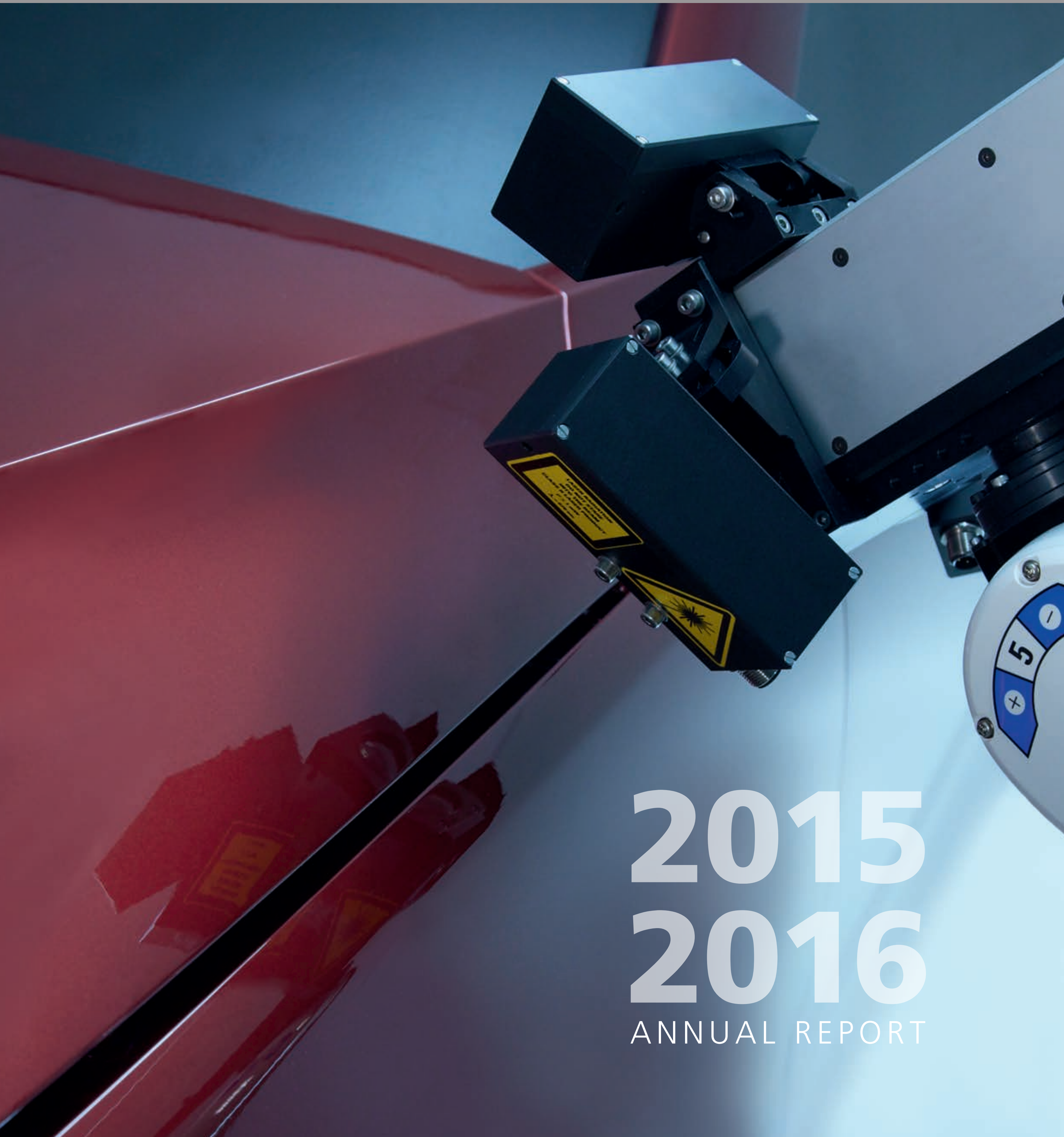
Fraunhofer IPM

FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM



2015 2016 ANNUAL REPORT

MEASURING · MONITORING · OPTIMIZING

Cover *Terahertz systems detect the thickness of individual layers of paint on car bodies.*

»Computing power meets measurement systems«

Prof Dr Karsten Buse, Director

Dear customers and partners,

Fraunhofer IPM develops and builds measurement systems that are setting world records for speed and precision. The fusion of mechanics, electronics and typically also optics – based on expertise gained from our current research – characterizes our technological developments. In recent years another trend has played an increasingly important role: digitalization. Today, a graphics processing unit has nearly the same computing power as a mainframe computer once had. This makes it possible to process data with incredible speed and precision, and marks the beginning of a new era in measurement technology.

