Fraunhofer
IPM

FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM

2016
2017
ANNUAL REPORT

MEASURING · MONITORING · OPTIMIZING

*<< **Cover** Process measurement technology for the beverage industry: Attenuated total reflection (ATR) spectroscopy can be used for liquid analysis. The light passed through the ATR crystal is totally reflected at the crystal boundary surface in contact with the liquid. This beam interacts with the liquid flowing across it via the resulting evanescent field at the crystal surface. An IR detector records full spectral profiles in selected ranges (view pages 42–43).*

- PRODUCTION CONTROL
- OBJECT AND SHAPE DETECTION
- GAS AND PROCESS TECHNOLOGY
- THERMAL ENERGY CONVERTERS

»Networks are strong within the scientific hub of Freiburg – to the benefit of our customers«

< Prof Dr Karsten Buse, Director

Dear customers and partners,

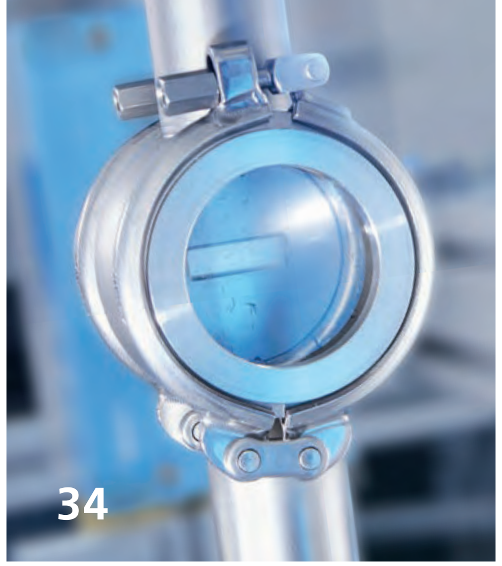
Stronger together is a motto that guides everything we do at Fraunhofer IPM: As our latest employee survey shows, our staff have extraordinarily high levels of motivation and commitment to working with their teams to produce the best possible solutions and services for our partners and clients. This ethos of working »together« is also evident beyond the walls of our institute: In Freiburg, we aim to connect everyone working in research and development.
This applies particularly to our collaboration with the Albert Ludwig University of Freiburg.
Fraunhofer IPM has now created and filled three full professorships together with the University of Freiburg. Under this arrangement, the Fraunhofer-Gesellschaft reimburses the university for personnel costs, whilst on the flip side, the appointed person has a markedly reduced teaching load yet still enjoys all the rights of a university professor. This system helps both partners: Teaching and research at the university are bolstered by the groups working under Fraunhofer professors. The new proposals and opportunities for specialization that this offers also attract outstanding students to the university. At the same time, our institute gains myriad opportunities for close collaboration with respected academics as well as contact with exceptional early-stage researchers.

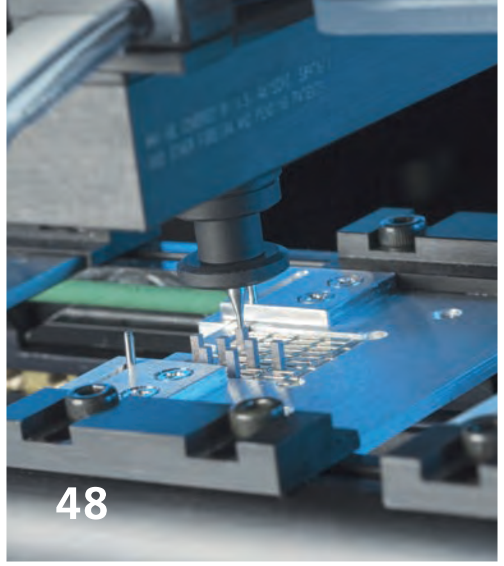
Three professorships at the University of Freiburg

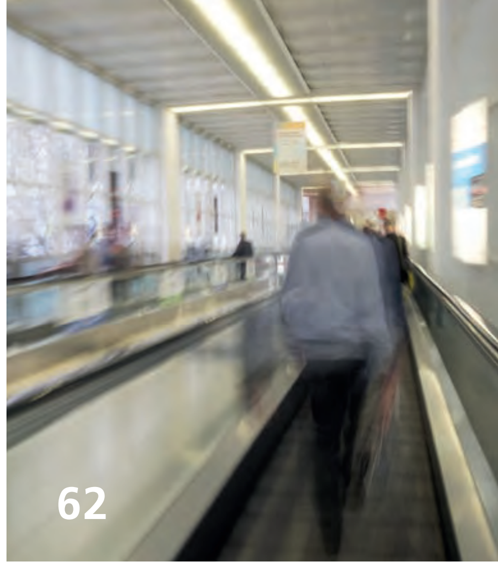
We have recently created a permanent W3 professorship on the »Monitoring of Large-Scale Structures« in the new »Department of Sustainable Systems Engineering« within the Faculty of Engineering. Prof Dr Alexander Reiterer, who is head of the »Object and Shape Detection« department at Fraunhofer IPM, was appointed to this post. His group at the university will work specifically on processing infrastructure measurement data. Amongst other things, this work will help to optimize the maintenance of railways, roads, tunnels, and bridges, and to enable the early identification of risks.
The »Gas Sensors« professorship aims to research and develop innovative working principles and materials for sensors. Jürgen Wöllenstein leads these endeavors at the »Department of Microsystems Engineering« in the Faculty of Engineering, and is also head of the »Gas and Process Technology« department at Fraunhofer IPM. I am delighted that we have been able to raise this successful collaboration to the top professional academic level of W3, and are now able to continue it permanently.
And there is, of course, also my own professorship in »Optical Systems«, likewise in the »Department of Microsystems Engineering.« The focus here is on novel, nonlinear optical, tunable laser light sources as well as sensors.
In further collective efforts, Dr Albrecht Brandenburg is engaged as an associate professor (Privatdozent) in the Faculty of Engineering, and has been for a good 15 years. Fraunhofer IPM is also planning to collaborate on the new Master's degree in »Applied Physics« by offering lab experience and a lecture offered by our colleague, the associate professor Dr Frank Kühnemann.
In recent years, Fraunhofer IPM has forged ever stronger links with the various institutes at the University of Freiburg. We have collaborators in engineering, computer science, physics, mathematics, chemistry, hydrology and forestry. This allows us to maintain our technological advantage and to offer our commercial clients globally competitive, first class services both now and in the future. Projects such as those described on the following pages illustrate this perfectly.

I hope you enjoy reading this report, and that it provokes many thoughts and ideas for exchange with Fraunhofer IPM.
Yours,

Karsten Buse







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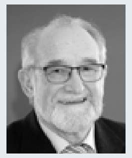

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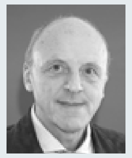

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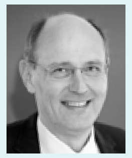

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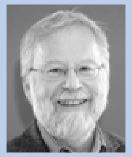

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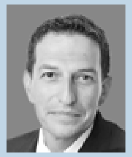

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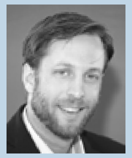

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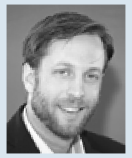

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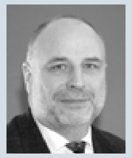

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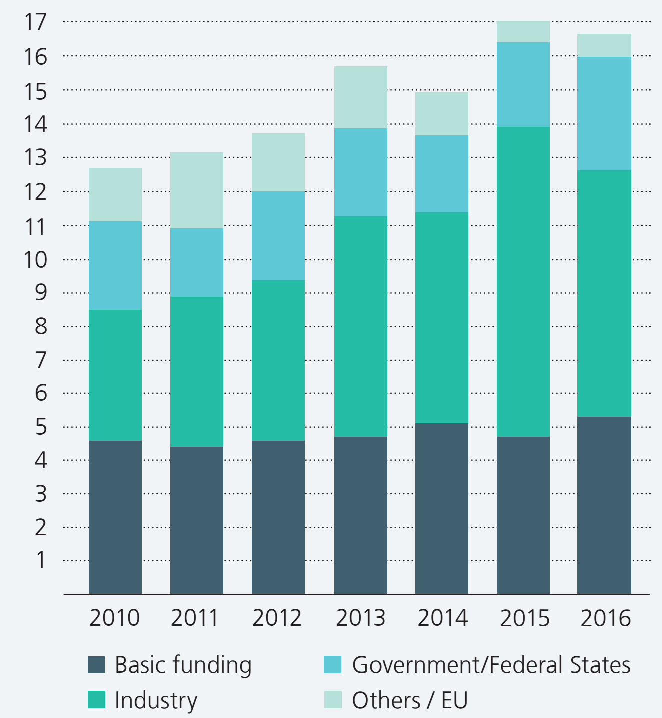
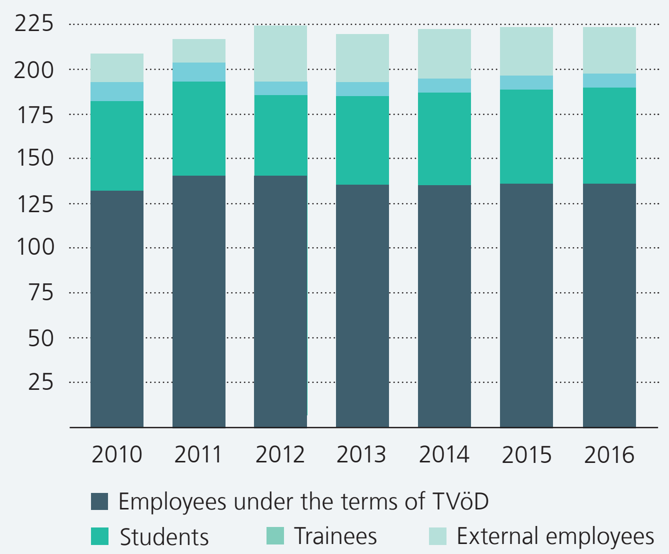
Operating budget 2010 to 2016 in million euros



Personnel development 2010 to 2016



FIGURES

Operating budget

In 2016, the operating budget of Fraunhofer IPM was 16.7 million euros, remaining at the high level of previous years. The operating budget comprises industry revenues, revenues from publicly funded projects and basic funding. The proportion of external funds, consisting of external public funds and industry revenues, was 69.1 percent, or 11.6 million euros. Industry revenues make up 7.4 million euros or a 44 percent share of the operating budget.

Personnel

The number of employees did not change compared to the previous year. In 2016, a total of 139 people were employed by Fraunhofer IPM under the terms of the Collective Agreement for the Public Service TVöD. Approximately 55 students and young professionals work at the institute, of which 45 are undergraduate and graduate students and 9 are trainees. In addition, Fraunhofer IPM has around 20 external employees as well as a number of interns and assistants. Employees are spread across three basic areas: Approximately 50 percent of employees are scientific staff, 35 percent are engineers and technical staff and 15 percent are clerical staff in the fields of infrastructure and workshop.

Saying farewell after 32 years: Institute liaison Patrick Hoyer presents Heinrich Höfler (right) with the »Fraunhofer-Taler«.

FAREWELL TO DR HEINRICH HÖFLER

On January 19, 2017, an honorary symposium was held to mark the retirement of the institute's longstanding deputy director, Dr Heinrich Höfler.

Dr Höfler came to the institute in 1984 after gaining his PhD. He became a head of department five years later, and then deputy director of the institute in 1995. In both of these roles, he did a great deal to shape the character of the institute as well as the business units that he led. He was awarded the Joseph-von-Fraunhofer Prize for his work on laser scanners in 2012. In his talk, institute director Karsten Buse alluded to the »Höflerian Rules« which ultimately underpin the success of Fraunhofer IPM. Former industry colleagues and representatives of the Fraunhofer-Gesellschaft reflected on the relevance of Höfler's work in their presentations. Fraunhofer institute liaison Dr Patrick Hoyer presented Heinrich Höfler with the »Fraunhofer-Taler« on behalf of the Fraunhofer Executive Board, and thanked him for his successful work over three decades at Fraunhofer IPM.

NEW »CENTER FOR MATERIALS CHARACTERIZATION AND TESTING« IN KAISERSLAUTERN

The »Materials Characterization and Testing« department became part of Fraunhofer ITWM at the beginning of 2017.

In future, expertise in measurement technology and data analysis will be pooled under the new »Center for Materials Characterization and Testing«. The »Materials Characterization and Testing« department, where research focused on terahertz technology, was founded by Fraunhofer IPM in Kaiserslautern in 2005. Since then, terahertz technology, which at the time was still in its infancy, has been developed to industrial maturity along with systems for layer thickness measurement and others besides. Fraunhofer ITWM's core competence lies in highly efficient algorithms for providing numerical solutions to physical questions. Integration of the center within ITWM is beneficial not only because of geographical proximity, but also considering the fact that alongside measurement technology, data interpretation plays an increasing role here. The state of Rhineland Palatinate, the Fraunhofer-Gesellschaft and Fraunhofer IPM are supporting the integration process over the next three years by providing funding of 1.6 million euros.

POOLING MATERIAL TECHNOLOGIES

From 2017 on, all expertise in the fields of developing, processing and characterizing materials will be pooled under the newly created »Materials« group.

A total of five employees working under the leadership of Dr Karina Tarantik will offer comprehensive services to the four specialist departments and industry clients alike, performing synthesis, processing, characterization and analysis of functional materials. In addition to chemical laboratories furnished with top class equipment, the team also has a 400 sqm, class 100/ISO 5 clean room at its disposal. Within the institute's organizational structure, the group forms part of the technical services.

A five-strong team working under Dr Karina Tarantik develops processes and characterizes functional materials.

PROFESSORSHIPS AT THE UNIVERSITY OF FREIBURG

For a number of years, Fraunhofer IPM has maintained connections with the Albert-Ludwigs-Universität Freiburg in the form of two associated professorships in the Department of Microsystems Engineering (IMTEK). In April 2017, Dr Alexander Reiterer assumed the »Professorship for monitoring large-scale structures« in the Department of Sustainable Systems Engineering (INATECH), which was newly established by Fraunhofer IPM and the University of Freiburg. Research carried out at the university is transferred to industrial application in cooperation with Fraunhofer IPM.

DEPARTMENT OF MICROSYSTEMS ENGINEERING – IMTEK

Professorship for Optical Systems
Prof Dr Karsten Buse

Research foci include nonlinear optical materials, optical resonators and the miniaturization of tunable laser light sources ranging from the ultraviolet to mid infrared spectral range. The opportunity to specialize in »photonics«, which was initiated in collaboration with other optics professors, has been integrated into the curriculum of the master's program in microsystems engineering.

