, the project has delivered an interactive 3D map of the Kochelsee marshland near Benediktbeuern – one of the biggest areas of marshland in the south of Germany.

Funded by the EUREKA European Network (Eurostars Program)

An interactive 3D map of the marshland in the Benediktbeuern area offers insight into its condition. It was generated by our project partner Remote Sensing Solutions as part of the MuSe3D joint research project.

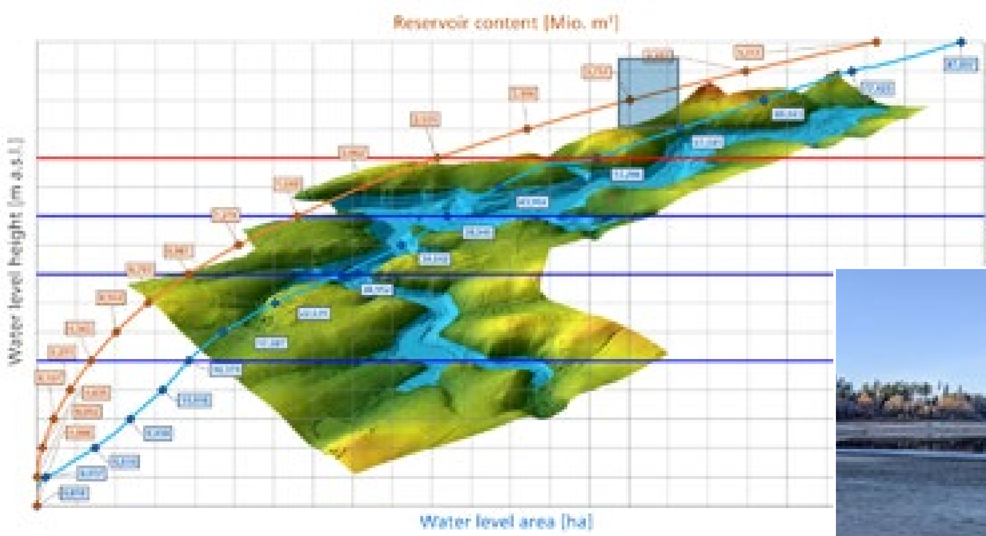
Reservoir surveying

High-end measurement technology delivers high-precision 3D data

After the disastrous floods in the Ahr Valley, all eyes were on the crucial role of dams and the dangers associated with them. Dams were already subject to strict monitoring in Germany beforehand, but it's difficult to collect data on the basin in the first place and it's often not detailed enough. Fraunhofer IPM and GEO Group GmbH worked together to test out a new concept at the Liebensteinspeicher reservoir in Bavaria. By combining several high-end measurement techniques, the project partners managed to successfully conduct a full survey of the reservoir with unprecedented precision.

While GEO Group surveyed the lake with an echo sounder on a boat, researchers from Fraunhofer IPM used the Lightweight Airborne Profiler developed at the institute to collect data from the air. The measurement system consists of a laser scanner, several cameras and positioning sensors, which are all very light and can be fitted to a drone. When collated, the combined data could be used for high-precision calculations, delivering a 3D model, a filling level curve and plans for the water level area and reservoir depth.

Combination of LiDAR and echo sounder measurement technology



High-precision data: Fraunhofer IPM worked with GEO Group to conduct a full survey of the Liebensteinspeicher reservoir in Bavaria.

In a class of its own: The camera system on our geomapping vehicle delivers georeferenced panoramic images with a resolution of 180 megapixels.

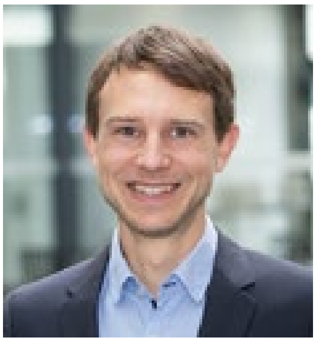
Mobile mapping vehicle

Six cameras for a high-definition 360° panorama

Cities and municipalities need surveying data to be as accurate as possible to allow for roads and buildings to be analyzed, planned and maintained. A geomapping vehicle, developed for Geotechnik GmbH, is setting new standards for the resolution of georeferenced panoramic images. The camera system installed on the roof of a small van delivers images with a resolution of 180 megapixels – that's six times the state of the art!

Six RGB cameras generate images of the surroundings at a frame rate of up to 8 Hz when the van is traveling at up to 140 km/h. Plus there are two panoramic cameras and a laser scanner providing additional depth information. A specific geometric camera arrangement and accurately synchronized data collection are required for the individual images to be combined to form one panoramic image. The high data rates of up to 4 GB per second also rely on highly optimized software and data handling strategies. The system has been designed to be able to accommodate thermal imaging cameras in future. Thermographic images provide key information on the energy efficiency of existing buildings.

"We are setting new standards for the resolution."



Dr. Philipp von Olshausen, Group Manager

OpOrTunIty project

Efficient tunnel inspection with multispectral laser

When it comes to monitoring the condition of tunnel structures, a combination of measuring methods is required, involving cameras, static laser scanners, tactile measuring equipment and visual checks. Thanks to a multi-sensor system developed by Fraunhofer IPM with Amberg Technologies AG and software partners as part of the OpOrTunIty (Operation oriented tunnel inspection system) project, tunnel inspections are set to be much more efficient in future. The tunnel inspection system TIS measures the geometry, surface structure and humidity all in one go to start with – and with accuracy down to the millimeter.

The key component of the sensor is a laser scanner that scans the tunnel wall at an angle range of almost 360° and generates up to 200 full measurement profiles every second. Multiple lasers with different wavelengths are superimposed and directed at the tunnel wall for measurements to be taken. The distance data is used to determine the 3D geometry of the tunnel, while the intensity of the backscattered light reveals structural features like cracks.

The humidity is measured by combining light from two lasers with specific wavelengths, which is characteristically absorbed by water.

Object and Shape Detection | Trade Fairs & Events

Online Forum on LiDAR and mobile mapping

In 2021, we held three online forums as part of our virtual event series:

- Trends in mobile data collection, October 14, 2021
- Trends in 2D and 3D image analysis, November 4, 2021
- Special applications, November 25, 2021

Events in 2022

Oceanology International
March 15–17, 2022

SMM
The leading international maritime trade fair
September 6–9, 2022

InnoTrans
International trade fair for transport technology
September 20–23, 2022

Intergeo
The Measurement Fair
October 18–22, 2022

MoLaS – Mobile Laser Scanning Technology workshop
Internal event
November 23–24, 2022

Measurement data is available in digital form, enabling it to be used for building information modeling (BIM) processes.

Funded by the Federal Ministry of Education and Research (BMBF) and the EU (Eurostars Program)

High-tech on a trolley: Our system measures geometry, surface structure and humidity all in one go.

Focus Digital 3D models

Digging in progress: Underground structural elements can now be recorded digitally for documentation purposes.

Our AI-based system generates georeferenced data required for documenting underground infrastructure.

Excavators have been let loose on the streets of Germany, with roads and pavements everywhere being dug up so that fiber-optic cables can be installed and pipelines can be upgraded. Once the job has been done, the ground is covered back over and nobody has any idea what has been installed where or how deep in the ground it is. What are the potential consequences? Regular power outages, disrupted internet connections and even gas explosions in the worst case scenario – and all because cables and pipelines are accidentally damaged by excavators at work. None of this would be a problem if the underground infrastructure were documented with careful precision. To this day, the location of structural elements underground tends to be roughly sketched by hand and entered manually into a geographic information system (GIS). This whole process is time-consuming and the information is often incomplete because details on depth in particular are not documented in full.

Mobile data collection with low-cost sensors

Fraunhofer IPM has worked in partnership with grid operator Bayernwerk Netz GmbH to develop a tool for creating a 3D digital picture of excavated areas, ensuring that all the information can be documented accurately and efficiently. A standard tablet is used to collect data and the TrenchLog software developed internally at the institute takes care of automated data analysis. The whole process is straightforward and doesn't require any specialist knowledge. The person conducting the survey holds the tablet and takes photos as he or she walks along the excavated area. Those images will later be used to generate a 3D point cloud. Equipped with a commercially available stereo camera system and an inertial sensor, the device accurately records data with a tolerance of 20 centimeters over a distance of 50 meters. A visual SLAM (simultaneous localization and mapping) algorithm is used for 3D reconstruction, ensuring that all data streams can be used in combination as effectively as possible. During the development phase, the team tested out the system in an excavated area on the institute's own site.