Digitalization is opening up new possibilities

In the daily project activities of our scientists, digitalization often proves to be a disruptive innovation: Measuring methods that were previously reserved for laboratory devices arenow so fast and robust that inline measuring stations have become feasible. Our terahertz layer thickness measurement systems resolve a quadruple coating within one second with micrometer accuracy, which is sufficient for robot-supported inline measurements. Our digital holographic 3D measurement systems supply millions of 3D measuring points per second, making it possible to check entire metal components at production speed. For sectors such as the automotive supply industry, this sort of 100 percent quality assurance is particularly appealing. Algorithms for chemometric evaluation lead to drastic improvements in signal-to-noise ratios and detection sensitivity in areas such as in gas sensor technology. Here we benefit from the fact that for nearly every measuring task, we know, for instance, which potential substances are expected in a mixture and what their spectral signatures look like. This is the basis of computer-intensive, intelligent data evaluation. The computing power available today makes sensor fusion possible in the first place. For example, when inertial measurement systems are coupled with laser scanners, very good algorithms and high computing power are needed to generate an absolutely referenced 3D point cloud in 3D space and draw conclusions as appropriate.

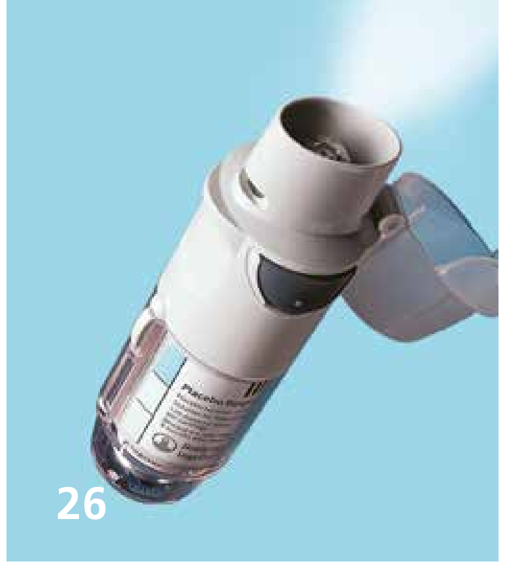
Software can replace hardware

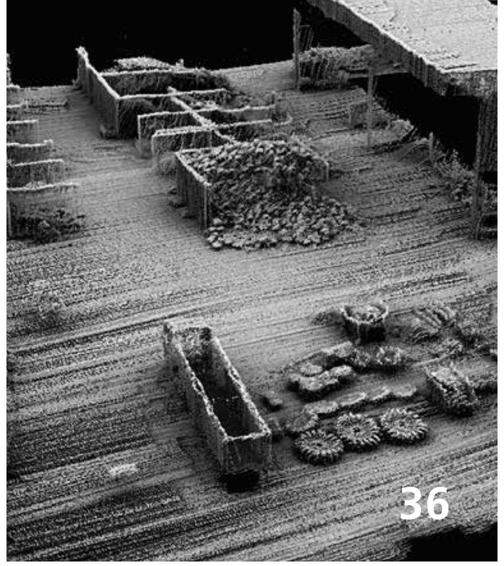
When hardware's only purpose is to eliminate or reduce reproducible and known measurement errors, recalculation sometimes allows entire hardware components to be eliminated without compromising the validity of the result. Costly lenses, for instance, may be replaced by inexpensive lenses, if the errors they cause are taken into consideration. This saves money and opens up entirely new possibilities in terms of system integration. In place of the »triad« of mechanics, electronics and optics, Fraunhofer IPM is increasingly turning to a »tetrad«: Digitalization is playing an increasing role and is only now revealing its true potential for measurement technology – including the potential for further surprises.

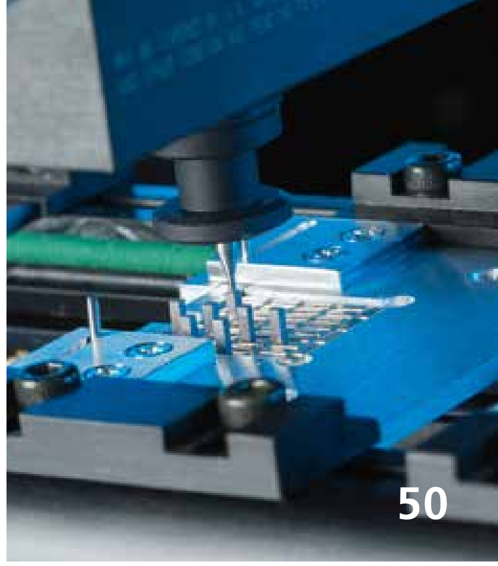
I hope you enjoy reading this report and wish you an inspiring exchange of information with Fraunhofer IPM.