Professorship for Gas Sensors
Prof Dr Jürgen Wöllenstein

Gas-sensitive materials, sensors and sensor systems are being developed under the auspices of this professorship, with research centering on miniaturized, energy-saving gas measurement systems. One area of focus is the development of cost-efficient, energy-saving sensors based on microsystems technology.

DEPARTMENT OF SUSTAINABLE SYSTEMS ENGINEERING – INATECH

Professorship for Monitoring Large-Scale Structures
Prof Dr Alexander Reiterer

Research foci include the inspection and monitoring of artificial and natural objects such as civil engineering structures, landslide-prone slopes or extensive areas of vegetation. In support of this work, innovative sensor concepts are being developed and implemented. Research activities include strategies for analyzing and interpreting data, including linkages to influence parameters, causative forces and changes measured, as well as the development and implementation of complete system chains – from data acquisition to data evaluation.

INTERNAL

OUR ADVISORY BOARD

A dedicated, competent and diverse board of trustees gives Fraunhofer IPM advice and support relating to strategic issues and decisions for the future.

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Dr Manfred Jagiella
Endress und Hauser Conducta GmbH & Co. KG

Members
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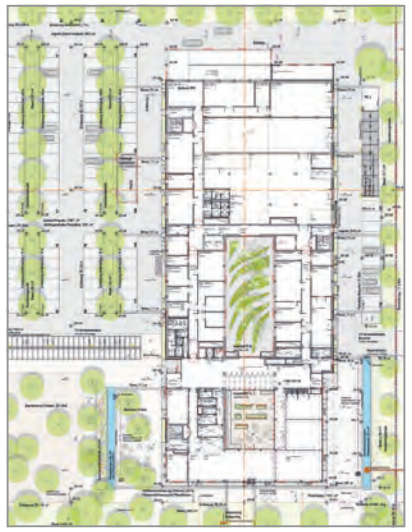


CORNERSTONE CEREMONY FOR NEW BUILDING IN 2017

2016 saw several important hurdles overcome in planning the new institute building.
The planning submission that forms the basis of the building proposal was finished and presented to the funding bodies. The building proposal was approved during the first quarter of 2017. At present, work on the execution plan is in full swing. Groundworks and shell construction are scheduled to start in April or May 2017. The cornerstone laying ceremony will take place on July 4, 2017 at the latest. We provisionally expect to move into the new building during the first quarter of 2020.

The new institute building measuring 6500 m² is being developed on the University of Freiburg's Faculty of Engineering campus.

MOLAS TECHNOLOGY WORKSHOP: A REPEAT SUCCESS

Over one hundred participants attended the Mobile Laser Scanning Technology Workshop in November 2016.

For Alexander Reiterer and his team, this marked a successful repeat of the event, which took place for the first time in 2014. Alongside scientific talks on calibration, applications, data processing, and visualization, two keynote presentations focused on the demands and expectations of industry: The role that laser scanners will play in autonomous driving and the challenges that must be overcome were illustrated by Dr Matthias Butenuth from IAV GmbH, an international automotive engineering service provider. Dr Jürgen Sturm from Google Germany explained methods for the 3D reconstruction of measurement data using the technology platform Google Tango. The next MoLaS Technology Workshop is being planned for 2018.

Over 100 participants listened to a total of thirteen talks on mobile laser scanning. Research and industry representatives had opportunities for discussions between the presentations.

MEASUREMENT TECHNOLOGY IN »INDUSTRY 4.0«

Measurement technology plays an important role in »Industry 4.0«.

Together with the microTEC Südwest Cluster of Excellence, Fraunhofer IPM organized a workshop in September 2016 on 100 % quality control tailored to digitized manufacturing processes.

How can we create smart links between production processes? What role does measurement technology have to play here? These were the type of questions debated by around 40 participants from research and industry. At the event, a marker-free track and trace technique developed at Fraunhofer IPM was given as an example of a measurement system geared specifically to the needs of digitized manufacturing. The technique was awarded a prize in the »100 Places for ›Industry 4.0‹ in Baden-Württemberg« competition, which is accompanied by a series of workshops and events.

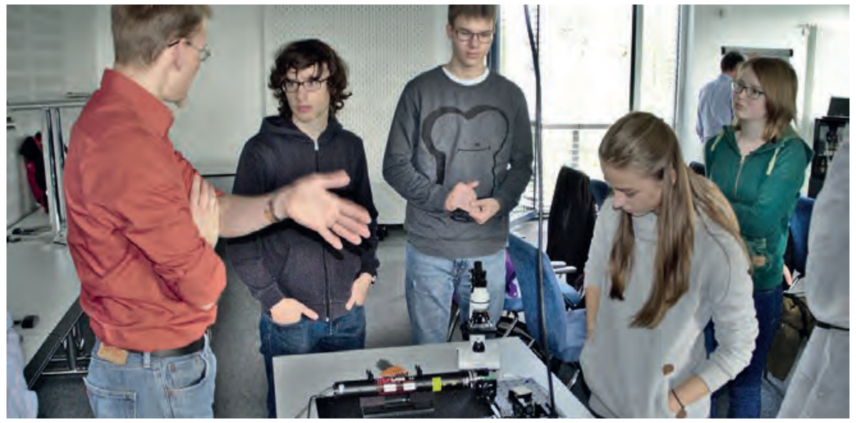
OPTICAL SENSORS IN MEDICAL TECHNOLOGY

Some 40 experts were invited to our institute in January 2016 to discuss optical analysis methods in medical technology.

Eight speakers provided an overview of technological trends in medical technology, with topics including endoscopy, surface analytics, and diagnostic applications of spectroscopy. Innovative medical technology products, the possibilities offered by optical diagnostics, new business models, and potential collaborations were all discussed. The event formed part of the »Spectaris Wissensraum« series and was organized jointly with the industry association SPECTARIS and the specialist Photonics Group of the Swiss networking platform SwissMEM.

Workshop participants unanimously agreed that medical technology benefits from optical analysis.

STUDENT PROJECT: 3D MICROSCOPY AT HOME



Pupils actively collaborate on constructing and developing a digital holographic 3D microscope.

Together, Fraunhofer IPM and pupils from the »Freiburg Seminar« are developing a digital holographic microscope for Open Science.

As part of the 3-year »HolMOS« project, pupils and researchers are developing a low-priced microscope for private use that enables 3D depictions of objects. At its core is a standard student microscope supplemented by a digital camera and a simple laser source. The pupils are working to test the microscope, draft a construction manual and develop an online user platform. Game publisher Kosmos is an associate project partner, and is testing the product for integration within its series of science kits. To launch the project, some 25 pupils from the »Freiburg Seminar« were invited to the institute in October. The »Freiburg Seminar« is an institution that supports particularly gifted and interested pupils from the Freiburg region.

OPEN INNOVATION

HolMOS is based on a concept of »Open Innovation«. Here, users exchange ideas via an online platform and contribute to the development of the product. The project is funded by the German Federal Ministry of Education and Research as part of the »Open Photonics« program.

MAGAZINE

GIRLS' DAY

The Girls' Day in April 2016 provided opportunities for activities such as building computers, tinkering with nanoparticles in chemistry labs, and mounting conducting paths onto chips.
For the 16th year running, Fraunhofer IPM gave 15 girls from grade 8 (14–15 years old) and above the chance to work on questions formulated specifically for their age group, thus giving them an insight into the laboratories and workshops of a research institute. Around ten scientists put the program together and supervised the schoolgirls throughout the day.

Pupils prepare microstructures for a chip in the clean room – whilst wearing clean room suits.

REGIOWIN: RESEARCH ON »INTEGRATED ENERGY-EFFICIENT INDUSTRIAL PARKS«

A total of 1.4 million euros has been awarded to Fraunhofer IPM and Fraunhofer ISE for three projects researching the technological foundations of future energy systems.
Under the RegioWIN Lighthouse Project »Integrated Energy-Efficient Industrial Parks« (»Vernetzte energieeffiziente Industrieparks«), three sub-projects have received grants: In the project entitled »Thermoelectric CHP«, several combined heat and power plants are being fitted with thermoelectric generators and heat exchangers to enable more efficient use of their waste heat. The »Gas Efficiency« project focuses on online measurement technology for analyzing renewable gas. »SmartBaden-Monitor«, a project run by Fraunhofer ISE, is intended to optimize building efficiency and enable automated load forecasts. The competition began in February 2013 and aims to drive forward regional development in Baden-Württemberg. Katrin Schütz, State Secretary at the Baden-Württemberg Ministry of Economics, Employment and Housing, announced the funding decision during a visit to Fraunhofer IPM in September 2016.

State Secretary Katrin Schütz awards funding for the RegionWIN Project »Integrated Energy-Efficient Industrial Parks« to Prof Karsten Buse (right) and Dr Andreas W. Bett from Fraunhofer ISE (left).

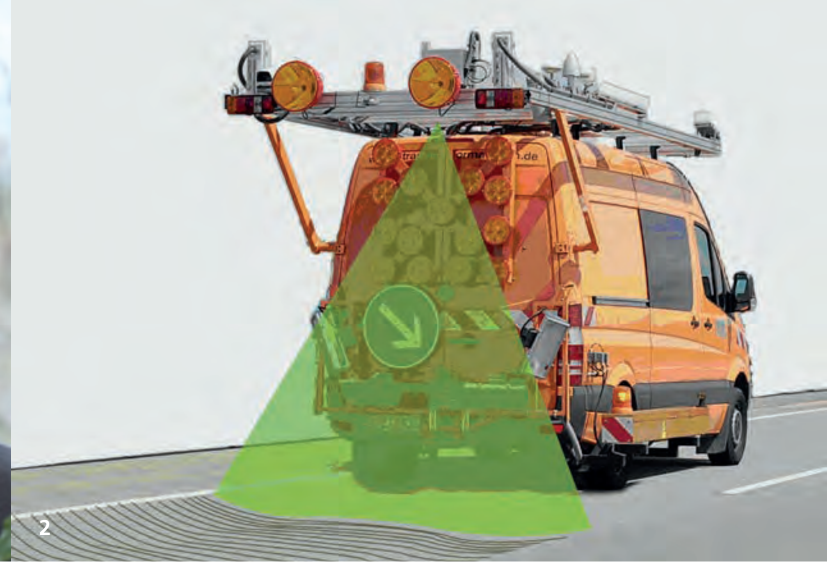
AWARD WINNING FIRE GAS SENSOR CONCEPT

Dr Carolin Pannek has been awarded the 2016 Hugo Geiger Prize for her fundamental research on fire gas sensors.
In her PhD thesis, she developed a new concept for gasochromic fire gas sensors, work that was rated by the jury as the second best doctoral dissertation in the entire Fraunhofer-Gesellschaft. With the publication of her paper, the researcher laid the foundations for waveguide-based gasochromic sensors. In so doing, she offered the first prospect of an alternative to conventional semiconductor gas sensors, which are unsuitable for fire gas detection. Sensors based on this principle would not only be highly sensitive and selective, they would also be extremely energy efficient, meaning they could be operated for up to five years on one set of batteries. The sensor design also allows manufacturing costs to be kept low. In contrast to widespread smoke detectors, fire gas sensors recognize fires much faster, since they measure the characteristic gases that are generated very early in the course of a fire.

Fraunhofer Executive Board member Prof Georg Rosenfeld (left) and Dr Ulrike Wolf, Head of Department at the Bavarian State Ministry (right), presented the Hugo Geiger Prize to Dr Carolin Pannek at the 16th Munich Science Days event.

AWARD FOR »TRACK&TRACE« FINGERPRINT

Fraunhofer IPM has been named as one of the »100 Places for ›Industry 4.0‹ in Baden-Württemberg« thanks to an innovative marker-free track & trace technique.
Under the »Track-4-Quality« project funded by the BMBF (German Federal Ministry of Education and Research), a technique was devised that enables components to be identified solely from their surface structure and thus clearly distinguished within the production process. The concept requires no additional marking and is therefore also suitable for low-priced, mass-produced parts. Complete traceability over the entire product lifespan holds particular appeal for sectors with high quality standards, such the automotive and medical technology industries. Within the competition, »Allianz Industry 4.0 Baden-Württemberg« awards prizes to innovative concepts that link production and value-adding processes intelligently together. Practical relevance is also taken into account in the judging, alongside the level of innovation.



»Let's try it!«

On behalf of LEHMANN + PARTNER GmbH, Fraunhofer IPM developed a laser scanner that surveys road surfaces. Since 2012, the Pavement Profile Scanner has been the only laser scanner approved by the Bundesanstalt für Straßenwesen (Federal Highway Research Institute – BASt) for this type of mapping. Dr Dirk Ebersbach is the CEO of LEHMANN + PARTNER GmbH.

Mr. Ebersbach, how did you come to work with Fraunhofer IPM?
We were both exhibitors at the Intergeo trade fair in 2010. At the time, Fraunhofer IPM was developing the »Pavement Profile Scanner« and we were looking for innovative new products. Up to that point, we had been using road assessment vehicles that required a 3.4 meter crossbeam to record the road surface conditions. This was extremely cumbersome, particularly in urban traffic. Then Fraunhofer IPM came along and said: »We can measure that with laser scanners – they are already in use on railways.« So our response was: »Okay, let's try it!«.

Did you already have customers at that point in time?
Our service portfolio has always comprised surveying ruts in the road surface. To do so we used a measurement system that required this big wide crossbeam. You had to notify the authorities of these surveys well in advance. You needed special security, and if anything was in the way you had to fold up the entire recording system. The survey data weren't as good as desired either. As a result, we had long been searching for an alternative system. Then we learnt from Fraunhofer IPM that if we were to use a laser scanner, we wouldn't have this troublesome crossbeam on the vehicle and would only need a small shoe box instead. If it worked, that was the route we should take.

Do you survey more road miles per day with the laser scanner than before?
No, the mileage is about the same. However, the new technology has created an entirely new market: We are now able to perform surveys in urban areas and have gained new customers in the form of municipalities.

What expectations did you have and were these fulfilled by the end of the project?
We wanted to replace the crossbeam system, and were entirely successful in doing so. The biggest hurdle for us was gaining approval from the BASt. In fact, their regulations were designed such that only crossbeam systems could gain authorization. And then we came along and said: »We've got this box which records exactly the same things, it just does it in a different way.« We had to do a lot of convincing, but in the end the BASt said: »We want one of those scanners, too.«

Was it difficult to find common ground between research and industry?
Both sides have to learn new things. We are civil engineers, our partners at Fraunhofer IPM are metrologists and physicists. Naturally, we sometimes talk at cross purposes. Nevertheless, thanks to many years of close collaboration, mutual understanding is growing – on both sides. Over time, we are therefore developing not only a common language, but also a partnership based on trust.