Control points for georeferencing

The measurement data is linked to the global navigation satellite system (GNSS). When it comes to georeferencing, the fact that the surfaces of cables and pipes are more or less all the same makes it difficult to identify individual reference points. With that problem in mind, the team relies on their own weather-resistant control points, which they temporarily attach to building walls and junction boxes. These reference points are included in the measurements, meaning that position measurement can be accurate to within a few centimeters. And they serve another purpose. Pipelines are often installed in long stretches, but it's not always possible to measure excavated areas spanning meters and meters in one go. Measuring in installments can be confusing, but sections can be overlapped when being documented if additional control points are put in place. The measurement data can then be collated to create one continuous image at a later stage.

Automatic detection of typical structural elements

If structural elements are to be documented properly, the type and quantity needs to be recorded alongside the location of cables, pipes and connectors underground. The TrenchLog software tool can pick these objects out of the measurement data and count them as soon as the data has been collected. This is possible because a deep learning algorithm was trained with previously defined types of objects, including pipelines and cables with different diameters and all kinds of connectors. The algorithm is part of an artificial neural network that has been trained with a comprehensive data set featuring relevant images. New elements can be added to that data set, depending on what needs to be documented.

A set of heuristics is applied to the data to reduce the number of image recognition errors. Data storage also needs to be optimized for the collection and analysis processes to run smoothly. For example, the point cloud is reduced to a fixed minimum distance between points to reduce the volume of data. Areas that overlap in images are not analyzed to speed up the process.

Visualization and image correction

The fact that the tool is easy to use also comes down to the clear presentation of the measurement data. The team developed a visualization component to ensure an undistorted 3D reconstruction based on the point cloud. The intuitive user interface allows for plausibility checks, manual corrections and data uploads to the cloud. This system is designed to cover stretches of up to 50 meters. And every meter counts on the journey to fully document thousands upon thousands of kilometers of trenches containing underground pipelines and cables that are excavated and covered over again through the years.

As simple as that: Data is collected using a standard mobile device. No specific prior knowledge is required to get the job done.

"We're seeing power and fiber-optic networks being expanded up a lot at the moment. Our tool helps by making 3D mapping efficient."

Dr. Christoph Werner, Group Manager

Overview Gas and Process Technology

When it comes to modern gas and process monitoring, we develop tailored measurement systems and methods.

Within our Gas and Process Technology business unit, we develop and produce measurement and control systems to fit our clients' briefs. Short measurement times, extreme accuracy and high levels of reliability are the hallmarks of our systems – no matter how extreme the conditions.

Our areas of expertise include laser spectroscopy methods, custom light sources and detectors, and energy-efficient sensor systems and quantum sensor technology. And we cover a wide range of applications, ranging from exhaust gas analysis and food transit monitoring to sensors and systems used to measure minuscule temperature differences.

Miniaturized sensors and systems

Spectroscopy methods

Quantum sensor methods

Our groups and focus areas

Integrated Sensor Systems

- Gas-sensitive materials
- Micro-optic infrared components
- Miniaturized gas sensor systems

Thermal Measurement Techniques and Systems

- Customized microstructures
- Thermal measurement systems
- Simulation of physical processes

Spectroscopy and Process Analytics

- Spectroscopy analytics
- Optical systems
- Evaluation methods

Nonlinear Optics and Quantum Sensing

- Nonlinear optics
- New spectroscopic measurement techniques
- Quantum sensor technology

"

Our expertise opens doors for gas and process measurement technology."

Prof. Dr. Jürgen Wöllenstein, Head of Department

Highlights Gas and Process Technology

Projects · Innovations · Events

TransHyDE project

Sensor concepts for a safe hydrogen infrastructure

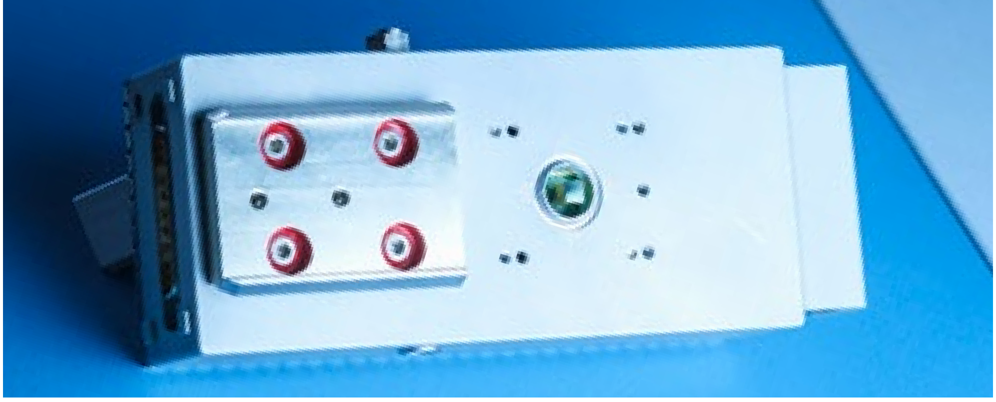
One gas, multiple measurement concepts. As part of the TransHyDE project, three Fraunhofer Institutes have joined forces with industrial companies to research sensor concepts and materials for a safe hydrogen (H_2) infrastructure. Our researchers have been developing and testing innovative measurement technology solutions for detecting leaks, measuring H_2 gas quality and analyzing impurities in hydrogen gas mixtures since spring 2021.

- A self-testing sensor is set to detect H_2 on the basis of a combination of specific thermal conductivity and sound velocity measurements.
- With the aim of continuously measuring the gas, the researchers have been working on a compact system with a cost-effective optical measurement technique involving Raman scattering.
- Infrared images together with image analysis by laser spectroscopy are set to enable contactless, imaging-based detection of H_2 and NH_3.
- Colorimetric sensors will make it possible to detect hydrogen with the naked eye in future. This technique will rely on a special paint that changes color when it comes into contact with the gases.
- A photoacoustic sensor system is set to detect traces of impurities in hydrogen. And a natural gas analyzer will be equipped with a H_2 thermal conductivity sensor to make it possible to determine the proportion of H_2 in natural gas mixtures and in turn the calorific value.

Lighthouse project TransHyDE

Funded by the German Federal Ministry of Education and Research (BMBF) (hydrogen lighthouse project), Projektträger Jülich (ptJ)

Hydrogen measurement techniques are covered in more detail from page 56 onwards



A technology platform has been created as part of the PaSIC project so that miniaturized IR components can be produced.

PaSiC project

New manufacturing procedure for miniaturized gas sensors

The market for gas sensors for occupational safety, environmental analysis and air quality monitoring is growing – and the demand for cost-effective, energy-efficient sensors with long-term stability is growing with it. The PaSiC project has seen Fraunhofer IPM work with research and industry partners to develop a technology platform for the creation of ceramic and silicon composites that can be used in miniaturized IR components for the first time (PaSiC project, silicon/ceramic hybrid substrate as an integration platform for photoacoustic and optical applications).

This will allow for the production of highly integrated photoacoustic and optical gas sensors in future. Components and sensors are produced on a silicon and ceramic composite substrate (SiCer) as a microsystem in wafer form. Our team has been developing a photoacoustic detector element, with thermal and optical simulations also being relied upon. An IR spectrometer adapted in-house is used to check the long-term impermeability of the composite material in the detector cells. We perform spectral and gas-dependent characterization with our gas measuring equipment.

Funded by the German Federal Ministry of Education and Research (BMBF) (HyMat, hybrid materials – new possibilities, new market potential funding initiative)

smartFire Project

Staying smart and stopping fire in its tracks

Electronic appliances and electrical devices are often the cause of fires breaking out. Combustion gases like toxic carbon monoxide (CO) are formed before any smoke appears. With that in mind, fire sensors should be placed as close as possible to the ignition source and should ideally detect typical combustion gases rather than smoke. Within the scope of the smartFire project, Fraunhofer IPM has been working with European sensor manufacturers and research partners to develop a colorimetric CO sensor that can be integrated into smart home networks. The objective is a reliable sensor which will take selective measurements over the long term and, most importantly of all, can be produced at a reasonable price in view of the large number of electrical devices found in private households. Our team has been developing a gas-sensitive dye for the sensing element and a printing technique that can be used to apply the gas-sensitive layer to the detector chip. The sensors are tested in different ambient conditions, such as different temperatures, humidity levels and gas compositions.

Funded by the EUREKA initiative (Eurostars program)

CO sensors can save lives.

Trace gas analysis with photoacoustics

What's the sound of methane?

Gases like methane can be detected selectively and to a high level of accuracy thanks to laser-based photoacoustics. Our researchers have been working on refining this technology as part of several research projects in 2021 with a focus on sensitivity, cost efficiency and the miniaturization of photoacoustic systems. The result was new measuring devices and new gas detection techniques.