Yours,

Karsten Buse







CONTENTS

MANAGEMENT

Director
Prof Dr Karsten Buse
P +49 761 8857-111
karsten.buse@ipm.fraunhofer.de

Deputy Director
Dr Heinrich Höfler
P +49 761 8857-173
heinrich.hoefler@ipm.fraunhofer.de

EXECUTIVE ASSISTANTS

Science Management
Dr Rosita Sowade
P +49 761 8857-222
rosita.sowade@ipm.fraunhofer.de

Business Development
Dr Armin Lambrecht
P +49 761 8857-122
armin.lambrecht@ipm.fraunhofer.de

Quality Management
Dr Arno Feißt
P +49 761 8857-288
arno.feisst@ipm.fraunhofer.de

SERVICES

Administration and IT
Jörg Walter
P +49 761 8857-120
joerg.walter@ipm.fraunhofer.de

Technical Services
Clemens Faller
P +49 761 8857-214
clemens.faller@ipm.fraunhofer.de

New Technologies and Patents
Holger Kock
P +49 761 8857-129
holger.kock@ipm.fraunhofer.de

PRODUCTION CONTROL

Head of Department
Dr Daniel Carl
P +49 761 8857-549
daniel.carl@ipm.fraunhofer.de

Deputy Head of Department
PD Dr Albrecht Brandenburg
P +49 761 8857-306
albrecht.brandenburg@ipm.fraunhofer.de

Inline Measurement Techniques
Dr Alexander Bertz
P +49 761 8857-362
alexander.bertz@ipm.fraunhofer.de

Optical Surface Analytics
PD Dr Albrecht Brandenburg
P +49 761 8857-306
albrecht.brandenburg@ipm.fraunhofer.de

MATERIALS CHARACTERIZATION AND TESTING

Head of Department
Prof Dr Georg von Freymann
P +49 631 2057 40-01
georg.vonfreymann@ipm.fraunhofer.de

Deputy Head of Department
Dr Joachim Jonuscheit
P +49 631 2057 40-11
joachim.jonuscheit@ipm.fraunhofer.de

Electronic Terahertz Measurement Techniques
Dr Fabian Friederich
P +49 631 2057 40-08
fabian.friederich@ipm.fraunhofer.de

Optical Terahertz Measurement Techniques
Dr Frank Ellrich
P +49 631 2057 40-04
frank.ellrich@ipm.fraunhofer.de

OBJECT AND SHAPE DETECTION

Head of Department
PD Dr Alexander Reiterer
P +49 761 8857-183
alexander.reiterer@ipm.fraunhofer.de

Deputy Head of Department
Harald Wölfelschneider
P +49 761 8857-161
harald.woelfelschneider@ipm.fraunhofer.de

Laser Scanning
PD Dr Alexander Reiterer
P +49 761 8857-183
alexander.reiterer@ipm.fraunhofer.de

GAS AND PROCESS TECHNOLOGY

Head of Department
Prof Dr Jürgen Wöllenstein
P +49 761 8857-134
juergen.woellenstein@ipm.fraunhofer.de

Deputy Head of Department
Gerd Sulz
P +49 761 8857-293
gerd.sulz@ipm.fraunhofer.de

Integrated Sensor Systems
Dr Marie-Luise Bauersfeld
P +49 761 8857-290
marie-luise.bauersfeld@ipm.fraunhofer.de

Thermal Measurement and Systems
Martin Jägle
P +49 761 8857-345
martin.jaegle@ipm.fraunhofer.de

Spectroscopy and Process Analytics
Dr Raimund Brunner
P +49 761 8857-310
raimund.brunner@ipm.fraunhofer.de

FUNCTIONAL MATERIALS AND SYSTEMS

Head of Department
Dr Heinrich Höfler
P +49 761 8857-173
heinrich.hoefler@ipm.fraunhofer.de

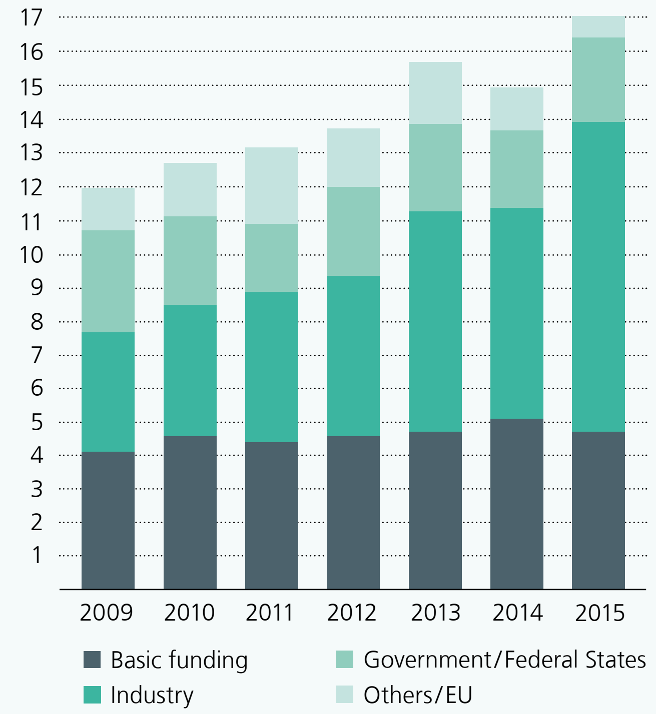
Deputy Head of Department
Dr Kilian Bartholomé
P +49 761 8857-238
kilian.bartholome@ipm.fraunhofer.de