What is the next development you have planned?
We have succeeded establishing the Pavement Profile Scanner. However, the survey vehicles still carry two enormous camera systems with a big flashing light unit. That is what we want to replace next, we want to get to the point where we only have our »small shoe box« on board.

Why is this compactness so important?
We have two business units: The first is purely for the provision of services, which we chiefly offer in Germany and Europe. The second is for the sale of equipment. In other words, we sell our systems worldwide. This is why it is extremely important to have a simple, flexible system. With a compact device, you only have to mount it once and then it is done.

How do you decide which innovations to invest in?
Innovation is rarely initiated by customers. As in the alleged words of Henry Ford, »If I'd asked people what they wanted they would have said faster horses, not cars«, we always try to place new products on the market off our own bat. The Pavement Profile Scanner (PPS) is not merely a ›faster horse‹, it is a completely new solution.

How do you decide which developments to offer as products?
We have a roadmap that lays out where we want to go and primarily contains products and services. We use it to decide which developments could help us to achieve our goals. Ultimately, though, you always have to go with your gut feeling. I put my money where my mouth is. I believe in the technology. We would never be able to develop a sensor on our own. We are too small for that, and we don't have the necessary expertise. Close partnerships with development partners such as Fraunhofer IPM therefore make perfect sense for us.

Thank you very much for talking to us!

Founded in Erfurt in 1990 and today employing a staff of around 200, LEHMANN + PARTNER GmbH offers surveying and consultation services for the maintenance of transport infrastructures. The medium-sized engineering firm employs ultra modern measurement technology to record the condition of roads, cycle paths, and footpaths. This data serves as a basis for managing, maintaining and expanding the transport infrastructure. As a member of the French VECTRA Group, LEHMANN + PARTNER GmbH also operates worldwide.

1 *Dirk Ebersbach: »Henry Ford didn't replace horses with faster horses, but with cars.«*

2 *The Pavement Profile Scanner (PPS) accurately records road surface conditions to within a few millimeters, even at speeds of up to 100 kilometers per hour.*

3 *Fraunhofer IPM is currently working on the »PPS plus« – a scanner that reliably records surface features such as cracks in addition to 3D profiles.*

4 *Dirk Ebersbach: »We would never be able to develop a sensor on our own.«*

BUSINESS UNIT **PRODUCTION CONTROL**

»We take a closer look at things – and fast.«

For production control, Fraunhofer IPM develops optical systems and imaging methods which can be used to analyze surfaces and 3D structures in production and to control processes. The systems measure fast and accurately so that small defects or impurities can be detected, even at high production speeds. This means that 100 percent production control in real-time is possible against the backdrop of the fourth industrial revolution.

A wide range of methods is used, including digital holography, infrared reflection spectroscopy and fluorescence methods, combined with fast, low-level image and data processing. The systems are used in applications such as forming technology in the automotive industry and for quality control in medical products.

Group Inline Measurement Techniques

- Surface inspection
- Shape measurements
- Marker-free component identification

Group Optical Surface Analytics

- Purity control and coating inspection
- Inline microscopy
- Laser-induced breakdown spectroscopy

< Optical systems scan component surfaces – for the purposes of quality assurance and tracing.

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GROUP **INLINE MEASUREMENT TECHNIQUES**

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The main focus of this group is on 2D and 3D measuring systems for industry. These systems supply high precision measurements in real-time and under hardest production conditions, for example for controlling sensitive production processes. This is achieved by a combination of optical measuring techniques with extremely fast data processing.

>> Measuring low-cost, mass-produced parts with complex geometries inline and tracing them across the production chain is now possible.

EXPERTISE

Real-time inspection systems with customized image processing | Robust holographic 3D sensors for measurement with sub-micron precision | Algorithms for evaluating microscopic surface structures

APPLICATIONS

Customer-specific systems monitor and control the quality of components with complex geometries | Holographic systems measure gear geometries in line, precisely and non-contact | Optical readers identify single components without additional markers

SPECIFICATIONS

SURFACE INSPECTION

- 100 percent inline surface monitoring of wire at feeding rates of 30 m per second
- Complete quality check of die-cast parts and forged parts with complex geometries
- Customized systems for harsh production environments
- Inline geometry and surface detection

SHAPE MEASUREMENTS

- 100 million 3D measurement points per second
- Working distance of up to 300 mm feasible
- Measuring fields of 30 × 30 mm²
- Absolute height precision, < 1 µm
- Lateral resolution, < 10 µm

MARKER-FREE COMPONENT IDENTIFICATION

- No need for additional markers
- Robust against local damage and contamination
- Reliable identification of components in large batches
- Short read-out time, < 100 ms
- Identification at production speed, < 500 ms

GROUP **INLINE MEASUREMENT TECHNIQUES**

Mark-free identification – clear and counterfeit-proof

Anyone wishing to trace production data back to individual components or to verify the authenticity of parts needs to be able to identify them unambiguously. In a digitized manufacturing environment, it is therefore essential to allocate identification data to components with precision. Fraunhofer IPM has developed an innovative track and trace technique which identifies mass-produced parts without the need for any additional markers, and does so based on each component's unique surface characteristics.

The quality of complex industrial products depends on the quality of many – often tiny – components. If just a small part within a large sub-assembly fails, it means that the entire batch is potentially defective and needs to be either rejected or recalled. The reason for this approach is that a clear correlation between the process data and individual components is lacking. Such correlations are only possible when every tiny part and semi-finished product carries its own individual signature. The marker-free »Track & Trace Fingerprint« system developed by Fraunhofer IPM records structural parameters in the part's surface and converts them into a unique digital signature (Fig. 1). This ensures the traceability that is so crucial to all »Manufacturing 4.0« processes, and at the same time offers intrinsic protection against counterfeiting – without the need for any additional marking.

Cost unrelated to production quantities

The process of tracing mass-produced parts not only needs to be reliable but also inexpensive. Established componentmarking methods require additional production steps such as engraving serial numbers, or attaching RFID labels and data matrix codes. Where sealing faces, decorative surfaces or ultra-small components are concerned, this is sometimes simply impossible. »Track & Track Fingerprint« does not incur any costs that are dependent on the production quantity. It merely uses what is already there – the microstructure of the component surface, which turns every mass-produced part into a unique item. As a result, the process also provides a certificate of authenticity, e.g. for safety components or for luxury goods.

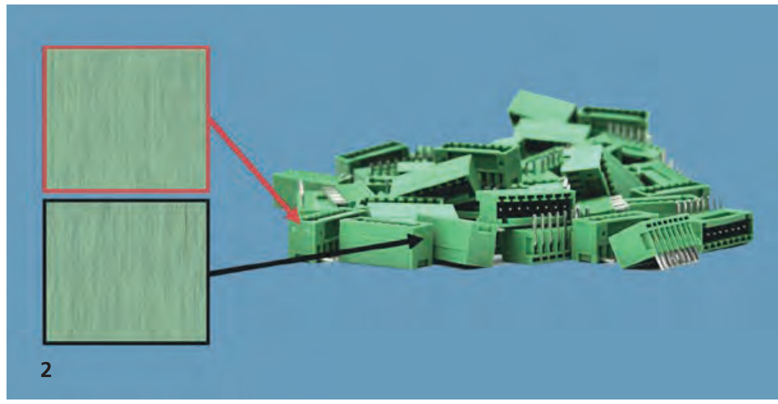
Even mass-produced parts are unique

Viewed under a microscope, almost all technical surfaces reveal incidental characteristics such as microstructures and interwoven colors that identify the item in question in a distinctive way. Every mass-produced part, every plug, every individual screw is therefore just as unique as a fingerprint. By comparing the data of a recorded signature with the signatures stored in the manufacturer's database, clear evidence that »the part was manufactured on day x with these production parameters« can be provided even years later. The sensor system can even register microstructures in smooth plastic surfaces (Fig. 2). Signatures are created from images captured in defined positions on the component surface which show specific structural features and their position in relation to one another. In order to distinguish the component at a later point in production, the entire process is repeated in the same position on the part and the identified signature is compared with all the signatures already stored in the database. If a match is found, the part being sought can be identified and the ID returned.

Furthermore, component mix-ups can be eliminated, even with very large batch sizes, since when performing the comparison with the signature database, the algorithm simultaneously generates a quality parameter that quantifies how good the recognition is. The process therefore monitors itself. At the same time, the sensor has been designed to enable a wide range of materials to be identified in line with the rate of production using the same hardware – from smooth plastic to precision-machined aluminum, cast iron and varnished surfaces.

INDUSTRY 4.0 is understood as being a virtually self-managed production process – one which is based on intelligent, digitally integrated systems. Following in the footsteps of mechanization, mass production and automation, the fourth industrial revolution – integration – is now on the starting blocks. In future, people, machines, equipment and products will communicate and cooperate directly with one another. Only full traceability of all parts at all times will enable us to optimize, not just individual production steps, but also the entire value chain as a whole.

1 *»Track & Trace Fingerprint« uses the individual surface microstructure of components to identify them, thus avoiding the need for marking.*



2 *Even mass-produced parts are unique: Simple plugs, for instance, have distinctive surface characteristics that are suitable for marker-free component identification.*

Identification without delays

In production, no time can be spared for component tracking. The marker-free track and trace technique therefore employs a camera-based sensor system which can record a part's microstructure in a fraction of a second using a CMOS image sensor, and then from it generates the signature for that component in real time according to a defined algorithm. This is stored, together with an ID, in a database. Reducing the image data to a simple bit sequence with low memory requirements makes »Track & Trace Fingerprint« a system that can be used inline. The software compensates for any potential positioning tolerances arising from handling using geometric points of reference, ensuring that the process will function reliably even in a harsh production environment.

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BUSINESS UNIT **PRODUCTION CONTROL**

GROUP **OPTICAL SURFACE ANALYTICS**

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The main focus of this group is the development of turnkey devices for surface analysis. These devices use fluorescence measurement techniques as well as infrared reflection spectroscopy and laser-induced breakdown spectroscopy. Fraunhofer IPM's long-standing experience in systems engineering encompasses optical units, image recording and image processing.

EXPERTISE

Fast, spatially resolved fluorescence measurement techniques with customer-specific lighting systems | Laser-induced breakdown spectroscopy | Inline microscopy systems with control units and data evaluation | Shortwave-infrared analysis: harnessing spectral dependence of absorption and scattering properties for materials analysis

APPLICATIONS

Inline purity control, revealing impurities on component surfaces | Detection of surface defects and surface coatings | Authenticity check by analyzing fluorescent pigments | Microscopy at production speed, e.g. 100 percent quality control of key components in medical devices | Substance-specific identification of materials on surfaces

SPECIFICATIONS

PURITY CONTROL AND COATING INSPECTION

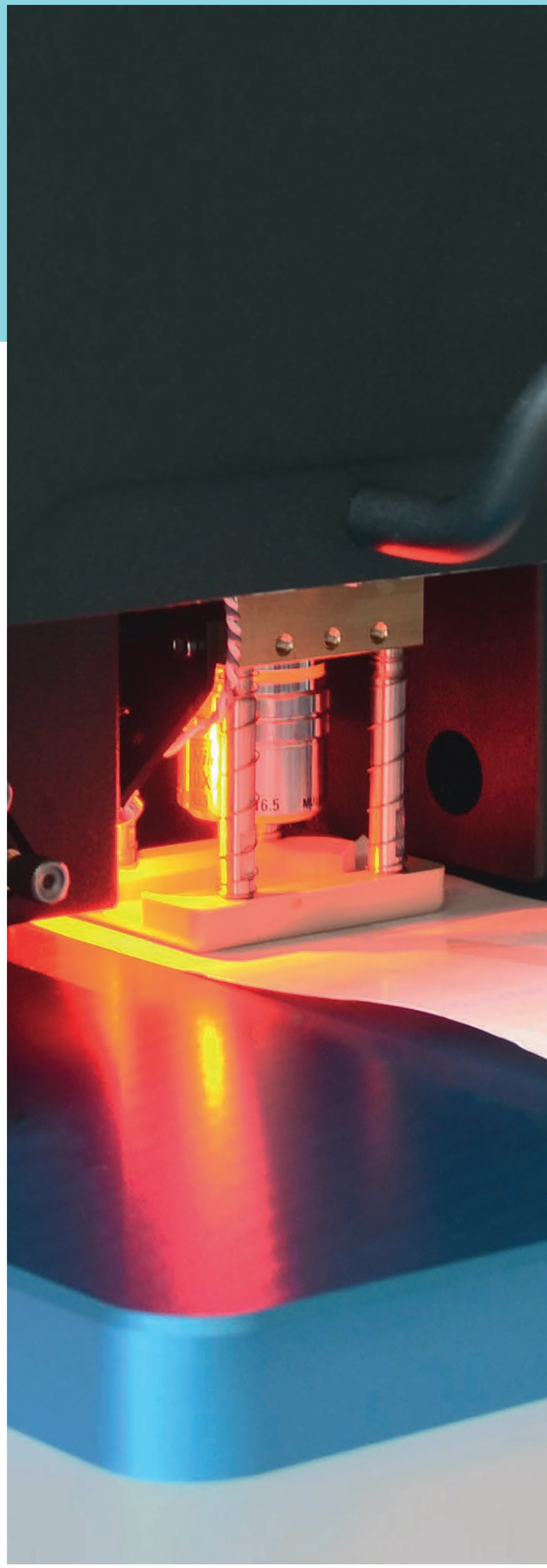
- Detecting position, form and quantity of film-like impurities at production speed
- Imaging detection of process auxiliaries such as lubricants, greases or cleaning agents (detection limit for standard lubricants: 0.01 g/m²)
- Camera system: detection area of some cm², optical resolution approx. 20 µm
- Scanner system: detection area of some m², optical resolution approx. 250 µm

INLINE MICROSCOPY

- Characterization of complex 3D microstructures
- Detecting structural defects, impurities, defective geometries or scratches
- Reproducibility of distance measurement in the submicron range
- Measuring device capability for determination of component geometries
- Frequencies of approx. 1 second

LASER-INDUCED BREAKDOWN SPECTROSCOPY

- Non-contact materials analysis on surfaces
- Layer thickness measurement of functional surfaces with thicknesses in the micrometer range
- Inline characterization of nanometer-thin anticorrosive coatings
- Detection of element concentrations in coatings in the order of ppm



>> Fluorescence measurement for forgery-proof tickets: A camera captures the random distribution of marker pigments.

GROUP **OPTICAL SURFACE ANALYTICS**

Imaging measurements of lubricant films – automated and in real-time

In metal sheet production, thin oil films perform three important tasks: They protect sheet metals against corrosion, prevent mechanical damage, and improve the friction performance of sheets during forming. In order to ensure optimum oil film quality, fluorescence imaging measurement systems record the thickness and homogeneity of films in real-time – on flat sheets and complex 3D punched parts alike.