The EU RedFinch project (mid-infrared fully integrated chemical sensors) resulted in Fraunhofer IPM developing a demonstrator for a mobile methane leak detector based on a miniaturized photoacoustic measurement cell. The PaMeSan project at the University of Freiburg involved us assisting with the development of an ultra-precise miniaturized system that can reliably detect methane in the ambient air. A MEMS microphone – also found in smartphones – is at the heart of that technology. The miniaturized sensors can selectively measure and detect gases like methane in the ppm and ppb range.

RedFinch: Funded by the EU (Horizon 2020)
PaMeSan: Funded by the Vector Foundation

Looking for leaks: Tobias Kolleth with the mobile, photoacoustic methane detector developed as part of the RedFinch project.

QUILT Fraunhofer lighthouse project

Quantum FTIR: Quantum optical version of FTIR spectrometer

What can be done to make wavelength ranges like infrared, UV and THz visible to the human eye and standard cameras when they are normally difficult to access? That was the question facing the researchers from six Fraunhofer Institutes working on the QUILT project (QUILT project, quantum methods for advanced imaging solutions).

As part of the QUILT project, Fraunhofer IPM developed the world's first quantum FTIR. As a quantum optical version of the standard Fourier transform infrared (FTIR) spectrometer, it can be used to conduct high-precision gas measurements for process analytics and other purposes. It's based on the phenomenon of entangled photons, whereby light particles are coupled when they're created and remain connected over wide spectral ranges. This way, it's possible to obtain information about an infrared photon interacting with a sample using its partner photon in the visible spectrum. This partner photon can be measured using a silicon detector.

The team presented the technology (patent pending) as a demonstrator system at LASER & World of Quantum 2022. Looking ahead, the aim now is to improve the detection sensitivity even further and add imaging to the system.

Funded by the Fraunhofer-Gesellschaft (lighthouse project)

AIMS³ project

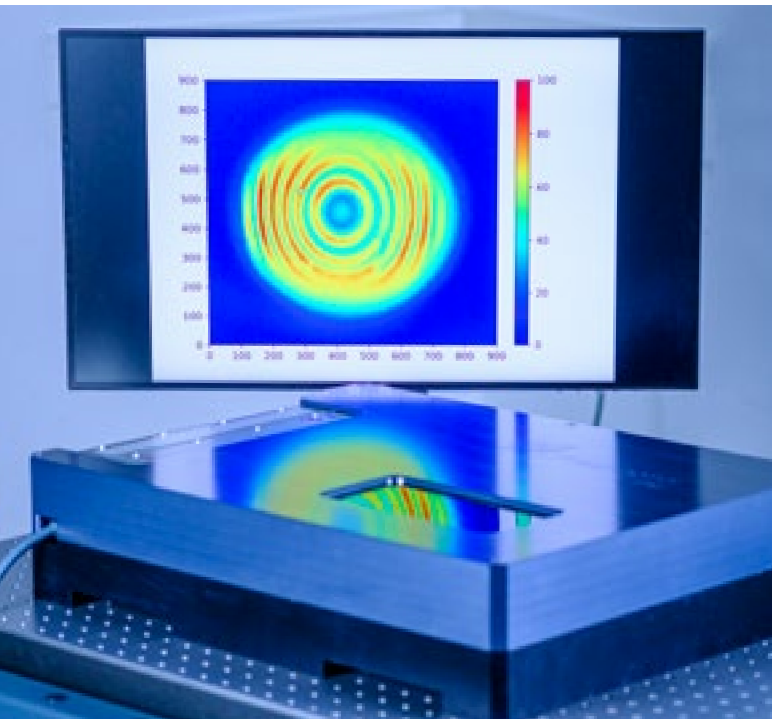
CO_2 sensor for deep-sea applications

The power of the sea to store carbon is astonishing. And it could prove to be highly advantageous in our efforts to reverse the climate crisis. Researchers working on the AIMS³ project have been looking into ways of storing CO_2 in oceanic basalt formations. But they have to proceed with the utmost caution to ensure that any resurgence of carbon dioxide and changes to the surrounding marine ecosystem can be detected immediately. The experiments have therefore been accompanied by extensive simulations, tests and measurements.

Fraunhofer IPM has been developing a CO_2 sensor for deep-sea applications for that very purpose. It is based on ATR spectroscopy and relies upon the principle of attenuated total reflectance (ATR). On the basis of this method, the sensor detects the amount of CO_2 dissolved in seawater within a matter of seconds, which is much faster than standard measurement systems that work in minutes rather than seconds. For monitoring the experiments on CO_2 storage, sensors measuring important parameters are mounted on underwater vehicles (landers) or on tow lines. This allows relatively large areas to be checked for e.g. possible leaks or changes in CO_2 concentration with spatial resolution. Beyond the scope of this project, the newly developed sensor is also set to be used for monitoring of CO_2 reservoirs. The AIMS³ project (focused on alternative scenarios, innovative technologies and monitoring solutions for storing carbon dioxide in oceanic crust) is part of the CDRmare Mission of the German Marine Research Alliance (DAM).

Funded by the German Federal Ministry of Education and Research (BMBF) (MARE:N – coastal, marine and polar research for sustainability research program)

The world's first quantum Fourier transform spectrometer for high-resolution, sensitive spectroscopy



"The Q-FTIR represents an important milestone in photonic quantum sensor technology."

Dr. Frank Kühnemann, Group Manager

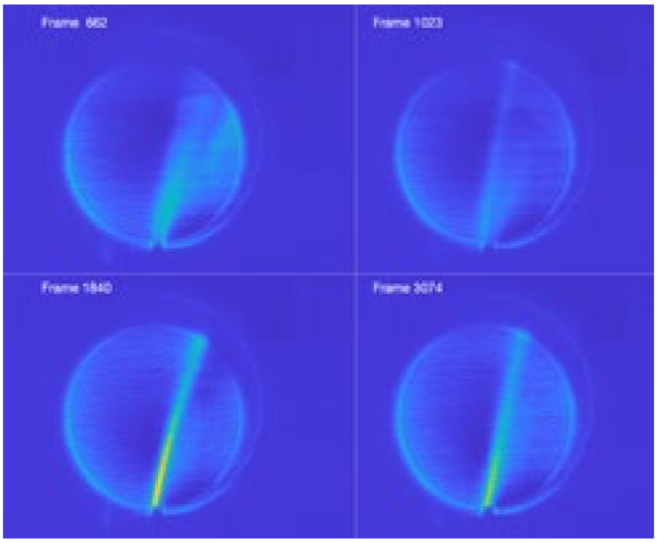
RISK project

New concepts for imaging gas detection

Gas leaks are usually detected using absorption spectroscopy. But Fraunhofer IPM researchers decided to try out a new approach as part of the RISK project, with a view to improving sensitivity when detecting gases. They developed a structure combining the imaging methods of traditional Schlieren method with laser technology for the infrared range.

The researchers managed to significantly improve the sensitivity with which leaking methane was measured during their initial experiments. The results of their research have already been described in a scientific publication, with another article in the pipeline.

Funded by the Fraunhofer-Gesellschaft (Discover project)



Good signal: A combination of traditional Schlieren method and IR laser technology is the key to improving the sensitivity of imaging gas detection.

OCTOPUS project

Ground control: light source for calibrating satellite instruments

Earth observation satellites provide researchers with valuable data. They are equipped with optical instruments that need to be accurately calibrated if measurements are to be performed properly in space. Working on behalf of the European Space Agency (ESA), Fraunhofer IPM has been developing a laser system to improve the calibration of optical measuring devices prior going into orbit. The laser-based light sources used for this purpose until now have not been as reliable or flexible as they've needed to be to get the job done effectively in practice.

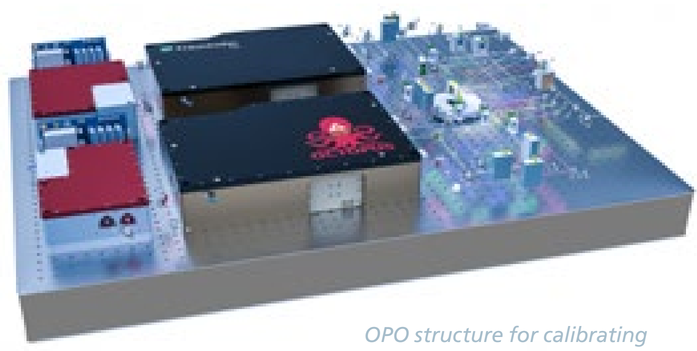
OCTOPUS

And so researchers are now relying on optical parametric oscillators (OPOs) as light sources. OPOs are unlocking specifications that have been out of bounds before – from the visible to the infrared spectrum. The C-WAVE and C-WAVE GTR OPO systems developed in partnership with HÜBNER Photonics are making that much clear (read the interview on page 22). The OPO that is being developed by the team working on the OCTOPUS project is also set to be tunable – fully automatically – from ultraviolet to shortwave infrared (300 to 2400 nanometers), emitting narrow-band laser light. The compact system requires little maintenance and has a modular structure, which allows for it to be moved around and integrated into various test settings (OCTOPUS project, optical calibration tool: optical parametric ultra-wide tunable source).