Magnetocalorics and Electrocalorics
Dr Kilian Bartholomé
P +49 761 8857-238
kilian.bartholome@ipm.fraunhofer.de

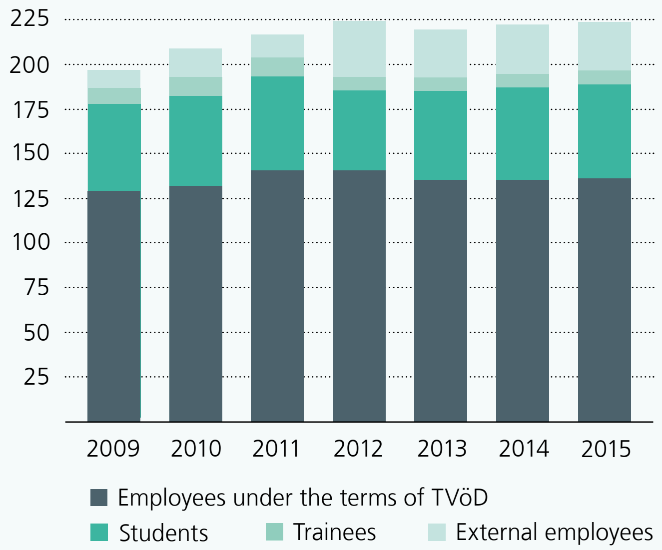
Nonlinear Optics
Dr Frank Kühnemann
P +49 761 8857-457
frank.kuehnemann@ipm.fraunhofer.de

Thermoelectrics
Dr Jan D. König
P +49 761 8857-329
jan.koenig@ipm.fraunhofer.de

Operating budget 2009 to 2015 in million euros



Personnel development 2009 to 2015



FIGURES

Operating budget

In 2015, the operating budget of Fraunhofer IPM was 17 million euros, an increase of 2.3 million euros over 2014. The operating budget comprises industry revenues, revenues from publicly funded projects and basic funding (including funds raised from internal projects of the Fraunhofer-Gesellschaft). The proportion of external funds, consisting of external public funds and industry revenues, was 72.7 percent, or 12.4 million euros. Industry revenues make up 9.3 million euros or a 54.4 percent share of the operating budget, which amounts to an increase of more than 11.5 percent over the previous year (42.9 percent or 6.3 million euros). The high percentage of industry revenues can be attributed to the success of very large industrial projects.

Personnel

The number of employees hardly changed compared to the previous year. A total of 139 people were employed by Fraunhofer IPM under the terms of the Collective Agreement for the Public Service TVöD, 17 of them at the Kaiserslautern site. Approximately 55 students and young professionals work at the Institute, 46 of which are undergraduate and graduate students and 9 are trainees. In addition, Fraunhofer IPM has around 25 external employees as well as a number of interns and assistants. Employees are spread across three basic areas: Approximately 50 percent of the employees are scientific staff, 35 percent are engineers and technical staff and 15 percent are clerical staff in the fields of infrastructure and workshop.

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MAGAZINE

EUROSENSORS CONFERENCE IN FREIBURG

The 29th EUROSENSORS Conference was held in Freiburg from September 6–9, 2015. The event is one of the largest and most important sensor conferences in Europe. It was organized by Fraunhofer IPM and the University of Freiburg's Department of Microsystems Engineering (IMTEK). During the conference, speakers presented and discussed the latest technological developments in the fields of sensors, actuators, micro- and nanosystems. Biosensors and biomedical and chemical sensors took center stage at this year's event. In addition to measuring pollutants in the air or in liquids, these devices are employed in areas such as bioanalytics and medicine, where they are used during blood analyses and implant procedures.

Approximately 550 participants had the opportunity to attend four plenary sessions, eight keynote speeches, and six guest lectures from internationally renowned scientists and industry representatives. The topics ranged from new sensors for medical engineering or the automotive industry to devices used in traditional process analytics environments. The event also included more than one hundred expert talks and around 230 poster presentations. An exhibition showcasing 20 companies and institutions was held in conjunction with the conference.