Punched and formed parts are manufactured from sheet metal in pressing plants for sectors such as the automotive industry. In order to be able to process these sheets, the material must be oiled prior to forming, and precise dosing of the lubricant is crucial to the quality of the formed parts. Fraunhofer IPM has now developed a process based on rapid fluorescence imaging measurement techniques which determines and controls the distribution of oil across the entire sheet. Fast laser scanners perform measurements for this purpose at rates of up to 200 lines per second. With a throughput of several meters of metal sheeting every second, the entire surface can be analyzed seamlessly as a direct part of the production process.

Lubricant distribution on sheet metals

Cold rolled sheet metals and finished sheets are coated with anti-corrosion oil as standard to protect them against corrosion as well as mechanical damage. Companies that process sheet metals expect them to be evenly oiled – over both the length and breadth of the sheet. Slightly thicker oil films are often used here, but using too much oil is a bad idea. This accounts for post processing steps sensitive to oil, such as adhesive bonding, coating or electrical contacting. In many cases, the sheets are not cleaned between cold forming and subsequent process steps, as a result quality problems arise.

In order to ensure a high level of quality, sheet metal manufacturers and processors therefore need to measure both the homogeneity and thickness of oil coatings – ideally across the entire sheet in one go.

Imaging measurement of lubricant films

The »F-Scanner« oil film measurement system developed by Fraunhofer IPM scans the sheet surface point-by-point using UV light. The majority of substances employed for sheet lubrication show strong fluorescence in the UV wavelength range, meaning that the oils convert part of the UV light into visible light. In contrast to this, most inorganic materials – the unoiled sheet surfaces in particular – do not display this behavior. The fluorescence of the oils can therefore be analyzed using a spectral filter which allows clear, contrasting measurement images of the thickness and homogeneity of oil coatings to be generated for the entire sheet surface.

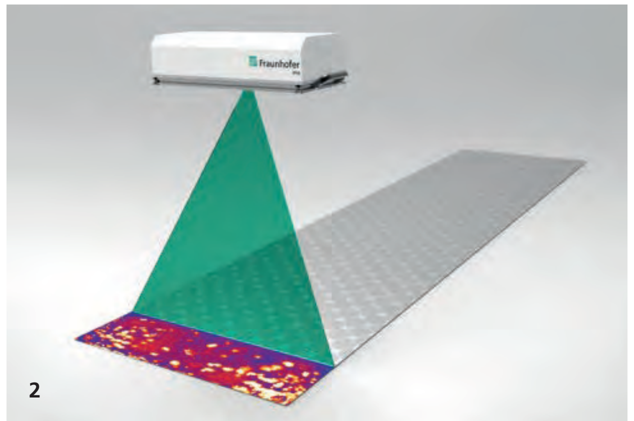
FLUORESCENT LIGHT is light that is emitted spontaneously just after a suitable material is stimulated. It generally has less energy than the excitation light previously absorbed. Many organic compounds such as oils emit strong fluorescence signals that are perfectly suited to measuring the thickness and homogeneity of thin films. If excitation light is passed over a surface using a scanner, it is possible to perform imaging measurements on lubricant coatings and to characterize the quality of oil films with great accuracy – even on complex shapes and large areas.

Even just a few milligrams per square meter of an organic substance can be detected with the »F-Scanner«. Potential lubrication defects can thus be reliably identified and rectified with selective re-oiling or washing.

Rapid surface scanning

Using an ultra-fast laser scanner, the »F-Scanner« system makes lubricant film imaging measurements based on fluorescence possible for the first time. The system scans 200 lines per second with a resolution of approximately 500 µm on sheet widths of up to two meters. These values enable high throughput rates combined with superior levels of sensitivity. The signals detected are combined to form a spatially resolved overall image. Thanks to its collimated laser beam, the system also features great depth of field. In addition to its application in monitoring sheet metal from rollstock, it can also perform comprehensive inspection of components with complex 3D freeform surfaces, in which case the UV laser beam scans the entire object.

Alongside sensor technology, automated image processing likewise always forms a central facet of Fraunhofer IPM's fluorescence measurement systems. This is the only way of analyzing fluorescence images in real time using pattern recognition. If levels of lubricant coating exceed or fall short of the defined threshold value, the subsequent process step can be adapted accordingly: The component may be rejected, the location marked or the oil quantity adjusted. This is how spatially resolved evaluation assists the inspection and documentation of lubrication quality in-line, and helps to optimize it on an ongoing basis as a result.



1 A defined amount of lubricant is applied to sheet metals as an anti-corrosion agent and for forming. However, storing and winding the metal sheets commonly leads to inhomogeneous oil distribution.

2 The »F-Scanner« can be adapted to each individual production environment. It consists of a modular imaging scanner unit and a system for evaluating measurement data which highlights differences in oil distribution.

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BUSINESS UNIT **OBJECT AND SHAPE DETECTION**

»We develop mobile laser scanners.«

In its »Object and Shape Detection« business unit, Fraunhofer IPM detects three-dimensional geometries and the location of objects. For this purpose, not only laser scanners but also custom-tailored lighting and camera systems are developed. These devices take measurements at high speed and with high precision, particularly from moving platforms.

We focus specifically on speed, robustness and long service life of the systems and efficient data evaluation. The systems scan objects and shapes over a broad size range: from tenths of a millimeter to into the 100-meter range. The measuring systems are in operation all over the world – for monitoring rail infrastructure and for measuring road surfaces. New applications include mobile data recording from the air, in water or by handheld systems.

Group Laser Scanning

- Systems for railway measurement
- Systems for road measurement
- Autonomous systems

< Laser scanners need to be particularly lightweight and compact to be used on aerial vehicles.

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BUSINESS UNIT **OBJECT AND SHAPE DETECTION**

GROUP **LASER SCANNING**

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The main focus of this group is the development of optical measuring systems based on time-of-flight measurement, which enable the distance between objects to be measured at high speed and high precision. Combined with a scanning unit, these systems capture three-dimensional object geometries. Mobile laser scanning requires precise positioning and orientation of the measurement system. For this purpose, special camera-based methods, if necessary combined with conventional inertial sensor technology, are developed in order to enable the allocation of the measurement data to a fixed local coordinate system.

EXPERTISE

Time-of-flight measurement systems measure distances with sub-millimeter precision | Fast laser scanners scan of the surroundings | Small, light-weight laser scanners designed for mobile platforms

APPLICATIONS

Scanners and camera systems gauge and monitor railway infrastructure such as tracks, platforms, and catenary wires | Measurement systems on mobile platforms and autonomous vehicles inspect objects difficult to access, e.g. under water or from the air | »Deep-Learning« algorithms automatically interpret 3D point clouds, classifying objects, e.g. in road scenarios

SPECIFICATIONS

SYSTEMS FOR RAILWAY MEASUREMENT

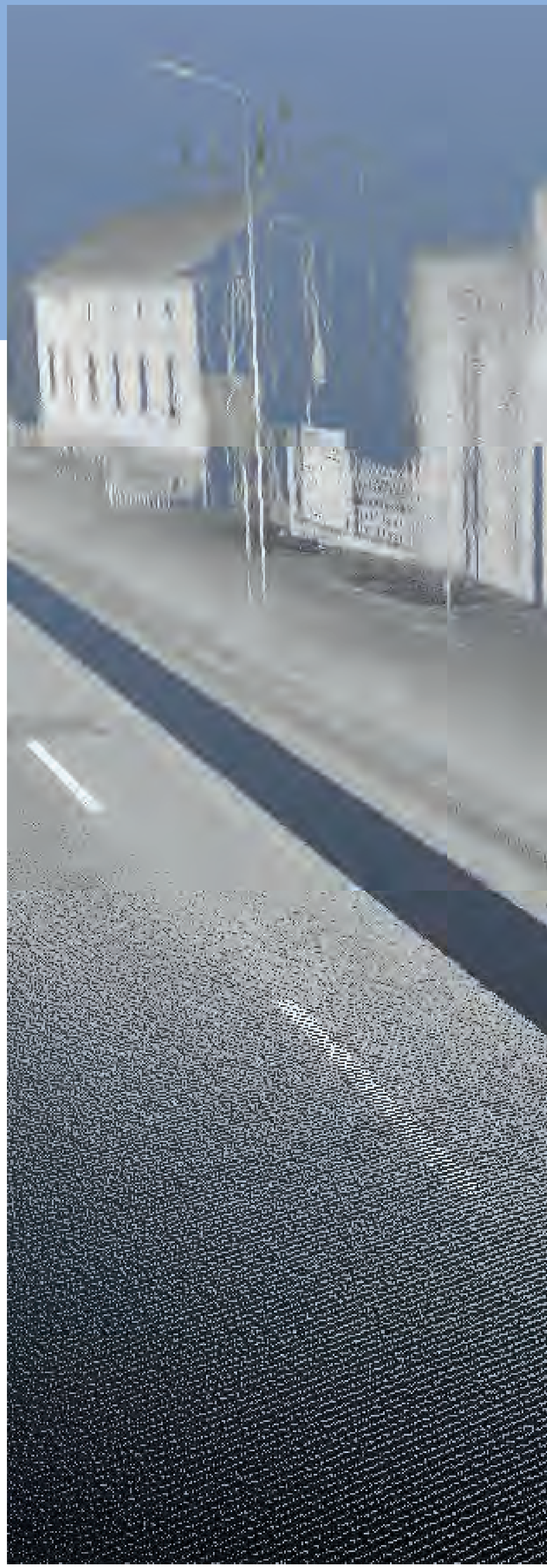
- Detecting catenary wires at speeds of 250 km/h
- Monitoring clearance profile of railways with a precision of 3 mm
- Profiling speed of 800 profiles per second
- Measuring rail track profiles with a precision of 0.3 mm

SYSTEMS FOR ROAD MEASUREMENT

- 2 million measurement points per second
- Measurement of transverse profiles with 0.3 mm precision
- Detection of 300 m wide road corridors with precisions of 3 mm
- Identifying cracks in road surfaces at speeds of 80 km/h with 1 mm precision

AUTONOMOUS SYSTEMS

- Measuring distances in turbid media
- Interpretation of 3D measurement data by methods such as »Deep Learning«
- Miniaturizing complex measurement systems for use on autonomous vehicles with a total weight of less than 1 kg
- Determining the position of mobile measurement systems by using visual odometry, positioning and orientation systems



>> Laser scanners provide detailed point clouds.

GROUP **LASER SCANNING**

Pure mathematics: Automatic object recognition

For humans, a lively street is like a very busy picture: cars, signs, trees, people and buildings, often one in front of the other. The brain is able to classify and pinpoint these objects effortlessly. But when an attempt is made to automate this process, it becomes clear how truly complex it is. As part of a research project, Fraunhofer IPM developed algorithms for the automatic identification and classification of objects on the road, with artificial neural networks forming the basis for pattern recognition.

Today, infrastructure is surveyed using high-performance cameras or laser scanners, which deliver high-resolution images and very accurate, georeferenced measurement data. Modern laser scanners record several million measurement points per second, providing a detailed map of the surrounding environment in the form of a 3D point cloud. The results are generally evaluated manually, which requires viewing extensive volumes of data (point clouds and image data). The automation of at least part of this time consuming process is the goal of a research project commissioned by Lehmann + Partner GmbH that Fraunhofer IPM is conducting for the Federal Highway Research Institute (BASt). The project involves developing algorithms to automatically identify, classify and locate elements of road infrastructure in 3D measurement data.

In order to evaluate road scenes, scientists are turning to complex learning algorithms based on the concept of deep learning using artificial neural networks (ANNs). This approach has been shown to be superior to traditional methods of object recognition. While the latter use feature sets provided by the developer, ANNs learn to recognize the relevant features on the basis of training data. In ANNs, the information provided passes through a large number of interconnected artificial neurons, where it is processed and transmitted to other neurons. ANNs learn the output patterns which correspond to specific input patterns with the help of manually annotated training data. On the basis of this »experience«, new types of input data can then be analyzed in real time. ANNs have proven to be very robust when confronted with variations on characteristic colors, edges and shapes.

Data fusion: Scanner data and camera images are merged to create the data pool

The more detailed the information in the data set, the more successfully objects can be recognized and classified. Camera and scanner data collected by a survey vehicle outfitted with laser scanners developed by Fraunhofer IPM and operated by project partner Lehmann + Partner form the basis of the project. Merged scanner and camera data serve as a suitable starting point for automatic object recognition. In one approach, georeferenced scanner data points are initially transferred to a grid format containing depth information and are then linked with RGB camera data. This pixel-based RGB-D(epth) data set contains a corresponding depth image for each RGB camera image, which makes it the ideal input format for ANNs. Scientists think that the depth values will help the network separate overlapping objects and generally make classifying and locating objects a more robust process.

DEEP LEARNING As a method of machine learning, deep learning is a subfield of artificial intelligence which relies on smart algorithms. For example, training data sets are used to identify objects in a picture. Deep learning is based on artificial neural networks and has been shown to be more robust when confronted with the varying forms and obscured, damaged or faded objects that are typical of street scenes than traditional methods of object recognition.

Using semantic segmentation to identify 3D georeferenced objects

The architecture of the network, in other words the number of network layers and the type of hierarchical links, is adapted to each specific task. The network is trained using a training data set. To this end, images are first semantically segmented manually and each pixel is attributed to a specific object class. Once a network has been trained with this data, it can be expanded to include additional object classes at any time with a new training data set. Using the pixel coordinates of the objects identified in the image data, the segmentation can be back-projected into the point cloud. To make this possible, the camera and laser scanner must be accurately aligned and the appropriate calibration parameters must be determined in a corresponding one-time process. Segmenting the point cloud enables georeferenced objects to be identified in 3D.

The topic of automatic object recognition is of interest to anyone faced with the task of evaluating large volumes of data. In the future, the challenges of surveying infrastructure will pale in comparison with the requirements of the automotive industry, which relies on this technology for self-driving vehicles. In autonomous driving, moving objects must be recognized in real time. This is where the neural networks of the human brain remain superior – for now.