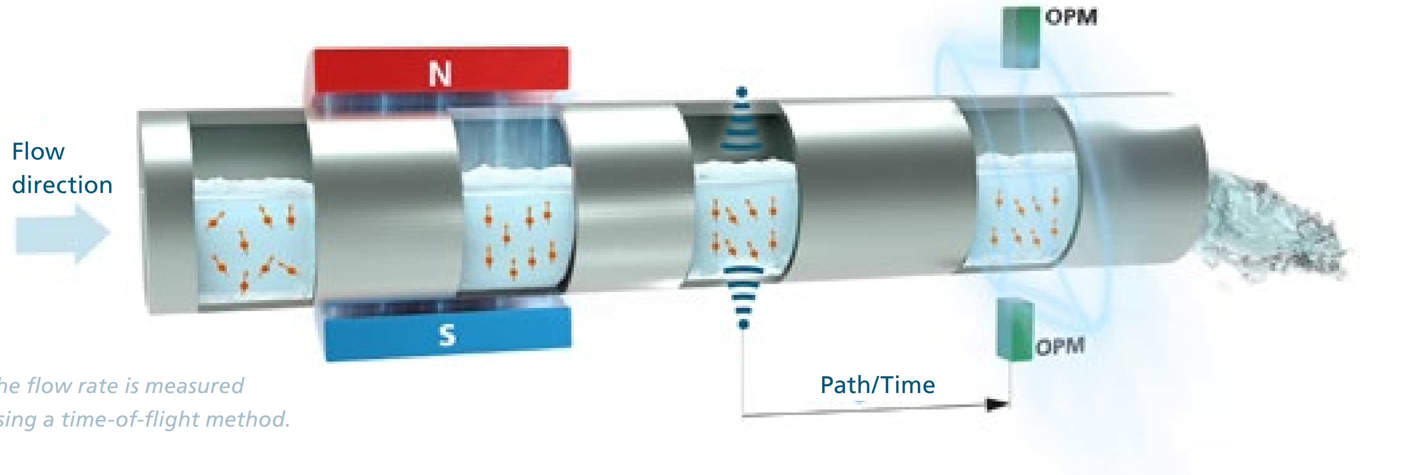
Spectrometer Ratiospect 2.0

Tool for molecular plant physiology

How do plants perceive light? The answer lies in their light-sensitive proteins, called phytochromes. Ultra-sensitive measurement technology is required to measure the reaction of phytochromes to light. The Ratiospect 2.0 optical absorption spectrometer developed by a team at Fraunhofer IPM on behalf of the University of Freiburg (chair of Molecular Plant Physiology) allows for a much quicker and more accurate measurement of light-sensitive plant protein concentrations than ever before. The spectrometer "switches" phytochrome molecules by laser exposure and measures the resulting characteristic transmittance changes. Ratiospect 2.0 measures transmittance changes from 100 percent to 99.999 percent and from 1.0 percent to 1.0001 percent in as little as just a few seconds. The equipment functions automatically, covering everything from handling the plant samples and taking measurements to processing and documenting measurement data.



OPO structure for calibrating optical satellite instruments



The flow rate is measured using a time-of-flight method.

QMag project

Flow measurements with optically pumped magnetometers

How quickly does a liquid flow through a pipe? That's an important question in the world of process measurement technology. For the "QMag – Quantum Magnetometry" project, we're researching a novel flow measurement method based on nuclear magnetic resonance (NMR). Standard NMR-based measuring devices function with strong magnetic fields that are technically challenging to create.

The team at Fraunhofer IPM is now working with exceptionally weak magnetic fields for non-invasive flow measurement for the first time. Ultra-sensitive optically pumped magnetometers (OPMs) acting as detectors are making this possible. The process involves polarizing the liquid (water in the first iteration) using a magnetic field to start with. As it flows, the local polarization is changed locally by creating a high-frequency pulse, which provides a kind of "time stamp". The OPM detects this marker in a magnetically shielded environment. The time difference between the marker and detection can be used to calculate the flow rate without contact or calibration – even in steel pipes. In future, this method is also to be used to measure the flow rate of multi-phase flows.

Funded by the Fraunhofer-Gesellschaft (lighthouse project) and the state government

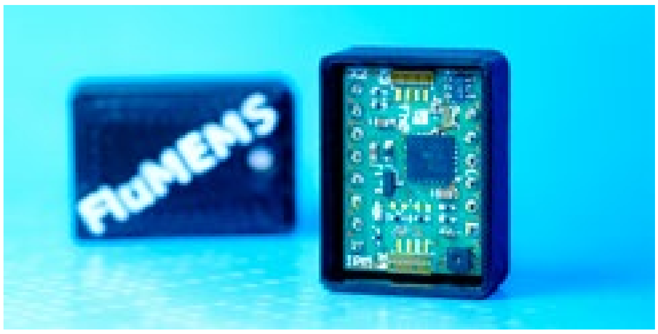
Scientific publication:
Noninvasive Magnetic-Marking-Based Flow Metering with Optically Pumped Magnetometers. Appl. Sci. 12, 1275 (2022)

Measuring stations

Sensors in extreme conditions

With high pressure, extreme temperatures and chemically aggressive media, things are often far from pleasant in many of the places where sensors are put to use. Before sensitive sensor technology is deployed in industrial production settings, power plant turbines or boreholes, tests need to be performed to check that it can withstand the harsh conditions there. We've extended our Harsh Environment Laboratory (HE Lab) for sensor technology stress tests, with the plan to be able to measure relatively large components. That means we can now test components with a length of up to 13 centimeters and a diameter of 3 centimeters at temperatures of 200 °C and pressures of up to 2500 bar. When working on full sensor systems, the length can extend to one meter and the diameter can be as much as 12 centimeters. We perform hydraulically and thermally dynamic test cycles on components and full systems on our test rigs. There's also the option of energizing and reading out data on components and systems on the test rig as a way of quickly identifying any defects and working out their cause. The hydraulic working medium is water, which ensures that the corrosive conditions in wellbores or in the deep sea are represented realistically. But it's still possible to take measurements in other working media like oil.

Hydrogen (H_2) is a key stress factor for sensors and components since many materials become brittle when they come into contact with it. This makes H_2 conveying components and sensors less reliable. Our team has developed a H_2 test rig for exposing components and full systems to pure hydrogen and non-flammable or corrosive gas mixtures at pressures of up to 400 bar and performing dynamic or static tests. There is also the option of heating components and systems up to 200 °C to speed up aging processes. The systems can also be read out online as required.



Energy efficient and cheap to produce: the FluMEMS micropellistor (demonstrator)

FluMEMS project

Micro-pellistors for the detection of combustible gases

Catalytic sensors, or pellistors, monitor the concentration of combustible and explosive gases like methane, propane and hydrogen in industrial facilities, at gas stations and in domestic gas heating systems. For the FluMEMS project, we have worked with two other Fraunhofer Institutes to develop a smart micro-pellistor as a demonstrator, which operates at much lower temperatures than the systems available on the market and consumes much less energy (FluMEMS project, MEMS-based thermal catalytic sensors for gases and liquids).

The sensor, which is cheap to produce with MEMS technology, is to be integrated into a CMOS chip environment later in 2022. For the pellistor, Fraunhofer IPM developed novel catalytic materials that contain fewer precious metals and are resistant to catalyst poisons like siloxanes and sulfur compounds. This does away with the need for the additional filters previously required to avoid the catalyst layer being destroyed. Without those filters, the size on the demonstrator could be reduced to $17 \times 10 \times 25$ mm³. With full monolithic integration, there's even potential to further reduce dimensions – including evaluation unit and housing – to $4 \times 4 \times 8$ mm³.
Within the scope of FluMEMS and two other projects, the team has improved the energy efficiency of pellistors even further with smart readout procedures, while reducing cross-sensitivity and disruptive influences. For instance, integrating an additional thermal conductivity sensor has made it possible to take quantitative hydrogen measurements, which is usually limited with standard pellistors.

Funded by the Fraunhofer-Gesellschaft (MAVO, market-oriented preliminary research)

Gas and Process Technology | Trade Fairs & Events

9. Gas Sensor Workshop

The forum for the gas sensor community was held online for the first time ever (see page 17).
March 18, 2021

Sensor+Test Digital Area

The Measurement Fair
May 4–6, 2021

Systems for measuring gases, liquids and solids were showcased alongside functional materials for gas sensor technology, thermoelectric and optics.