2 *In 2015, Fraunhofer IPM hosted the internationally renowned EUROSENSORS conference together with the Department of Microsystems Engineering (IMTEK) of the University of Freiburg.*

WORKSHOP ON MOISTURE MEASUREMENT TECHNIQUES

The »Contactless Moisture Measurement Techniques« Workshop, which was held by Fraunhofer IPM for the first time in October 2015, attracted significant interest from industry. From grain to apartment walls and natural gas, the locations where moisture can occur are as diverse as the measurement techniques needed to record moisture levels. Contactless measurement techniques are particularly proficient at detecting moisture levels and are suitable for a number of applications. During the workshop's presentations, around 50 participants, predominantly from industrial sectors, discovered more about the latest technological advancements in a variety of contactless moisture measurement processes. The technologies presented included NIR spectroscopy, microwave transmission and the rather new technique of terahertz spectroscopy. An exhibition and poster presentations rounded off the workshop program.

SUCCESSFUL GAS SENSOR WORKSHOP

GASSENSOR WORKSHOP

Around 70 participants from science and industry discussed the latest developments in gas sensor technology at the Gas Sensor Workshop organized by Fraunhofer IPM in September 2015. Now in its sixth year, the high-quality event inspired exciting discussions between science and industry representatives about the most recent trends in gas sensor technology.

The areas of focus included semiconductor gas sensors, electrochemical sensors, photoacoustics, and IR and laser spectroscopy. Nine presentations covered an extensive array of topics, ranging from »Opportunities and Challenges Presented by the Raman Spectroscopy of Gases« to »Sensors Based on Porous Silicon and Aluminum Oxide Substrates«. An industry exhibition was held simultaneously with the event. The next Gas Sensor Workshop is due to take place on March 16, 2017.

1 *Flexible sensors, showcased at the 6th Gas Sensor Workshop.*

QUANTUM CASCADE LASERS ARE READY FOR USE BY INDUSTRY

On November 12, 2015, Fraunhofer IPM held a workshop titled »Quantum Cascade Lasers (QCL) in Industry«. More than 70 experts from industry and science gathered at the event to discuss the latest advancements in this technological field as well as their economic opportunities. The overall message of the closing discussion was that laser technology in the mid-wave infrared region has the potential to become widely used in industry.

The automotive sector, for example, already successfully uses quantum cascade lasers (QCL) for exhaust gas analysis. The trade exhibition held in conjunction with the workshop presented examples of devices ready for batch production. QCL measurement systems detect exhaust gas much more quickly and with greater sensitivity than conventional techniques, a benefit that needs to be developed in the future.

3 *Dr Armin Lambrecht, who is responsible for business development at Fraunhofer IPM, chaired the discussions on opportunities for QCL technology in industrial measurement techniques.*

BLOWING BUBBLES INSPIRES SCIENTISTS OF THE FUTURE

Experiments involving light enthralled young and old alike at the Children's Afternoon at Fraunhofer IPM in July 2015. The Institute's scientists were on hand to answer all manner of questions on subjects ranging from the colors of the rainbow to the accuracy of optical measure devices. The next generation of researchers also had the opportunity to »touch« light during experiments involving blowing bubbles and a lot of water, which proved very popular given the hot weather. The event was held to mark the »International Year of Light« as proclaimed by the United Nations. This initiative was celebrated simultaneously in the form of Children's Afternoons held at all six institutes belonging to the Fraunhofer Group for Light & Surfaces.

1 *Children's Afternoon to mark the »International Year of Light«.*

GIRLS' DAY

Held at Fraunhofer IPM for the 15th time on April 23, 2015, the Girls' Day is becoming a tradition. The event once again gave schoolgirls aged 10 to 16 the opportunity to take a tour of the Institute's laboratories and workshops as well as gain an insight into scientists' daily work. During sessions such as »The Laser Magnifying Glass«, »How Can I Build a Microchip?«, and »How Can I Build a Flashing Circuit?«, the girls had the chance to experiment with light waves, build conductors, and make an integrated circuit. Around ten scientists put the program together and accompanied the schoolgirls throughout the day.

»GREEN PHOTONICS« JUNIOR RESEARCH AWARD

Vincenz Sandfort secured second place in the 2015 »Green Photonics« Junior Research Award for his Master's thesis, which he completed at Fraunhofer IPM. The prize is awarded annually by the Fraunhofer Green Photonics Innovation Cluster to young researchers whose theses investigate the sustainable use of light. Sandfort's thesis was titled »Investigations into Using Photonic Crystal Fibers to Strengthen Raman Gas Scattering Signals«. During his research, the young scientist developed a highly sensitive Raman gas measurement system for continuous, contactless and sustainable monitoring of the gas network. The thesis was supervised by Prof Dr Jürgen Wöllenstein.

TWO AWARDS FOR THERMOELECTRICS RESEARCH

Fraunhofer IPM has recently received two prizes for research conducted in the field of nanoscale thermoelectric superlattice systems: The Hugo Junkers Prize awarded by the Saxony-Anhalt Ministry of Sciences and Economic Affairs was presented to the team led by Dr Jan D. König. Together with researchers from the Martin Luther University of Halle-Wittenberg and the Max Planck Institute of Microstructure Physics, the scientists won first place in the main category of »Most Innovative Basic Research Projects«.