1 *Recognizing, classifying and locating objects on the roads is time consuming. Pattern recognition using artificial neural networks automates this process.*

2 *Camera image and evaluated measurement image: Colored segmentation masks mark the forms of the identified objects.*

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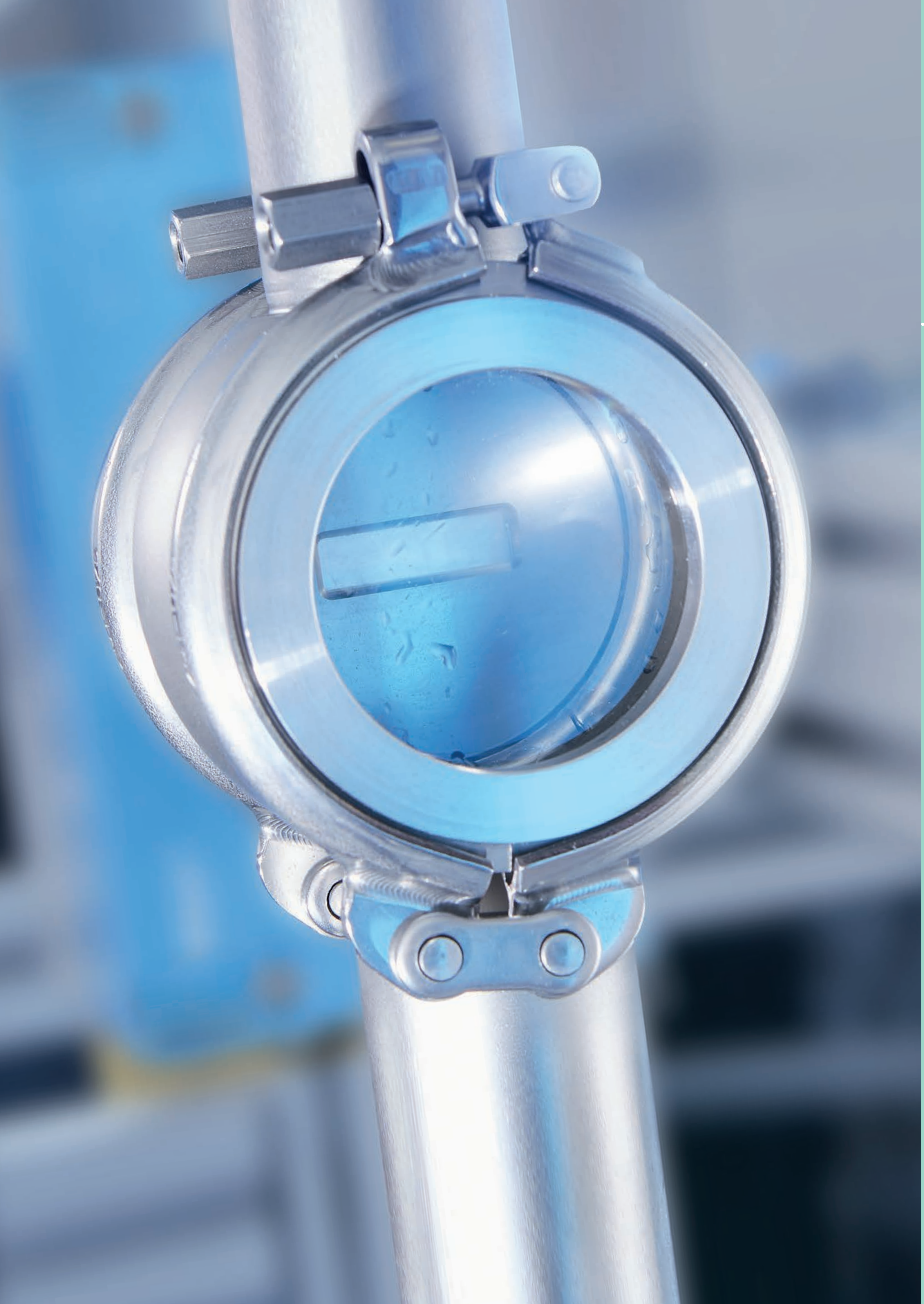

BUSINESS UNIT **GAS AND PROCESS TECHNOLOGY**

»We develop measuring technology – from sensors to complex systems.«

In its »Gas and Process Technology« business unit, Fraunhofer IPM develops and manufactures measuring and control systems to meet customer requirements. The main features of these systems are short measurement times, high precision and reliability, even in extreme conditions.

The expertise in the business unit includes laser spectroscopic methods for gas analysis, energy-efficient gas sensors, particle measuring technology and thermal sensors and systems. The scope of applications is massive – it extends from flue gas analysis and transport monitoring for food to sensors and systems for measuring very small temperature differentials.

Group Integrated Sensor Systems

- Gas sensitive materials
- Micro-optical components
- Miniaturized gas sensor systems

Group Spectroscopy and Process Analytics

- Spectroscopic analytics
- Optical systems
- Non-linear optics

Group Thermal Measurement Techniques and Systems

- Custom-made microstructures
- Thermal measurement systems
- Simulation of physical processes

< Spectroscopic sensors monitor the quality of drinks during production – without making a detour to the lab.

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GROUP **INTEGRATED SENSOR SYSTEMS**

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The main focus of this group is the development of functional gas sensitive materials and surfaces, and miniaturized gas sensor systems. Gas sensor technology and electronics are combined in compact, low cost microsystems for this purpose.

EXPERTISE

Customer-specific synthesis and processing of gas sensitive materials for specific applications | Micro-structured IR emitters as light sources in micro-optical sensors (MOEMS) | Embedding energy efficient gas sensor systems into wireless sensor networks

APPLICATIONS

Efficient air conditioning technology through selective detection of gases such as CO_2 | Early detection of fire gases like CO, NO_2 und NH_3 | Food quality monitoring in food warehouses or during transportation

>> In future, colorimetric fire gas detectors will identify fires at an early stage by measuring carbon monoxide and nitrogen oxide.

SPECIFICATIONS

GAS SENSITIVE MATERIALS

- Materials synthesis and processing, layers of a few nm to some µm, coatings of micro-structured substrates (MEMS)
- Semiconductor gas sensors: metal oxide layers such as SnO_2, WO_3 or $Cr_{2-x}Ti_xO_{3+z}$ with catalytic additives
- Colorimetric gas sensors, e.g. color change materials for CO, NO_2 und NH_3

MICRO-OPTICAL COMPONENTS

- IR emitters for a wavelength range of 5 to 12 µm, can be modulated if desired
- IR detectors (e.g. made of PbSe) for a wavelength range of 3 to 5 µm
- Diffractive optics, e.g. Fresnel lenses made of silicon or components for IR emitters

MINIATURIZED GAS SENSOR SYSTEMS

- Detection of gas concentrations from ppb to percent according to measurement principle applied, modular systems by combining various sensor principles
- Sensor technology for energy self-sufficient systems with wireless communication
- Miniaturized gas chromatography systems, photo-acoustic systems and filter photometers

GROUP **INTEGRATED SENSOR SYSTEMS**

Sulfur sensor for use on the high seas

Ship emissions heavily pollute marine ecosystems and are extremely detrimental to the health of humans in harbor areas. Alongside carbon dioxide and nitrogen oxides, seagoing vessels primarily emit large quantities of sulfur oxides. A new photoacoustic sensor system has now been developed that is intended to enable continuous monitoring of maritime SO_x emissions in future. This will be many times cheaper than the SO_x measurement systems currently available, yet will deliver comparable performance.

Sulfur oxides can trigger lung and cardiovascular diseases, and as water-soluble gases they contribute to the acidification of bodies of water and soil. However, low-sulfur marine fuels are far more expensive than heavy fuel oil. For this reason, shipping companies will continue to use heavy fuel oil in future, regardless of the stricter limits. Gas scrubbers installed on board ships will therefore be used to purify exhaust gas, removing harmful sulfur oxides to bring emissions into line with those of low-sulfur fuels.

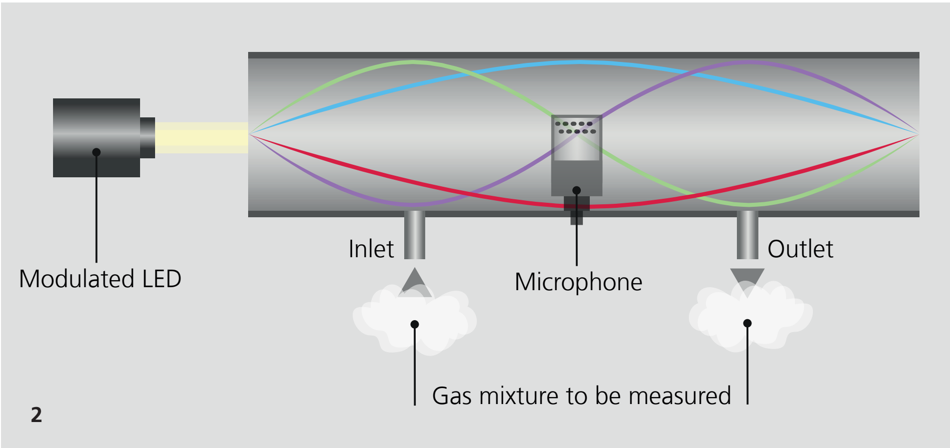
Measuring actual emissions

The International Maritime Organization's gauge for judging emission control is the actual output of SO_x, irrespective of the fuel used. Special exhaust gas measuring technology, which determines emission values every four minutes, will therefore be mandatory from 2020 on. Fraunhofer IPM is working together with industrial partners to develop a low-cost, photoacoustic sulfur oxide sensor system for marine use. The sulfur oxide measurement systems currently available on the market cost between 50 and 150 thousand euros – meaning that retrofitting an entire fleet will be a sizeable investment for ship-owners.

Photoacoustics: high measurement accuracy with inexpensive components

Photoacoustic sensors operate by converting light energy into sound. Here, the absorption of electromagnetic radiation by gas molecules is detected directly using a pressure transducer, which identifies the increase in pressure resulting from this absorption. Today's photoacoustic SO_2 measurement systems operate with relatively expensive lasers. The new sensor system, however, aims to employ low-cost, commercially available UV LEDs as light sources and microphones as detectors. As a result, the anticipated cost of such sensors is in the region of 5000 euros, in other words more than ten times cheaper than the current technology. The relative ease of handling provides a further advantage. Laser-based photoacoustic sensors are costly and difficult to stabilize, particularly under harsh measurement conditions. In the new sensor system, scientists use high power UV LEDs in a wavelength range of 270 to 310 nm, which corresponds precisely to an SO_2 absorption peak in the UV range. This prevents cross sensitivity to other gases. The aim is to achieve measurement accuracy in the region of 0.1 ppm. Depending on the exact process, photoacoustic systems employ virtually no mechanical parts, allowing them to operate maintenance free for a period of at least 12 months.

STRICTER EXHAUST GAS LIMITS FOR INTERNATIONAL SHIPPING From 2020 on, the International Maritime Organization (IMO) is imposing tighter limits on global sulfur emissions. The current limit on sulfur content in heavy fuel oil is set at 3.5 percent – and is thus up to 3500 times higher than the value permitted for motor fuel. In future, the SO_x emissions from seagoing vessels will be required to have a fuel sulfur content of just 0.5 percent. The so-called »Emission Control Areas« in the EU and the US already impose limits of 0.1 percent.



1 *In future, on board measurement technology will ensure that stricter limits on air pollutants are met.*

2 *The light is guided into the measurement cell through a window. A microphone records a photoacoustic signal in the gas flow which provides information on the concentration of different gases.*

The key component in a resonant photoacoustic sensor system is the measurement cell. Light from the UV LED is guided into the cell through a window incorporated into its side. Gas exchange occurs through an inlet and outlet aperture. A commercial microphone measures the photoacoustic signal. Initial tests with CO_2 show that measurements can be performed under gas flow, removing the need for additional valves and pumps to extract the gas samples. Work within the »E-MASUM: Marine Sulfur Monitor« project, funded as part of the Eurostars program, focuses on measuring SO_2, which constitutes 95 percent of sulfur oxide emissions. A later sulfur monitor will be equipped with an additional CO_2 sensor, allowing sulfur concentrations to be analyzed in relation to fuel consumption. To ensure that the sensors are suited to use in a marine environment from the very outset, the project partners are working closely with manufacturers of marine gas scrubbers and sensor systems. A field test demonstrator is being operated until the project concludes in 2018, and is intended to show that photoacoustic measurement systems can work reliably on board seagoing vessels. The majority of the 90,000 ships that cross the world oceans will need to install gas scrubbers and corresponding measurement technology in the near future — the market potential is therefore immense.

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BUSINESS UNIT **GAS AND PROCESS TECHNOLOGY**

GROUP **SPECTROSCOPY AND PROCESS ANALYTICS**

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The main focus of this group is the development of spectroscopic systems for the detection and analysis of gases, liquids and solids. The group uses its long experience in exhaust gas, combustion gas and particle measuring technology for this purpose. Methods such as Raman, ATR or laser spectroscopy are employed. The group's services range from laboratory testing to prototype development and support in the implementation of batch production processes.

EXPERTISE

IR and laser spectrometers as a basis for measurement systems in gas and liquid analytics and materials testing | Methods for simulation and analysis of special optical assemblies and electronic components | Development and realization of tunable laser light sources for spectral ranges not yet covered

APPLICATIONS

Gas analyzers for monitoring the caloric value of natural gas in pipe systems | Fast process spectrometer for exhaust gas test bench in the context of motor development | Imaging IR measuring technology for safety and leakage surveillance of industry plants

SPECIFICATIONS

SPECTROSCOPIC ANALYTICS

- Optical trace gas analyzers based on quantum cascade lasers (QCL): sensitivity of 10 ppb for N_2O or NH_3 and 10 ppm for O_2
- Raman spectroscopy: analysis of liquids, biological cells or gases
- ATR spectroscopy: measuring gas concentrations in liquids down to the ppm range
- Laser absorption spectroscopy: determining residual absorption of down to 1 ppm in materials
- Chemometric data processing methods

OPTICAL SYSTEMS

- Multi-reflection absorption cells: 0.1 to 15 m optical path, up to 200 °C
- Mirror optics: White, Herriott and single pass set-ups, UV optics
- Resonator systems: broadband optical ring resonators and linear resonators
- Simulation: optics, mechanics, current, electronics

NON-LINEAR OPTICS

- Optical-parametric oscillators: tunable from 450 nm to 5 µm, 10 mW to 2 W output (depending on wavelength)
- 1 MHz line width
- Frequency doubling: over 50 percent conversion efficiency
- MIR-NIR conversion: recording of MIR process data with more than 5000 spectra per second

>> Robust process measuring technology is required by industrial sectors such as the chemical industry.

GROUP **SPECTROSCOPY AND PROCESS ANALYTICS**

Process measurement technology for the beverage industry

In order to ensure quality in drinks manufacturing, CO_2, alcohol and sugar content need to be measured regularly during production. In future, a sensor with online capability based on ATR spectroscopy will record these values continuously – without making a detour to the lab.