Sensing with Quantum Light

WE Heraeus Seminar on Quantum Sensor Technology
September 26–29, 2021

Frank Kühnemann was the Co-Chairman, while the seminar and poster were the work of the QUILT team.

eHarsh seminar

Closing seminar for the Fraunhofer eHarsh lighthouse project
November 29–December 3, 2021
Expert lectures by Martin Jägle, Thermal Measurement Techniques and Systems

- Thermal-electrical impedance spectroscopy
- Set-up for high pressure tests at high temperature

Events in 2022

LASER World of PHOTONICS 2022
World's leading trade fair for components, systems and applications of photonics
April 26–29, 2022

Sensor+Test
The Measurement Fair
May 10–12, 2022

Achema
World Forum for the Process Industries
August 22–26, 2022

Futuras in Res – The Quantum Breakthrough
September 28–29, 2022

Focus Hydrogen measurement techniques

Due to the risk of explosion, systems carrying hydrogen require constant monitoring by sensors.

Hydrogen is a key component in the energy transition. Reliable, robust and cost-effective sensor technology is required for it to be used safely.

New sensors for a safe hydrogen infrastructure

There are high hopes for hydrogen (H_2) as an energy carrier for the future. While the gas is relatively easy to produce, there are some risks associated with its widespread use. After all, hydrogen is highly flammable. And many metals become brittle when they come into contact with the gas. That means there is a significant risk of leaks and, consequently, explosions. For hydrogen pipelines, storage tanks and supply points to be used safely, new sensor concepts are called for. The hydrogen sensors available today fail to meet the stringent requirements for measurement accuracy, service life and cost effectiveness imposed here.

Within our Gas and Process Technology business unit, we are working on multiple research projects dedicated to innovative hydrogen measurement technology. And the results are coming in the form of stationary and mobile sensors that can be used to monitor critical points in the hydrogen infrastructure – either constantly or as part of a strict strategy. These sensors need to be relied upon to accurately detect H_2 and the transport gas ammonia (NH_3) over long periods and in extreme conditions as well as to determine the absolute concentrations of the gases.

Industry collaboration

Alongside our work on sensor concepts relating to leak detection, we are developing and adapting measurement technology to determine gas quality working jointly with industry partners. Our researchers working on these projects are looking into a range of measurement techniques, while all focusing on the common goals of meeting the high safety standards associated with H_2 infrastructures and creating cost-effective solutions for comprehensive monitoring.

Plug and Measure: miniature H_2 sensor as a demonstrator

A hydrogen sensor was first created as part of the Fraunhofer H2D project that was completed in 2021. The compact sensor, which can be connected to a computer via a USB port, measures H_2 concentrations of 0.4 percent in air in under a minute. Produced with MEMS technology, this sensor doesn't use much energy and can therefore also be incorporated into battery-operated systems.

The sensor utilizes one of hydrogen's characteristics to detect the gas: H_2, like helium, has a high degree of thermal conductivity, which clearly sets it apart from all the other gases – and air in particular. In fact, hydrogen conducts heat seven times faster than air does, allowing even extremely low concentrations in air or other gases to be detected by thermal conductivity measurement.

Thermal conductivity detectors (TCDs) are nothing new in the world of gas detection. They are based around a heating element that doubles up as a temperature sensor. The heating power of the sensing element is proportional to the temperature and, consequently, the concentration of the gas owing to the high thermal conductivity of H_2. In other words, the temperature can be used to determine the concentration of hydrogen in a H_2-air mixture. TCD sensors measure at operating temperatures below 100 °C, putting them in a range that is significantly below the temperature at which hydrogen ignites (585 °C). What's more, TCDs cover a wide measuring range – from less than 1 percent to 100 percent hydrogen in air.

Commercially available TCDs are sensitive to interferences such as high humidity or draft – an absolute no-go when it comes to use within hydrogen measurement technology. The research team has compensated for this cross-sensitivity by introducing smart signal evaluation.

Fraunhofer IPM engaged in largest hydrogen research initiative

Innovative measurement technology solutions for detecting leaks, measuring H_2 gas quality and analyzing additional gas components in gas mixtures containing hydrogen are the intended product of the joint project called "TransHyDE_FP2: safe infrastructure." This is Fraunhofer IPM's contribution to the hydrogen lighthouse projects, which represent the largest research initiative of the BMBF to date, with funding amounting to 740 million euros (see page 50).

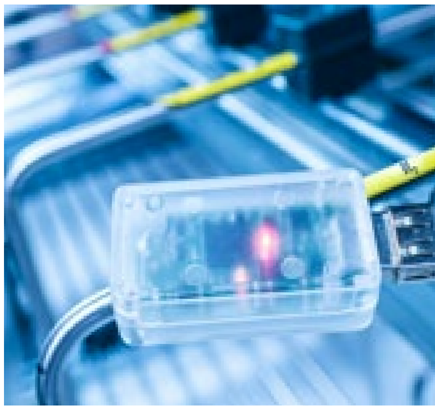
Mobile sensors for regular leak testing

Even in low concentrations hydrogen is flammable – in higher concentration the gas is explosive. That's why systems containing hydrogen have to be perfectly sealed – and stay that way for a very long time. Under the WALD project, we've been working with industrial partners since 2022 to develop a mobile H_2 sensor system that can be used to check that transportation networks and end consumer systems are free from leaks. The hand-held detection device for regular leak testing is being developed on the basis of two measurement principles combined. Intrinsically safe, the sensor will cover a wide measuring range and guarantee high measurement certainty.

H_2 sensor for fuel cell drives

Emission-free fuel cell systems operated with "green" hydrogen are set to be used primarily in powerful commercial vehicles in future. Bearing the stringent safety standards within the automotive industry in mind, highly robust and reliable H_2 sensors are an absolute must. As part of the HySABi project funded by the Federal Ministry for Economic Affairs and Energy (BMWi), we've been working with industrial partners since 2021 to develop a novel H_2 sensor system for exhaust gas systems on the basis of two complementary measurement principles. The sensors are integrated monolithically on a chip, meaning they don't take up much space or require much energy at all.

Read more about our hydrogen projects.



Small and sparing: The H_2 sensor, which measures just 6 × 2 cm² and can be connected to a computer, measures H_2 concentrations of 0.4 percent and above in air in under a minute.

"Widespread use of hydrogen simply isn't possible without robust, reliable and cost-effective sensors."

Dr. Carolin Pannek, Project Manager

Overview Thermal Energy Converters

We can pump and convert heat highly efficiently. That's our contribution to the cooling technology of the future.

The Thermal Energy Converters business unit researches technology for pumping, converting, transferring and controlling heat. We develop, design and assemble efficient thermal energy conversion systems, including caloric heat pumps and cooling systems based on magnetocaloric, electrocaloric or elastocaloric materials and thermoelectric modules and systems which use waste heat.

Moreover, we are conducting research on novel designs for efficient heat transfer based on heat pipes and heat pipe-based thermal switches for regulating heat flows.

Thermoelectric conversion of waste heat

Cooling with caloric systems

Heat transfer via heat pipe

Our groups and focus areas

Thermoelectric Systems

- Development of thermoelectric modules and systems
- Conversion of waste heat into electricity in the milliwatt to kilowatt range
- Innovative Peltier cooling
- Structural, thermal and electrical analytics of components and materials

Caloric Systems

- Heating and cooling without harmful fluids
- Development of magnetocaloric, elastocaloric and electrocaloric systems
- Development and characterization of heat pipes for thermal management

“We pump, convert, transfer and control heat – always adapting to novel applications.”