The team was recognized for its theoretical work on the optimization of thermoelectric materials using nanostructuring and on manufacturing methods for the cost-effective, flexible production of layers.

Physicist Dr Markus Winkler was awarded the »Young Scientist Award« from the German Thermoelectric Society (DTG) for his PhD thesis about thermoelectric nanoscale superlattice systems. As the reasons behind his nomination, the panel of judges praised the high scientific value of his thesis and the care with which he produced the superlattice systems. According to the judges, the thesis provides a number of findings, which are relevant to industry, about the manufacture of thermoelectric micro-modules and thermal sensors. As part of his PhD thesis, Winkler developed a method for manufacturing particularly powerful superlattice systems using molecular beam epitaxy and sputtering processes. Winkler shared the award, which came with 1000 euros of prize money, with Florian Gather from the Justus Liebig University of Giessen.

PRIZE FOR »BEST CLIENT ACQUISITION 2015«

The team led by Dr Albrecht Brandenburg was presented with the prize for »Best Client Acquisition« for winning the largest industry contract awarded to the Fraunhofer-Gesellschaft in 2015. The contract was placed by the pharmaceutical company Boehringer Ingelheim microParts GmbH that commissioned Fraunhofer IPM to supply measuring devices worth a total of more than 1.3 million euros. The prize was awarded during the »Netzwert 2016« symposium, an annual networking event for Fraunhofer scientists.

Contracts with industry make up a significant share of the Fraunhofer-Gesellschaft's funds. In 2015, Fraunhofer IPM received industry orders amounting to around 9.3 million euros.

2 *Dr Albrecht Brandenburg (left) accepts the prize for »Best Client Acquisition 2015« from Alfred Gossner (center), member of the Fraunhofer executive board. On the right Dr Dirk Hecker of Fraunhofer IAIS.*

PROFESSORSHIPS IN FREIBURG AND KAISERSLAUTERN

Fraunhofer IPM is affiliated with the local universities in Freiburg and Kaiserslautern by associated professorships. This means that we have direct contact with basic research and have access to the latest research results.

Technical University of Kaiserslautern
Faculty of Physics

Chair Optical Technologies and Photonics
Prof Dr Georg von Freymann

The research group studies the interaction between light and matter. One of the objectives is to produce three-dimensional microstructures and nanostructures as a basis for functional materials in photonics and material science. Another focus is on optically reprogrammable structures for spintronics as building blocks for tomorrow's computers.

Albert Ludwigs University of Freiburg
Department of Microsystems Engineering – IMTEK

Laboratory for Optical Systems
Prof Dr Karsten Buse

The main fields of research are nonlinear optical materials and whispering gallery resonators. One aim is to miniaturize optical parametric oscillators. The »photonics« specialization created with other optics professorships has been included in the curriculum for the Microsystems Technology Master's Degree. Group leader Dr Ingo Breunig is in charge of research work in this area of the department.

Laboratory for Gas Sensors
Prof Dr Jürgen Wöllenstein

The laboratory develops gas-sensitive materials, sensors and sensor systems. Research is focused on miniaturized, energy-saving gas measuring systems. One focus is on the development of low-cost and power-saving sensors, manufactured in microsystems technology.

2 *Campus of the IMTEK at the University of Freiburg.*

»SUSTAINABILITY CENTER FREIBURG«

Pilot project for predicting environmental disasters

The assessment of geological hazards requires a number of environmental parameters to be observed and interpreted over long periods of time. In the MulDiScan project, scientists at Fraunhofer IPM and the University of Freiburg are working towards finding a better way of predicting phenomena such as floods, landslides, and forest fires.

»This requires us to gather high-quality measurement data about changes to the structural landscape from vast swathes of land that are sometimes difficult to access,« comments Dr Alexander Reiterer, project co-ordinator at Fraunhofer IPM.

To achieve this aim, the scientists are using small unmanned aerial vehicles (UAVs) to which measuring devices are fitted. Equipped with sensors that measure parameters such as temperature and humidity, these devices are very quick at capturing precise, detailed, three-dimensional images of the terrain. Once the data has been collected, Fraunhofer IPM is working alongside researchers at the University of Freiburg to interpret it. This requires considerable work, as in order for reliable predictions to be made, the information needs to be combined with further measurements and empirical findings.

MulDiScan is one of twelve pilot projects to be conducted as part of the Sustainability Center Freiburg initiative, which is being funded by the state of Baden-Württemberg, the University of Freiburg, and the Fraunhofer-Gesellschaft.

MORE SPACE FOR INNOVATION AND CREATIVITY

Fraunhofer IPM is set to open a new home on the Faculty of Engineering's campus in Freiburg. The building will have a usable floor area of around 6,500 square meters. Approximately a third of this area has been reserved for office space, while the remainder will be occupied by state-of-the-art laboratories, workshops and other usable areas. Plans for the building, which is currently the largest Fraunhofer construction project in Baden-Württemberg, date back to 2012. Much has happened since then, as the planners have found a plot of land, chosen an architecture firm, and drawn up a floor plan. Construction is due to commence in September 2016 with the building expected to be ready for use by the end of 2019.