Anyone enjoying a beer at the end of a long working day relies on the fact that it will taste as it always does. In alcoholic fermentation, a complex biological process takes place which converts sugars into alcohol and carbon dioxide. Knowing precisely how and when this conversion takes place is crucial to the quality of the beer. For this reason, taking samples at regular intervals during the production of beer, wine and spirits as well as soft drinks, and analyzing them in a laboratory is standard practice. The ability to take measurements directly within the process would therefore simplify the procedure significantly. Together with the Centec Gesellschaft für Labor- und Prozessmesstechnik mbH, Fraunhofer IPM is developing an optical infrared measurement system for liquid analysis that works on the principle of attenuated total reflection (ATR) spectroscopy and, alongside dissolved carbon dioxide and alcohol content, also records levels of sugar in its various forms in-situ.

Compact, spectrally adaptive, pyroelectric detectors

A few isolated inline liquid analysis systems are already available on the market. They measure density, sound, turbidity and the optical refractive index of the liquid in order to draw conclusions concerning relevant variables such as essence, alcohol and original wort, based on calibration and comparison with stored comparative lab data. However, the sum parameters they determine provide no specific information on ingredients and their concentrations. Yet the inaccuracy that results from the fluctuating composition of natural raw ingredients, which may affect product quality, makes this information necessary.

In the new liquid sensor, scientists employ ATR spectroscopy in the mid-infrared range. Here, the light beam passed through the ATR crystal is totally reflected at the crystal boundary surface in contact with the liquid. This beam interacts with the liquid flowing across it via the resulting evanescent field at the crystal surface. After it has passed the entire crystal, the transmitted light is collected by a detector. Pyroelectric detectors with spectral filter elements are used for this purpose. If, for instance, only CO_2 concentrations are to be determined, spectral band-pass filters are employed that are specifically tuned to the characteristic absorption bands of around 4.3 µm. However, to identify several components simultaneously with one sensor, pyroelectric detectors are also being used for the first time in combination with tunable Fabry-Perot filters. They record full spectral profiles in selected ranges. Registering a quasi-continuous spectral range in combination with chemometric methods makes it possible to distinguish spectrally overlapping components (e.g. different sugars, ethanol, etc.). CO_2 and ethanol exhibit particularly characteristic absorption bands in the wavelength range from 3.1 to 4.4 µm. In the case of sugar (and also ethanol), this spectroscopic fingerprint lies between 8 and 10.5 µm. The compact detectors operate maintenance free, with no mechanical parts, and are integrated within a hermetically sealed sensor head. When other parameters, such as temperature, are involved, the concentrations of selected components are determined and read out following chemometric data analysis. Initial test series with a variety of liquids confirm that the sensor supplies sufficiently accurate, reproducible values for CO_2 and ethanol.

ATR INFRARED SPECTROSCOPY In ATR-IR spectroscopy, a beam of light is passed through a reflection element where total internal reflection occurs before the beam is collected by a detector. In this process, an optical near-field forms at the boundary surface of the element – this is the so-called evanescent field which penetrates into the sample. The wave interacts with the sample and is absorbed in certain material-specific wavelength ranges. Subsequent to its repeated total internal reflection, the areas absorbed in the beam's spectrum attenuate accordingly and provide a concentration measurement for the desired substances.

1 Measurements that can be performed directly within processing will make quality control in drinks production significantly easier.

2 The sensor determines the concentrations of CO_2, alcohol, and sugar in the flowing liquid as a direct part of the process.

A particularly harsh measurement environment

The harsh conditions that prevail in beverage manufacturing present a significant challenge. Large fluctuations in temperature and pressure, noise and jarring have an impact on ATR elements, light sources and detectors. Appropriate miniaturized sensor technology ensures, however, that these influential factors are recorded so as to correct any potential measurement errors. To maintain a constant inert atmosphere in the sensor head, it must be reliably sealed. As a result, it was necessary to perform testing on custom-made food grade seals in order to guarantee this. Other work focused on determining sugar concentrations and optimizing chemometric evaluation.

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GROUP **THERMAL MEASUREMENT TECHNIQUES AND SYSTEMS**

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This group develops thermal sensors and systems made of various materials. Flexible substrates allow very small temperature differentials to be measured using so-called calorimeter chips and a wide range of material parameters, such as thermal and electrical conductivity, to be determined using press-on measuring structures.

EXPERTISE

Development and manufacture of custom-tailored microstructuresand microsystems | Customer-specific measurement systems for temperature dependent determination of material parameters | Coupled thermal-electrical finite element models for thermal impedance analysis

APPLICATIONS

Low-cost fluid sensor technology on polymer substrates, e.g. for monitoring oil quality | Sensors for measuring fouling processes in industrial plants | Modelling and validation of energy storage systems for geothermal applications

SPECIFICATIONS

CUSTOM-MADE MICROSTRUCTURES

- Microstructures for organic electronics, heaters and microfluidics with structures of typically 1 µm
- Thermopile sensors, fouling sensors, calorimetric sensors
- Thermal sensors for determining material parameters, especially thermal conductivity
- Electronic tongues

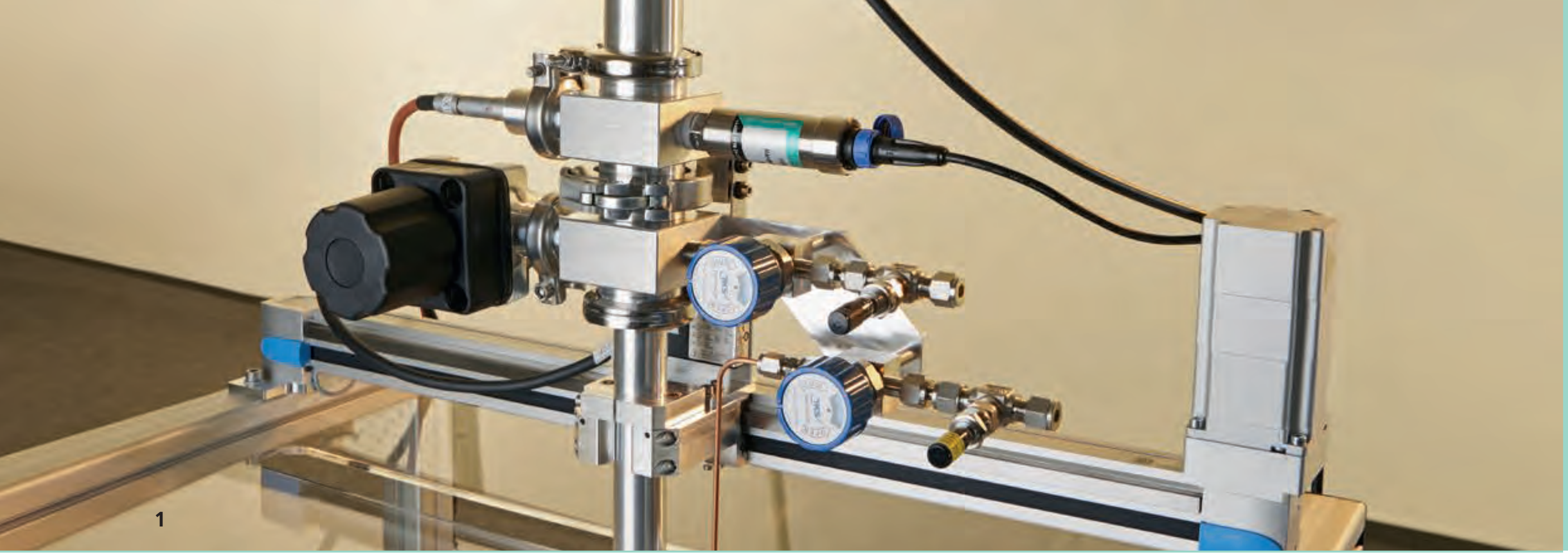
THERMAL MEASUREMENT SYSTEMS

- Systems for determining electrical conductivity, charge carrier concentration, Seebeck coefficient, majority charge carriers, e.g. by way of Hall measurements on semiconductors from –200 to 800 °C
- Systems for measurement of thermal properties of solids, liquids and gases by employing methods such as impedance and 3 omega

SIMULATION OF PHYSICAL PROCESSES

- Coupled finite element models (FEM)
- Computational fluid dynamics (CFD) combined with thermal analysis
- Simulation of geothermal processes and design of energy storage devices
- Thermal management for electronic systems

>> Simulation of geothermal processes forms the basis for novel energy storage systems.



GROUP **THERMAL MEASUREMENT TECHNIQUES AND SYSTEMS**

High temperature materials characterization

In order to characterize semiconductors and other solid materials, the temperature of samples often needs to be controlled in a very precise and specific way. Fraunhofer IPM has optimized its IPM-HT-Hall high-temperature Hall measurement station to allow materials to be characterized at temperatures of between 20 and 800 °C, with up to four material parameters being investigated simultaneously.

Commercially available Hall measurement devices – also known as »Physical Property Measurement Systems« – are based on cryostat systems and are therefore designed for low temperatures from around 4 K to a maximum of 400 K. To date few commercial systems have been made available for the range from room temperature to 800° C, which is particularly useful for thermoelectric materials and high temperature semiconductors. Fraunhofer IPM has therefore developed a novel setup specifically for Hall measurements from 20 to 800 °C which enables quick, easy and reliable measurement. The new IPM-HT-Hall measurement station has been successfully tested up to 800°C. In addition to determining electrical properties, the measuring station can also be used to perform extremely precise measurements of thermal and magnetic properties in various geometries over a wide temperature range with up to five different magnetic field strengths.

Optimizing functional materials

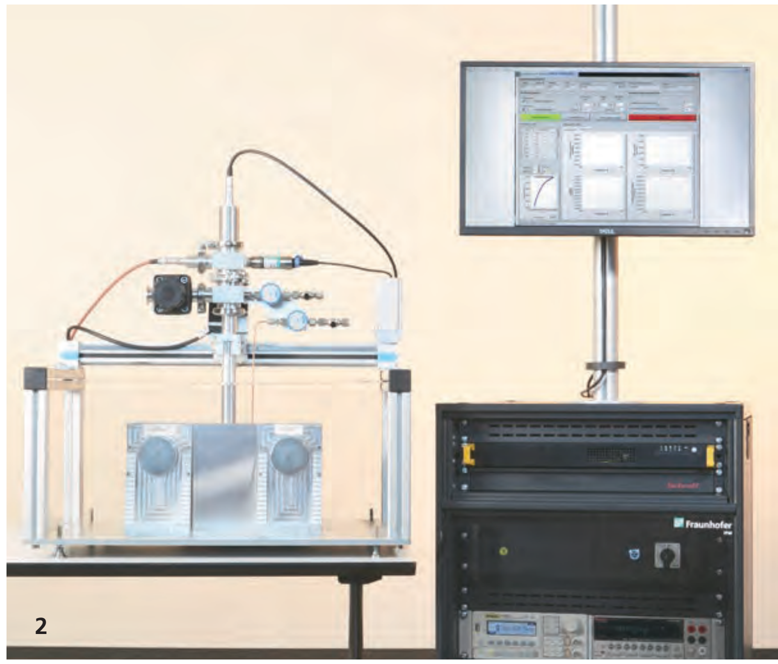
Modern semiconductor components often work at temperatures well above room temperature. In order to ensure the best operational settings – e.g. by doping – the component's characteristic material properties must also be measured at the actual operating point – e.g. at high temperatures. »Doping« is the process of adding a specific quantity of impurity atoms to a semiconductor with the aim of influencing the number, mobility and type of charge carriers. It is not only doping, however, but also ambient temperature that has an influence on the number of charge carriers. The higher the temperature within the material, the more charge carriers become activated. Here, IPM-HT-Hall helps to detect the impact of doping at different temperatures. The system is highly sensitive and records even minimal changes in the concentration of charge carriers. Furthermore, alongside standard sensor heads for Hall measurements, the new high temperature measurement station allows operators to integrate their own unique sensor heads and independently developed measurement electronics into the system.

Universal and variable – for many specialist tasks

Hall measurements have become an almost indispensable tool in the development of modern materials. Fraunhofer IPM's high temperature Hall measurement station is ideally suited to optimizing very specific materials such as thermoelectric semiconductors or semiconductor gas sensors. Optimizing thermoelectric semiconductors: The charge carrier concentration in these materials can also be increased with specific doping to improve electrical conductivity. However, doping also unintentionally causes the Seebeck coefficient to drop. This coefficient defines the voltage in the thermoelectric material caused by a difference in temperature. In order to achieve optimum efficiency in the thermoelectric material, both the charge carrier concentration and the Seebeck coefficient must be taken into consideration. Since, as a rule, less than a single dopant atom is introduced per 1,000,000 thermoelectric material atoms, it is obvious that precise doping is essential here. This process can be accurately controlled by using Hall measurements.

Developing semiconductor gas sensors: When characterizing gas sensor materials, it is important to be able to measure characteristic material properties at precisely defined high temperatures and to perform these measurements with precisely controlled gas concentrations. Here, the new Hall measurement station offers the opportunity to start measurements automatically once the necessary conditions are stable, or to start them following checks by metrologists.

HALL-EFFECT Edwin Herbert Hall discovered the Hall effect named after him in 1879. He observed the fact that electric current in a conductor can be influenced by applying a magnetic field. The voltage created as a result allows scientists to gain deep insights into the conductor material being investigated. This effect can be measured via the voltage, which is tapped perpendicular to both the current and the magnetic field on the conductor.