Dr. Olaf Schäfer-Welsen, Head of Department

Highlights Thermal Energy Converters

Projects · Innovations · Events

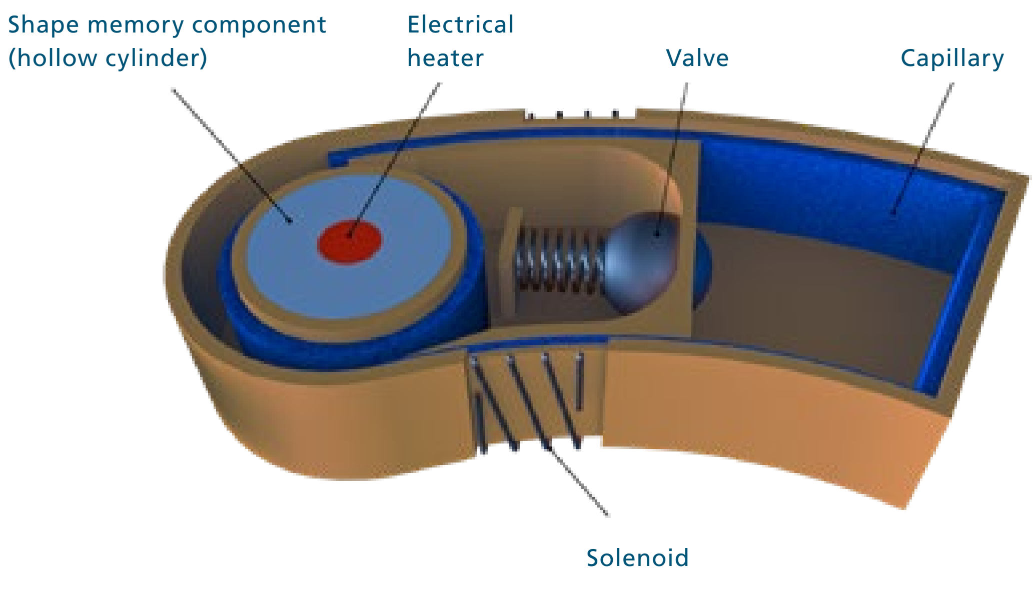
100 times faster heat release for actuators

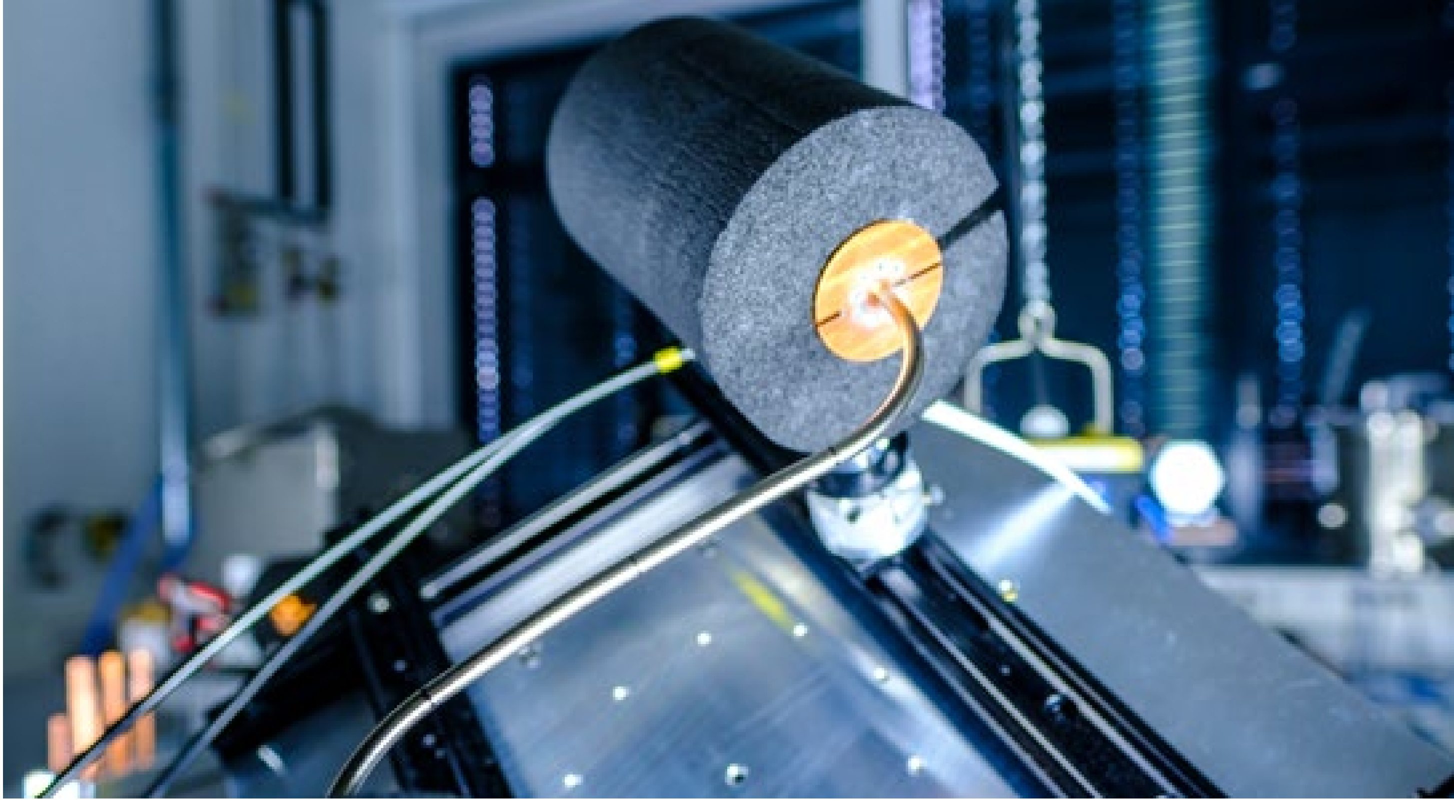
HochPerForm project

Switchable heat pipes for efficient cooling of shape-memory actuators

The displacement, power, frequency and size of an actuator varies depending on its type. Actuators based on thermal shape-memory alloys (SMAs) are high-performing drive elements. Compared to piezo, pneumatic and hydraulic actuators, they generate much more power within a small space and they don't require complex peripherals. SMA-based actuators provide displacement by means of a shape change induced by heating the material. When the material cools down, it returns to its original shape. Actuators made of thin wires that operate in line with this principle are widely used in cameras, smartphones and domestic appliances. But actuator drives in production facilities require more force, meaning the actuator bodies need to be massive. The problem here is that they only cool gradually by means of free convection. This restricts their power density despite the high energy density. With a view to increasing that power density, Fraunhofer IPM has been developing switchable heat pipes that are set to make the heat release 100 times faster and enable switching frequencies of over 1 hertz as part of the HochPerForm project. The team, which also includes researchers from Fraunhofer IWU and Fraunhofer IFAM, will demonstrate the technology using an adaptive bearing in a machine tool, laying the foundation for the use of compact yet powerful actuators in industrial manufacturing.

Funded by the Fraunhofer-Gesellschaft (PREPARE project)





New measuring station

Custom heat pipe checks and characterization

Heat pipes have an important part to play whenever efficient cooling concepts are required, such as in electronics. These fluid-filled pipes can convey considerable amounts of heat over small areas. It's often the case that they need to be customized, with the information on their properties (such as thermal conductivity and transferable heat output) often being insufficient, not reliable enough or only available in relation to certain conditions. Fraunhofer IPM has developed a new measuring station where heat pipes can be accurately characterized and tested in specific conditions. The measuring station makes it possible to check heat pipes with different diameters, bends and lengths. Specific details like the tilt angle and spatial orientation can be adjusted accordingly. Thanks to optimized insulation and a model to predict heat losses, the heat fluxes through the heat pipe can be accurately determinded.

We can characterize and test heat pipes in specific conditions at the measuring station we've been developing.

MagMed project

Magnetocalorics: milestone on the journey toward market viability

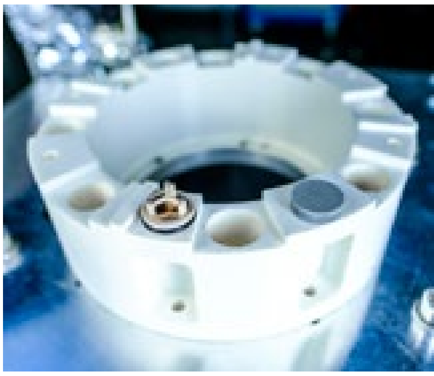
After four years of research, Fraunhofer IPM has achieved a resounding success in the performance of magnetocaloric systems as part of the MagMed project. That success has come in the form of a magnetocaloric cooling system with a world-record power density of 12.5 watts per gram of magnetocaloric (MC) material. And it's largely down to an innovative concept for enhancing the heat exchange with the magnetized material, which has always been a weak point for systems in the past.

In previous magnetocaloric systems, the heat exchange involved pumping liquid, which only works up to a certain cycle frequency. Not to mention that pressure loss and the power required for the pumps have a negative impact on the energy balance and carbon footprint of such systems. The cooling concept developed by our team uses latent heat transfer in a heat pipe. A fluid – water in this case – evaporates on the warm side of a hermetically sealed pipe and condenses on the cold side, allowing for the passive transfer of heat. This enables much higher cycle frequencies and, in turn, higher power densities. The follow-up project, MagMed 2, involves taking this concept and developing a lab refrigerator as a demonstrator (MagMed project 1/2, development of an efficient, refrigerant-free cooling technology).

Funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK)

"Magnetocalorics is considered a disruptive innovation."