1 *The proposed Institute building has three stories, inner courtyards for letting in plenty of light, floors of different heights, and a modular façade.*

»GOOD VISUALIZATION MAKES IT EASIER TO INTERPRET MEASUREMENT DATA.«

Professor Christoph Müller on the visualization of 3D data. Müller spent a research semester at Fraunhofer IPM from October 2015 to January 2016. During this time, he focused on visualizing measurement results as part of the »Forschungsallianz Kulturerbe« (Cultural Heritage Research Alliance) project, which is seeing scientists at Fraunhofer IPM work in collaboration with the stonemasonry at Freiburg Minster.

Professor Müller, how did you come to work with our Institute?

Some of our students have been collaborating with Fraunhofer IPM to visualize measurement data since 2012. Since clearly presented measurement results are more beneficial for customers, both partners were highly attracted by the idea of working together. To ensure future projects are a success, we need to develop a deeper mutual understanding, which is why I decided to spend my research semester at IPM.

What is the connection between computer graphics and measurement technology?

Distance-based 3D measurement techniques generate complex point clouds that ultimately always require human interpretation. The high level of visualization that this demands is now possible in real-time. From the outset, computer graphics have been concerned with finding ways of visualizing complex data in real-time. From the user's point of view, how should measurement results best be displayed? What is even technically possible? The development of innovative devices like smart glasses, which companies such as Google Glass and Microsoft are pursuing at tremendous expense, is opening up new ways of interacting. At this early stage, research is needed into the technology's potential advantages and areas of application. Together, we can build knowledge in this field that IPM could use in its work. From research projects to attractive internships and thesis opportunities, our university enjoys a host of benefits from collaborating in such a practical way with this renowned institute.

What have you achieved to date?

As part of the Forschungsallianz Kulturerbe project, we have researched how useful augmented reality glasses available on the market are as a visualization aid. Here, we've succeeded in improving the usability of the glasses by replacing the poor space tracking system with an alternative solution. I've also had the chance to test Google Tango, a novel device in which the measurement technology is built into a tablet. In both cases, we have found that the grand announcements made by the manufacturers should be treated with caution.

What does the future of your cooperation with IPM hold?

Our next step will be to turn our ideas for projects into proposals. In the medium term, we are considering an institutional cooperation, possibly in the form of a joint working group.

Thank you for the interview!

Cultural Heritage Research Alliance

As a member of the »Forschungsallianz Kulturerbe« (Cultural Heritage Research Alliance), the Fraunhofer-Gesellschaft is investing in technology for preserving cultural heritage. As part of the project, Fraunhofer IPM is developing methods for the on-site 3D capturing of sculptures. Currently, if a sculpture on a historical building becomes damaged, the original must be removed and a plaster cast made to serve as a model. In the future, however, by providing restorers with precise 3D data about the statue in question, much like a CAD drawing, the aim is to create a revolutionary, digital restoration method. To build the digital 3D model, the statue is photographed on site, using a camera to take images of the exterior and an endoscope to capture the often delicate inner structures from the inside. Specially created algorithms are then used to put together the 3D model from the large collection of individual images. Since the 3D data documents the current condition of the sculpture, it can be used as a template for restoration work. Alternatively, by being collected into a large data pool, it can provide art historians with brand new research material to supplement their field work.

How could 3D data make the work of stonemasons easier?

In the future, the data could be used to support restorers in recreating sculptures from scratch. The scientists' vision is for parts that require removal to be displayed on augmented reality glasses and projected onto the workpiece. As the restorer works, interactive measurements are taken that compare the actual and intended appearance of the sculpture and visualize any discrepancies. When copying sculptures, stonemasons currently use their own visual judgment and manual measurement techniques.

1 *The scientists are aiming at constructing the plaster model needed for the restoration of sculptures on the basis of digital data.*

2 *Prof Christoph Müller*

CHRISTOPH MÜLLER, born in 1968, is a computer scientist and mathematician. He has been working as a Professor for Computer Graphics and Game Engineering in the Faculty of Digital Media at Furtwangen University since 2010. His teaching and research areas include computer graphics, 3D modeling / technical 3D design and real-time 3D software development.

1 *Thomas Gießler on the topic of innovation: »It's vital that we're always two steps ahead of the competition.«*

2 *Fraunhofer IPM's sensor head records nine million 3D measuring points per reading – ten times a second.*

»WE LEARNED A LOT FROM EACH OTHER.«

Werner Gießler GmbH commissioned Fraunhofer IPM to develop a fully automatic in-process inspection system for precision turned parts. The system verifies at one-second intervals the sealing surfaces of precision turned parts that are around the size of a thumbnail, and can reliably detect micro-defects as small as a few micrometers. Read on for an interview with Managing Director Thomas Gießler.