1 *Thanks to the new high temperature Hall measurement station, semiconductor materials can be characterized and optimized at temperatures exceeding 800 °C.*

2 *Alongside standard sensor heads for Hall measurements, other sensor heads and measurement electronics can also be integrated into the station.*

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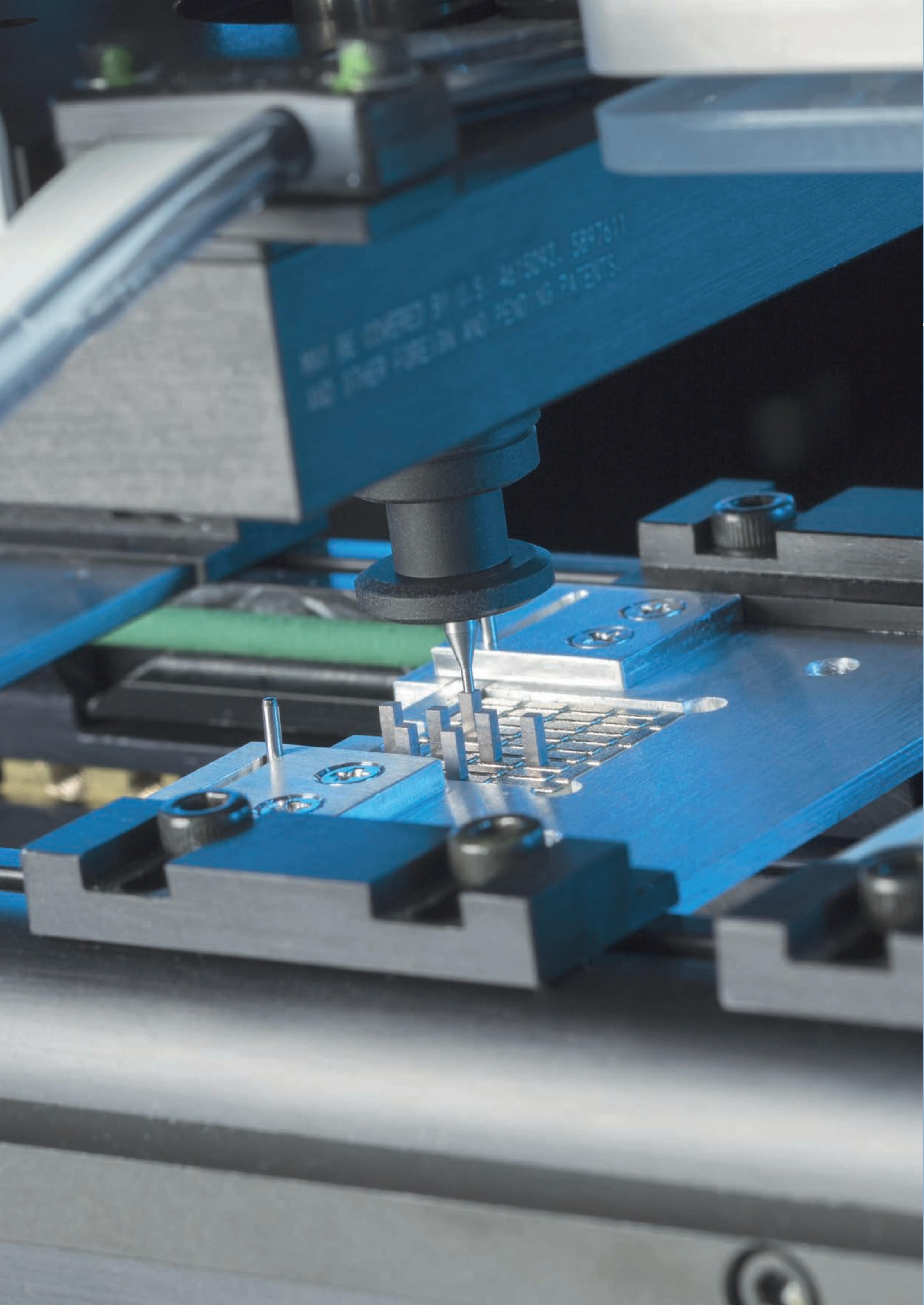

BUSINESS UNIT **THERMAL ENERGY CONVERTERS**

»We integrate outstanding material properties into systems«

Functional materials with special physical properties are a focus of the research performed by the »Thermal Energy Converters« business unit. We use caloric and thermoelectric materials to build innovative systems for cooling, temperature control and converting heat into electricity. Using these materials in heat pumps, cooling systems and generators makes the systems we develop especially environmentally friendly, cost-efficient and durable. Our work draws on more than 20 years of experience in material synthesis and far-reaching expertise in special measurement techniques, simulation, module construction and system integration.

Group Calorics and Thermoelectrics

- Cooling and heating
- Thermal management
- Waste heat recovery

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< Positioning robot for the semi-automatic fabrication of high-temperature thermoelectric generators – a step towards industrial module production.

GROUP **CALORICS AND THERMOELECTRICS**

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The group's primary goal is the development of efficient and environmentally friendly cooling systems, heat pumps and thermoelectric generators on the basis of innovative functional materials. This work is guided by questions of environmental compatibility, industrial manufacturing, integration into systems and not least availability of raw materials. When it comes to materials development, the focus is always on the specific application in a system – from thermoelectric high-temperature generators to the use of Peltier modules to exploit waste heat for temperature management to environmentally friendly cooling systems that are based on magnetocaloric, electrocaloric and elastocaloric materials and do not require harmful refrigerants.

>> Thermoelectric generators raise the electrical and hence economic efficiency of combined heat and power plants.

EXPERTISE

Magneto-, electro- and elastocaloric systems for efficient cooling and heating | Pulsed heat pipes for the efficient transfer of thermal energy from hotspots | Cost-efficient production of thermoelectric modules

APPLICATIONS

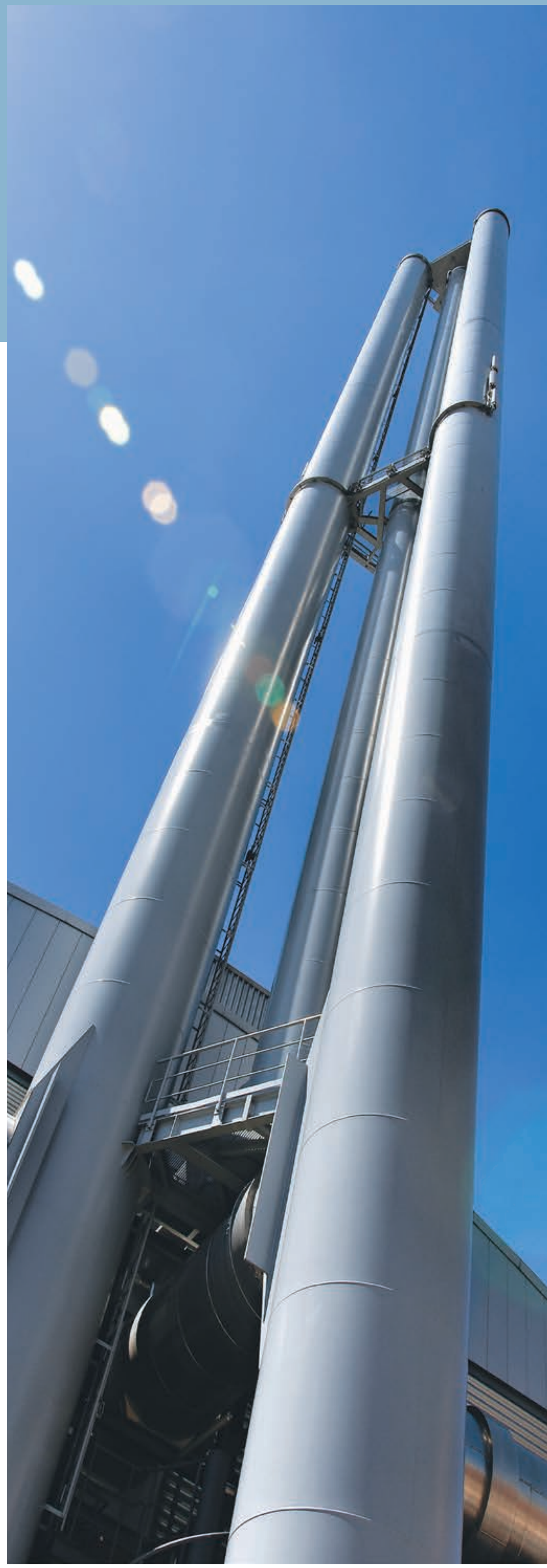
Efficient caloric cooling systems for air-conditioning in cars without harmful refrigerants | Optimized thermal management for reduced failure risk of electronic devices | Thermoelectric generators for enhancing electrical efficiency of combined heat and power plants

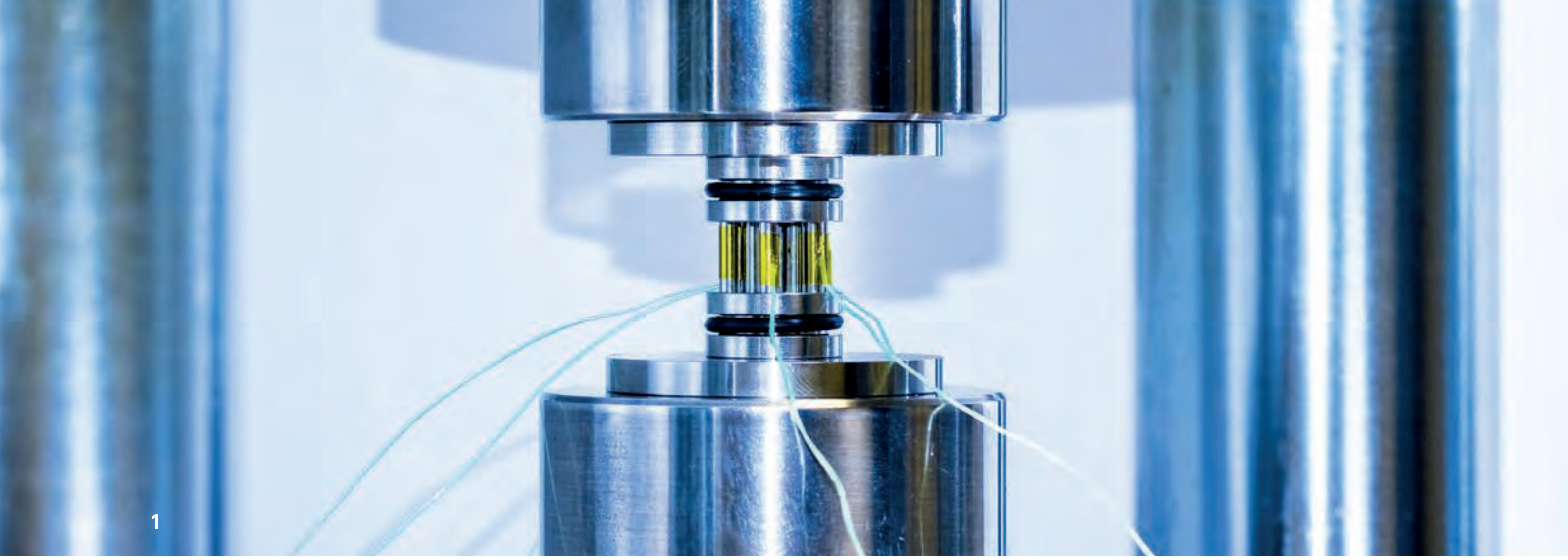
SPECIFICATIONS

COOLING AND HEATING
- Less need for energy thanks to efficient technology
- Cooling without harmful refrigerants
- Compact system design through high energy density of caloric materials
- Low-maintenance systems

THERMAL MANAGEMENT
- Fast and precise temperature regulation with Peltier elements
- Passive cooling of electronic parts by means of heat pipes
- Efficient thermal distribution by using pulsed heat pipes

WASTE HEAT RECOVERY
- Thermoelectric modules for high-temperature applications
- Enhancing electrical efficiency of CHPP with the help of thermoelectric modules
- Turning waste heat into electrical energy: in cars and in industrial processes





1 *Heat generated by pressure: Elastocaloric materials heat up when deformed. This reversible effect can be exploited in the construction of heat pumps.*

GROUP **CALORICS AND THERMOELECTRICS**

Efficient elastocaloric heat pumps

Heat pumps operate almost exclusively with compressors, regardless of whether they are used for heating or cooling. They pollute the environment with refrigerants and achieve only comparatively low levels of efficiency. Fraunhofer IPM is therefore developing efficient elastocaloric heat pumps that exploit an innovative new heat transfer concept as an alternative to compressor technology.

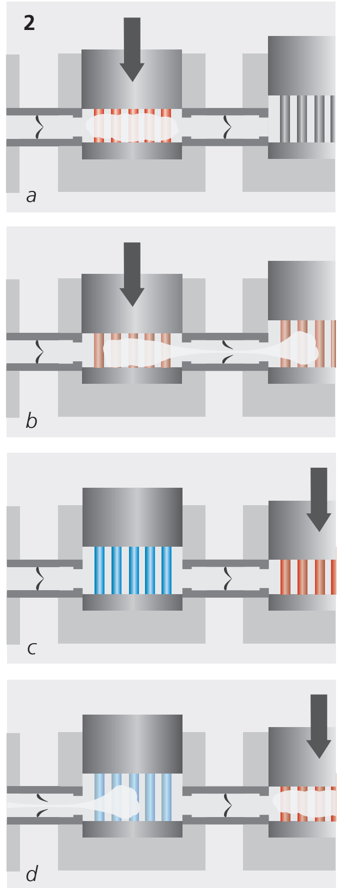
Air-conditioning devices in homes and cars, fridges and geothermal heating systems all work with heat pumps. Most of the refrigerants employed in them are dangerous or harmful, as a result of which the EU is gradually phasing in restrictions on their usage from 2020 on. New technologies for the heat pump market, which is worth millions, are therefore urgently needed. For some years now, solid-state caloric systems based on magnetocaloric, electrocaloric or elastocaloric materials have been seen as promising alternatives and have been the subject of intensive research, including at Fraunhofer IPM.

Elastocaloric (EC) materials can adopt two different crystal structures. When pressure is exerted on them, a crystalline phase change takes place in which the material warms from the initial temperature T_0 to $T_0+\Delta T$. The heat generated is carried off via a heat sink and the temperature of the material returns to the temperature T_0. If the mechanical stress is removed, the material cools to a temperature below the initial level ($T_0-\Delta T$). When the material is placed in contact with an area that needs to be cooled, it absorbs heat until the initial temperature is reached. Repeatedly exerting stress on the material then removing it, and combining this with an appropriate means of heat dissipation, allows a cycle to form. This creates an efficient heat pump – for cooling or heating without harmful refrigerants. Shape-memory alloys such as the commercially available nickel-titanium alloy Nitinol are among the materials with a significant elastocaloric effect, big enough to enable a large temperature difference.

Latent heat transfer increases efficiency

Using an experimental set-up, researchers at Fraunhofer IPM achieved a temperature difference of 15 K when applying a pressure of 750 MPa to Nitinol rods. Other research teams have also achieved comparable temperature differences. It is the transfer of heat between the EC material and the heat exchanger, however, that is the decisive factor in the overall efficiency of electrocaloric heat pumps. Conventional concepts use active fluid pumping to achieve this. The disadvantage of this approach is that pumping restricts heat transfer and limits the cycle frequency of the system to just a few Hertz. By employing the concept of latent heat transfer, Fraunhofer IPM is for the first time adopting a passive approach that is already utilized in heat pipes and thermosiphons. Here, heat is transferred (latently) by evaporating and condensing a fluid such as water or ethanol. The fluid is contained in a hermetically sealed tube that is free from all extraneous gas, and is present in both liquid and gaseous form. The heat transfer coefficient during evaporation reaches values of up to 100 kW / (m²K), and is therefore many orders of magnitude higher than that achieved with classic systems. Several elastocaloric units are connected in series and designed as thermal diodes, so that heat is transported segment-by-segment in a single direction such that one side of each segment is cooled and the other heated. Initial estimates show that heat can be transmitted from one segment to the next in milliseconds, allowing the system to operate with a frequency of over 10 Hz. This patented combination of latent heat transfer and thermal diodes in an elastocaloric heat pump promises to offer high levels of pumping capacity and a high degree of efficiency.