Dr. Jochen Kopitzke, representative of project partner Philipp Kirsch GmbH, a company that manufactures cooling technology



World record: Magnetocaloric system with unprecedented power density

6270 watts of cooling power per kilogram of material across 10 million cycles

Nature Communications Physics

Under pressure: Elastocaloric cooling system with long-term stability

Long-term stability is one of the biggest challenges associated with elastocaloric (EC) systems. In EC systems, mechanical tensile or compressive loads are applied to a shape-memory material, which heats up in the process. If the heat is transferred via a heat sink and the force field is removed, the material cools to below the starting temperature. This reversible effect follows the principle of a heat pump to create a cooling cycle.

The tensile load that's usually at the heart of EC systems quickly causes material wear and tear, but the material lasts much longer when a compressive load causes the temperature effect instead. And yet the unfavorable surface-to-volume ratio results in less effective heat transfer. Thanks to our team's innovative idea for efficient heat transfer, the dilemma of long-term stability and power density has been solved. The answer is latent heat transfer through the evaporation and condensation of a fluid – just like in a heat pipe. This way, the demonstrator system achieved long-term stability of 10 million cycles with a cooling power of 6270 W per kilogram of EC material, exceeding the values delivered by similar systems by some considerable margin. The results of this research have been published in the prestigious journal Communications Physics. (ElastoCool project, Elastocalorics: Development of highly efficient heat pumps without harmful refrigerants for heating and cooling).

Scientific publication: Long-term stable compressive elastocaloric cooling system with latent heat transfer. Commun. Phys. 4, 194 (2021)

Funded by the German Federal Ministry of Education and Research (BMBF)

Junior academic awards

Researchers awarded prizes for research on magnetocalorics

Dr. Lena Maria Maier and Alexandra Kaube have been awarded junior academic awards by the Eva Mayr-Stihl Foundation for their outstanding research work in the field of magnetocalorics. In her doctoral thesis, Maier investigated ways of increasing the specific power of a magnetocaloric cooling system. She developed an innovative concept for efficient heat transfer based on the condensation and evaporation of a fluid. The magnetocaloric system she designed significantly surpasses existing systems in terms of cooling power and cycle frequency.

In her Master's thesis, Alexandra Kaube designed a way to recirculate fluid in a magnetocaloric system. This prevents the magnetocaloric material from drying out and ensures the thermal long-term stability of this kind of system. Her innovation has boosted thermal stability from a few minutes to more than an hour and a half. Rather than relying on the standard methanol, Kaube used water as a non-flammable and non-hazardous working fluid.

InnoCool – Joint study calorics

Exploring market opportunities for caloric systems

Are caloric systems a game-changer for air-conditioning and refrigeration technology? Given the fact they've identified the potential for disruptive innovation in the technology, researchers and industrial players are keen to work together to determine whether caloric systems might be able to replace compressor-based cooling systems in future. There are still a number of technological hurdles to overcome before widespread use is an option. And we want to consider industry perspectives and market requirements at the earliest possible point in the development process. Our InnoCool workshops brought together manufacturers, technology developers and research units to discuss technological concepts and market opportunities for caloric systems with a long-term view to making progress. The use of caloric cooling technology was discussed in the context of various applications, including refrigerators, wine coolers, portable cool boxes and heat pumps for private homes. A study summarizing the results has been distributed exclusively to everyone involved (around 40 participants).

Right: The market opportunities for caloric cooling systems were covered at the InnoCool workshops.

Thermal Energy Converters | Trade Fairs & Events

InnoCool workshops

As part of the InnoCool joint study
March 16, 2021, April 22, 2021, July 7, 2021,
October 26–27, 2021

Events in 2022

InnoCool workshop
Final workshop for the InnoCool joint study
April 7, 2022

Progetto Fuoco
Trade fair for biomass heating systems
May 4–7, 2022

Chillventa
The world's leading exhibition for
refrigeration technology
October 11–13, 2022

Focus Efficient thermal switches

Heat pipe-based thermal switches can switch and control heat flows very efficiently.

We're using hydrophilic sorbents to develop new concepts for heat pipe-based thermal switches.

Temperature control without sensor technology or control engineering

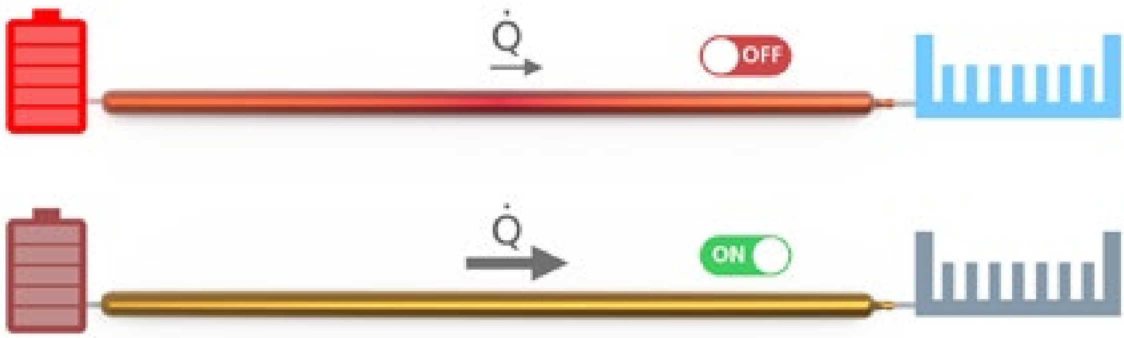
Regulating the temperature of components in the fields of electromobility, battery technology and mechanical engineering becomes increasingly important as power density rises. Fraunhofer IPM is developing a new generation of thermal switches using switchable heat pipes, which provide an autonomous and efficient heat management system – without complicated sensor technology or control engineering. Using a switchable heat pipe, temperature control requirements can be substantially reduced in many systems.

More efficient heat flux regulation

Using thermal switches, heat flux can be activated, deactivated and regulated – quite similar to common electric switches. Conventional designs for thermal switches have several disadvantages: When in the "on" position, the thermal resistance is high, and the switches are large, often with a complex design and containing moving parts. For more widespread use, thermal switches must also become more efficient and cost-effective.

New thermal switch design

Fraunhofer IPM is collaborating with other Fraunhofer Institutes on a new generation of thermal switches based on switchable heat pipes. A heat pipe is comprised of a metal tube, in which a fluid is held in both its gas and liquid phase. When a heat source is placed on the hot side of the heat pipe, the temperature rises, causing the fluid to evaporate. Then, condensation occurs on the cold side of the tube, where the heat sink is located. Thus, heat transfer in a heat pipe takes places by transporting latent heat. This method



of heat transfer is very effective and provides heat pipes with a very high thermal conductivity. For this reason, heat pipes are generally well suited as the basis for thermal switches.

Hydrophilic sorbents

Assembling a heat pipe thermal switch requires hydrophilic sorbents with temperature-dependent regulating effects to be put into the heat pipe. The sorbents can take on hydrophilic or hydrophobic properties. Switching between these properties occurs at defined transition temperatures, which can be adjusted by varying the composition of the sorbent. In its hydrophilic state, the sorbent absorbs the liquid, which is then no longer available for the evaporation and condensation processes. This stops the heat transfer process, cutting off heat transport more or less completely ("off" position). Above the transition temperature, the absorbed water is released, latent heat transfer can continue through evaporation and condensation processes, and the thermal switch is turned back to the "on" position. A patent has been registered for the thermal switch design described here.

Reduced temperature control requirements for many applications

Switchable heat pipes can be used for a variety of purposes. For example, battery systems, fuel cells and other systems function best at a certain "optimal temperature." If the systems' temperatures are not controlled, their capacity, performance and service life are diminished. Using a switchable heat pipe, temperature control requirements can be substantially reduced. Until the desired operating temperature is reached, the switchable heat pipes transfer almost no heat. If a certain operating temperature is exceeded, the "on" position is activated and excess heat is effectively dissipated. This all takes place automatically, without the need for external intervention or complex sensor technology and control engineering. The switchable heat pipes are therefore suited as "thermal emergency switches", which can dissipate heat if a critical temperature is exceeded.

This solution for heat pipe-based thermal switches can be adapted to many fields of application. Fraunhofer IPM is currently talking to businesses about developing initial system demonstrators. The sectors being covered are electromobility, stationary energy storage (batteries) and aerospace.

Learn more about our research on switchable heat pipes.

Switchable heat pipes are compact and do not require any moving parts. They are easy to integrate and guarantee a very high heat transport capacity.

"We're researching switchable heat pipes with a view to making thermal switches more efficient and cost-effective."

Dr. Markus Winkler, Project Manager

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Large-scale projects 2021 Funded by the public sector

Fourteen research projects with a financial volume of more than one million euros each for Fraunhofer IPM have been worked on by our scientists over the year 2021. The list includes those projects that received funding from the public sector or the Fraunhofer-Gesellschaft.

HOLOMOTION Dynamic holographic measurement technique for mapping freeform metal surfaces / Sub-project: Researching a method for performing interferometric measurements in motion – dynamic holography
Duration: February 1, 2017–March 31, 2023
Funding: BMBF; project sponsor: VDI Technologiezentrum GmbH

MagMed Development of an efficient, refrigerant-free cooling technology (system development and measurement technique)
Duration: June 1, 2017–May 31, 2021
Funding: BMWK/Forschungszentrum Jülich GmbH

eHarsh Sensor systems for extremely harsh environments
Duration: July 1, 2017–December 31, 2021
Funding: Fraunhofer-Gesellschaft (Lighthouse project)

QUILT Quantum methods for advanced imaging solutions
Duration: September 1, 2017–November 30, 2021
Funding: Fraunhofer-Gesellschaft (Lighthouse project)

FluMEMS MEMS-based thermal catalytic sensors for gases and liquids
Duration: April 1, 2018–December 31, 2021
Funding: Fraunhofer-Gesellschaft (MAVO)

MultiVIS University cooperation with Furtwangen University (HFU)
Duration: July 1, 2018–December 31, 2023
Funding: Fraunhofer-Gesellschaft (cooperation program with Universities of Applied Sciences (UAS))

Elasto-cool Elastocalorics: Development of highly efficient heat pumps without harmful refrigerants for heating and cooling
Duration: August 1, 2018–December 31, 2021
Funding: BMBF / VDI/VDE Innovation und Technik GmbH

ISLAS Intracavity laser spectroscopy for ultra-sensitive detection of trace gases
Duration: March 1, 2019–June 30, 2022
Funding: Fraunhofer-Gesellschaft (MAVO)

QMag Development of two complementary quantum magnetometers for measuring minuscule magnetic fields with high resolution and sensitivity at room temperature
Duration: March 21, 2019–March 31, 2024
Funding: Fraunhofer-Gesellschaft (Lighthouse project)

LaserBeat Impact hammer test using light – non-contact full inspection of tunnels on the basis of laser-induced structure-borne sound
Duration: April 1, 2019–March 31, 2022
Funding: Fraunhofer-Gesellschaft (WISA)

ElKaWe Electrocaloric heat pumps
Duration: October 1, 2019–September 30, 2023
Funding: Fraunhofer-Gesellschaft (Lighthouse project)

HochPerForm Ultra-compact fast actuator technology based on shape-memory alloys
Duration: March 1, 2020–February 28, 2023
Funding: Fraunhofer-Gesellschaft (PREPARE)

MIAME Micrometer to meter: Laser light for 3D measurements on the meter scale with accuracies in the sub-micrometer range
Duration: April 1, 2020–March 31, 2023
Funding: Fraunhofer-Gesellschaft (PREPARE)

QTWP QT waveguide plus: Labor upgrade for LNOI technology and waveguide characterization
Duration: September 1, 2021–August 31, 2023
Funding: BMBF; project sponsor: VDI Technologiezentrum GmbH

Network Our partners

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

Fraunhofer Group for 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 a total of approximately 1900 employees, the six Fraunhofer Institutes in the Group work together to solve complex, application-oriented customer inquiries at the cutting edge of science and technology. But the Fraunhofer Institutes are not only partners in innovation. 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 bring together academic research and industry.

Chairman of the group is Prof. Dr. Karsten Buse, the central office is headed by Dr. Heinrich Stülpnagel (Fraunhofer IPM).
www.light-and-surfaces.fraunhofer.de/en

Fraunhofer-Gesellschaft

- Fraunhofer Group for Light & Surfaces
- Fraunhofer Agriculture and Food Industry Alliance
- 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
- CNA Center for Transportation and Logistics Neuer Adler e.V. – Cluster Rail Technology
- 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)
- Deutscher Hochschulverband (DHV)
- Deutsche Hydrographische Gesellschaft e. V. (DHyG)
- Deutscher Kälte- und Klimatechnischer Verein e.V. (DKV)
- Deutsche Physikalische Gesellschaft e. V. (DPG)
- Deutsche Thermoelektrik Gesellschaft e. V. (DTG)
- Draht-Welt Südwestfalen – netzwerkdraht e. V.
- Forum Angew. Informatik und Mikrosystemtechnik e. V. (FAIM)
- Gesellschaft Deutscher Chemiker e. V. (GDCh)
- Green City Cluster Freiburg
- microTEC Südwest e. V.
- Nano-Zentrum Euregio Bodensee e. V. (NEB)
- Photonics BW e. V. – Innovations-Cluster für Optische Technologien in Baden-Württemberg
- Strategic 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.

International

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

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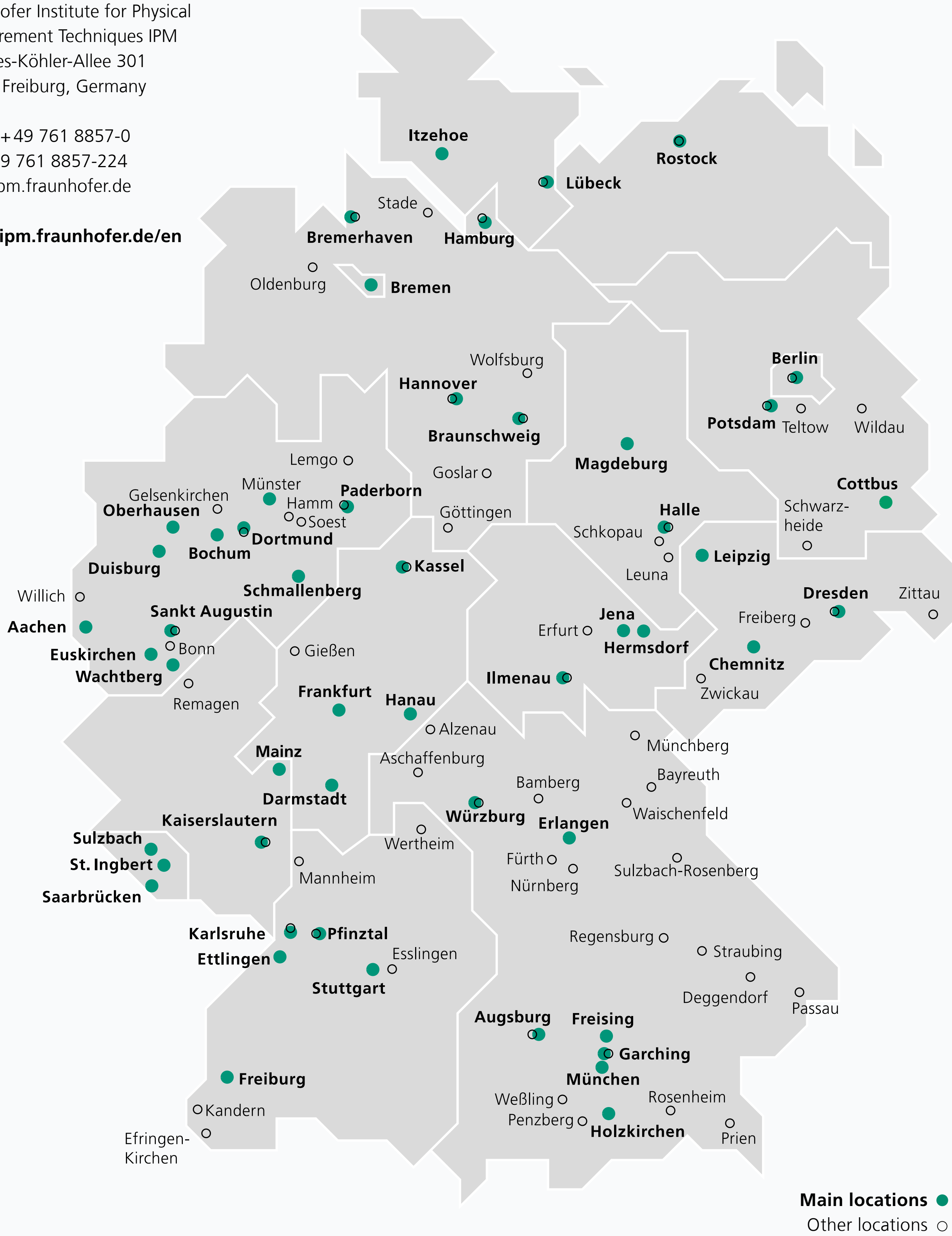

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The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

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Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of €2.9 billion. Fraunhofer generates €2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

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