THE ELASTOCALORIC EFFECT was observed as long ago as the early 19th century when rapidly stretching and releasing Indian rubber. Some 50 years later, the physicist J.P. Joule reported on small reversible temperature changes in metal and wood caused by applying force. It wasn't until the 1980s, however, that studies were performed on latent heat development and the corresponding temperature changes seen in NiTi and Cu-based materials.



2 *How an EC segment works: Phase 1 – compression: (a) The EC material is compressed and heats up; the liquid present evaporates. (b) This causes the vapor pressure in the segment to rise, the valve to the right opens, the gaseous fluid escapes and latent heat is transferred to the next segment. Phase 2 – release: (c) The external force is removed and the EC material cools. (d) The vapor pressure falls and a vacuum develops in relation to the previous segment. Gaseous fluid flows in and heat from the previous segment is absorbed.*

First prototypes developed

To date, IPM researchers have achieved a temperature lift of 10 K by setting up a system based on commercially available EC materials. The next goal is to build an EC heat pump as a demonstration unit that achieves a pump capacity of 100 W and a temperature difference of 35 K at a coefficient of performance of over 5. A series of challenges must be overcome in order to do this, however. Firstly, the material needs to display cycling stability. Furthermore, the desired coefficient of performance can only be achieved through maximum possible recovery after elastic deformation. The intention is therefore to develop a suitable concept for energy recuperation using eccentric actuators. Extensive simulations and design optimizations are also required here.

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RESEARCH OF PRACTICAL UTILITY

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 69 institutes and research units. The majority of the 24,500 staff are qualified scientists and engineers, who work with an annual research budget of 2.1 billion euros. Of this sum, 1.9 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

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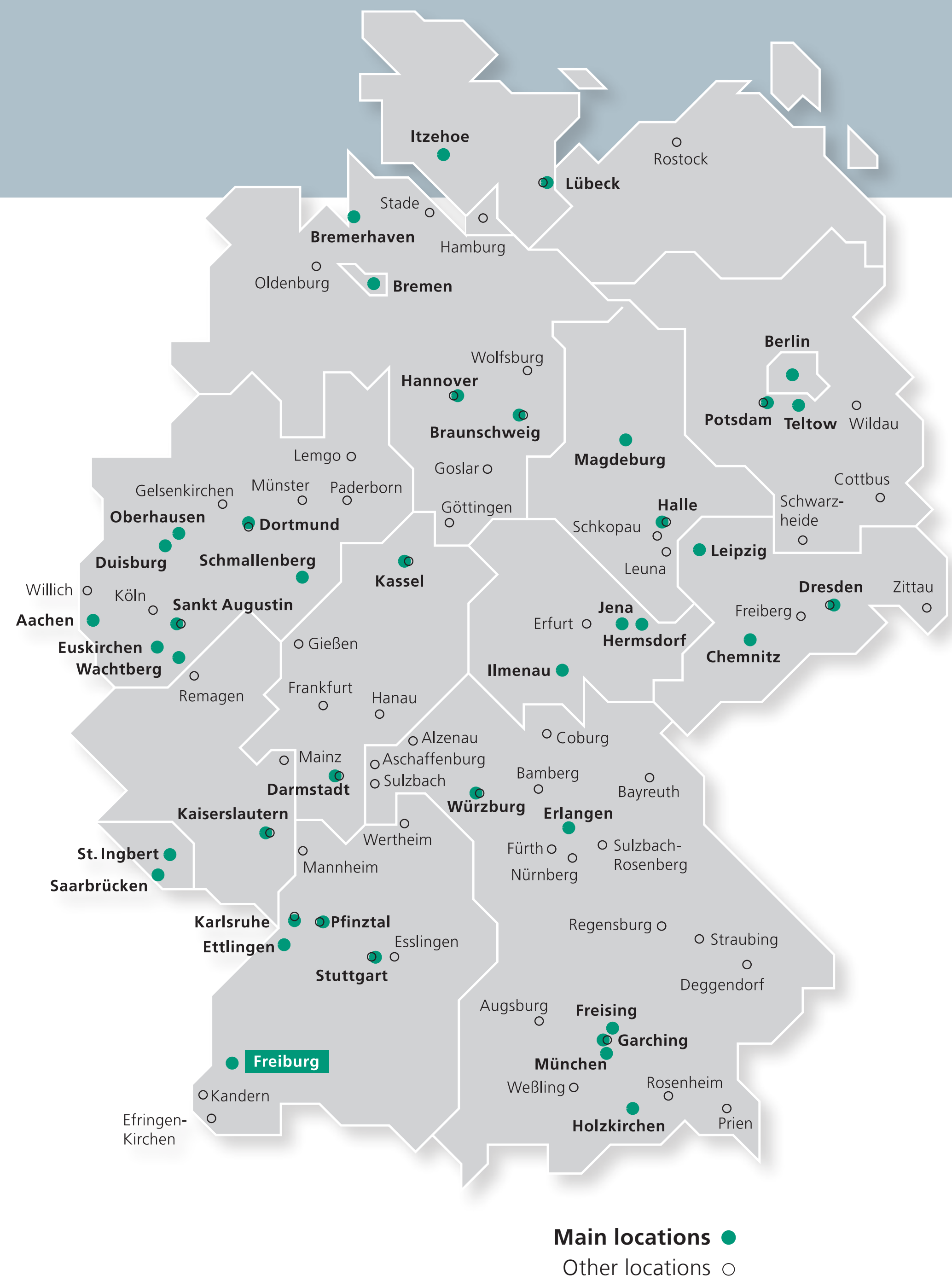

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OUR PARTNERS

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

Fraunhofer-Gesellschaft

- Fraunhofer Group Light & Surfaces
- Fraunhofer Cleaning Technology Alliance
- Fraunhofer Food Chain Management Alliance
- Fraunhofer Traffic and Transportation Alliance
- Fraunhofer Vision Alliance

International

- AAAS – American Association for the Advancement of Science
- ACS – American Chemical Society
- ETS – European Thermoelectric Society
- ITS – International Thermoelectric Society
- IEEE – Institute of Electrical and Electronics Engineers
- MRS – Material Research Society
- OSA – Optical Society of America

Germany

- AMA Fachverband für Sensorik
- Arbeitskreis Prozessanalytik der GDCh und DECHEMA
- Biovalley Deutschland e.V.
- CAST e.V. – Competence Center for Applied Security
- CNA Cluster Bahntechnik e.V.
- DFO – Deutsche Forschungsgesellschaft für Oberflächenbehandlung
- DKV – Deutscher Kälte- und Klimatechnischer Verein e.V.
- Draht-Welt Südwestfalen – netzwerkdraht e.V.
- DTG – Deutsche Thermoelektrik Gesellschaft e.V.
- FAIM – Forum Angewandte Informatik und Mikrosystemtechnik e.V.
- GDCh – Gesellschaft Deutscher Chemiker
- Green City Freiburg Regional Cluster
- innoEFF Innovations- und Effizienzcluster
- Klimaschutz am Oberrhein e.V. (Strategische Partner)
- microTEC Südwest e.V.
- Nano-Zentrum Euregio Bodensee e.V.
- Photonics BW Innovationsnetz für Optische Technologien
- SPECTARIS – Deutscher Industrieverband für optische, medizinische und mechatronische Technologien e.V.
- VDI/VDE – GMA Gesellschaft für Mess- und Automatisierungstechnik
- VDSI – Verband für Sicherheit, Gesundheit und Umweltschutz bei der Arbeit e.V.

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FAIRS 2016

wire
International Wire and Cable Trade Fair
Düsseldorf, April 4 – 8, 2016
Fraunhofer IPM presented a method for contactless layer thickness measurement using terahertz waves as well as the WIRE-HR wire inspection system, which conducts a complete inspection of the wire surface during the drawing process at speeds of up to 30 m/s.

Hannover Messe
Digital Factory
Hannover, April 25 – 29, 2016
Baden-Württemberg shared booth on Industry 4.0
At the Hannover Messe 2016, Fraunhofer IPM presented the Track & Trace Fingerprint process for marker-free component identification. This process enables full traceability, even for small, inexpensive parts.

Control
International Trade Fair for Quality Assurance
Stuttgart, April 26 – 29, 2016
Fraunhofer-Allianz Vision booth
Fraunhofer IPM presented systems for marker-free tracing of components on the basis of their surface structure, image-based inline detection of residual contamination and defects, and contactless inline layer thickness measurements using terahertz waves.

E-MRS Spring Meeting
European Materials Research Society
Lille, May 2 – 6, 2016
Booth with Quick-Ohm Küpper & Co. GmbH
At the spring meeting of the European Materials Research Society, Fraunhofer IPM collaborated with Quick-Ohm Küpper & Co. GmbH to present individual measurement systems for materials characterization.

Sensor+Test
The Measurement Fair
Nuremberg, May 10 – 12, 2016
Fraunhofer-Gesellschaft booth
Fraunhofer IPM presented mechanically flexible gas, liquid and solid-state sensors for applications in areas such as food chain management, automobiles, process control and biotechnology.

parts2clean
Leading International Trade Fair for Industrial Parts and Surface Cleaning
Stuttgart, May 31 – June 2, 2016
Fraunhofer-Gesellschaft booth
Fraunhofer IPM presented two exhibits on quality control and identifying defective components during production processes in the automotive and medical technology industries as well as in plant construction and roll-to-roll processes.

InnoTrans
International Trade Fair for Transport Technology
Berlin, September 20 – 23, 2016
Fraunhofer-Gesellschaft booth
Fraunhofer IPM presented the Contact Wire Inspection System (CIS), which determines both the position and degree of wear of as many as ten contact wires simultaneously with one single measurement process.

Chillventa
The Exhibition for Energy Efficiency, Heat Pumps and Refrigeration
Nuremberg, October 11 – 13, 2016
Fraunhofer IPM demonstrated a novel, patented system concept for caloric cooling based on latent heat transfer.

electronica
World's Leading Trade Fair for Electronic Components, Systems and Applications
Munich, November 8 – 11, 2016
Fraunhofer-Gesellschaft booth
At electronica 2016, Fraunhofer IPM presented systems for using imaging to test for contamination and identify defects as well as for real-time measurement of micro deformation in electrical components.

FAIRS 2017: PREVIEW

Control
Stuttgart, May 9 – 12, 2017

Sensor+Test
Nuremberg, May 30 – June 1, 2017

LASER World of PHOTONICS
Munich, June 26 – 29, 2017

INTERGEO
Berlin, September 26 – 28, 2017

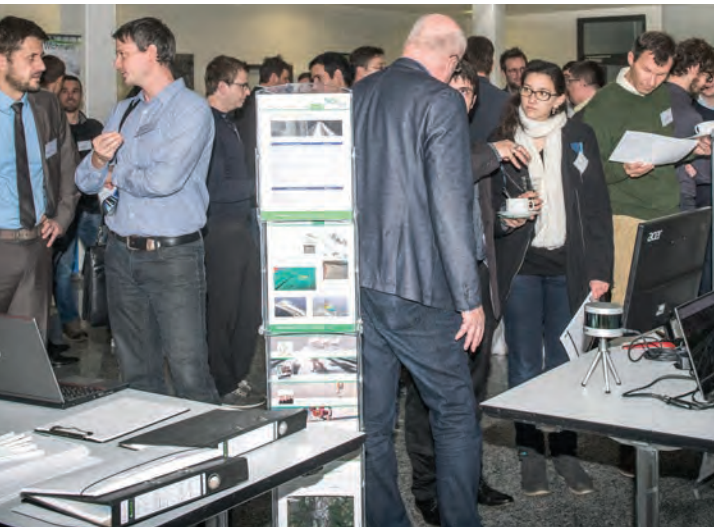
DeburringEXPO
Karlsruhe, October 10 – 12, 2017

parts2clean
Stuttgart, October 24 – 26, 2017

Blechexpo
Stuttgart, November 7 – 10, 2017

^ At the »Digital Factory« of the Hannover Messe, Fraunhofer IPM presented »Track & Trace Fingerprint«, a system for tracing components without markers.

EVENTS AND WORKSHOPS AT FRAUNHOFER IPM



Lively discussions took place during breaks at the MoLaS Workshop: Fraunhofer IPM organized the event on mobile laser scanning for the second time.

Spectaris Wissensraum: Modern optical analysis methods in medical technology
Fraunhofer IPM, Freiburg, January 28, 2016
Experts reported on current requirements in the field of optical diagnostics and discussed various approaches that use optical sensors.

Internationaler Terahertz-Workshop 2016
Fraunhofer IPM, Kaiserslautern, March 15–16, 2016
Terahertz technology is an exciting and rapidly developing field. The goal of the seventh International Terahertz Workshop was to give scientists and industry the opportunity to share knowledge and experience.

Girls' Day
Fraunhofer IPM, Freiburg, April 28, 2016
In 2016, Fraunhofer IPM participated in international Girls' Day for the 16th time in order to spark girls' interest in pursuing scientific careers. Girls in eighth grade and above had the opportunity to visit Fraunhofer IPM and see its laboratories and workshops.

MoLaS–Technology Workshop Mobile Laser Scanning
Fraunhofer IPM, Freiburg, November 23–24, 2016
Mobile laser scanning has developed into a key technology in 3D surveying. At the Mobile Laser Scanning Workshop, internationally recognized experts presented the latest technological trends in this field to over one hundred participants.

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Übersetzungsbüro Peschel, Freiburg

Picture acknowledgements
ArTo / Fotolia (p 32)
christian42 / Fotolia (p 41)
Dominik Probst (p 14)
Fraunhofer IPM (p 27,39,53)
Holger Kock (p 3,4,5,6,7,9,12,13,16,18,19,22,23,25,29,35,49,52)
Kai-Uwe Wudtke (p 4,5,28,34,43,46,47,48)
Kai-Uwe Wudtke / Montage: Fraunhofer IPM (Cover)
kister scheithauer gross architekten (p 11)
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Kushnirov Avraham / Fotolia (p 45)
Lehmann + Partner GmbH (p 17,31,33)
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Petra Bork / pixelio.de (p 51)
Sabine Gabele (p 14)
Andreas Blug (p 13)

Print
Druckerei Herbstritt GmbH, 79350 Sexau

FSC MIX Papier aus verantwortungsvollen Quellen FSC® C106855

www.ipm.fraunhofer.de/en