WERNER GIESSLER GMBH manufactures complex precision turned parts, particularly for supply to the automotive industry. Based in Elzach near Freiburg, Germany, the medium-sized company employs around 130 people and made a turnover of 13.2 million euros in 2015. Depending on the end client's requirements, the heat- or surface-treated components are supplied as individual parts or groups of components.

Mr Gießler, how did you come to work with Fraunhofer IPM?

We had already contacted several companies, but none of them were able to offer a solution which met our requirements. Our client Bosch demands 0 ppm, which means that out of a million components supplied not a single part may be faulty. This would be almost impossible to achieve by checking the parts manually under a microscope. We eventually contacted Fraunhofer after a Google search displayed the Institute's name among a list of potential partners. And although the problem initially seemed insurmountable even to Fraunhofer, it was gradually found to be within the realms of possibility. We learned a lot from each other during the process.

What expectations did you have and were these fulfilled by the end of the project?

The turned part, on which we need to ensure that the sealing face is 100 percent fault free, is found in 70 percent of all common rail diesel injection systems for HGVs worldwide. We are Bosch's sole supplier and this part accounts for 50 percent of our turnover. This means that we were extremely interested in finding a solution (i.e. a sensor) to perform the final inspection of the component's surface. We specified a number of requirements such as the cycle times and feed-in. Fraunhofer IPM succeeded in seamlessly integrating its sensor into our environment and ensuring that it could perform rapid optical surface testing.

Was it difficult to find common ground between research and industry?

We have already built many systems, for example sorting machines as well as interfaces to machinery and automated equipment. Communicating with Fraunhofer IPM's measurement technology experts therefore did not present completely new territory for us. Like us, their thoughts and actions are very industry driven. Since we were on the same wavelength, we were able to commission the job only eight weeks after making initial contact with Fraunhofer IPM!

To what extent will the investment in measurement technology pay off for you?

To date, the final inspection process, which we have now automated with the help of Fraunhofer IPM, has been manually performed by an external service provider as part of a labor-intensive procedure that requires staff to examine each individual part under a microscope. Fraunhofer IPM's sensor costs less than two years' worth of visual inspections. We were delighted to receive advance funding from ZIM, a funding program for SMEs run by the German Federal Ministry for Economic Affairs and Energy, for a number of decisive feasibility studies. This support was crucial, as it enabled us to significantly lower the financial risk from the outset. The entire inspection system will have paid for itself after three years.

In your opinion, when does working with an external research partner prove worthwhile?

For me, it is essential that working with an external development partner enables my company to achieve a unique position on the market. I'm not really prepared to take risks, and essentially wish to use innovations to ensure that my employees' jobs as well as my own position are secure. We would gladly work with Fraunhofer IPM in exactly the same way again. It's vital that we're always two steps ahead of the competition.

What are the technological challenges facing suppliers in the metalworking industry?

Suppliers are being presented with ever greater risks. When you get involved with large companies, it is essential that you have the appropriate inspection equipment in place. Companies that have not learned this won't survive for long. A specific example of this is the fact that we were only awarded our seven-year contract as Bosch's sole supplier for a specific turned part because we boast a large number of unique selling points in the required process. It is these that secured us this line of business.

Fraunhofer IPM is located less than 30 kilometers from your business – how important was this close proximity?

During the initial part of the selection process, it was Fraunhofer IPM's competences alone and not its location that made it a contender. At first, staff at Fraunhofer told us that our requirements would be impossible to fulfill. However, they then visited us a short time later to examine the entire challenge in detail. This meant that their proximity to us was indeed extremely beneficial. Our partnership was and is exemplary – and could possibly lead to further projects in the future. Our company has considered launching such highly specialized inspection systems onto the market in collaboration with Fraunhofer. We would provide the handling technology, while Fraunhofer IPM would build the sensor.

Thank you very much for talking to us!

3 *»Companies that have not learned to test the quality of their components won't survive for long,« predicts Thomas Gießler.*

Measurement technology ensures the quality of precision turned parts.

»Industry 4.0: We develop measurement systems to secure quality.«

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 Industry 4.0. A wide range of methods is used, including digital holography, infrared and reflection spectroscopy and fluorescence methods, combined with fast, low-level image and data processing. The systems are used in applications such as forming technology and in the automotive industry.

Inline Measurement Techniques

The main focus of this group is on 2D and 3D measuring systems for industry. These systems supply evaluated data 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 evaluation processes.

Optical Surface Analytics

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 and reflection spectroscopy. Fraunhofer IPM's long-standing experience in systems engineering encompasses optical units, image recording and image processing.

CONTACT

Dr Daniel Carl
Head of Department
P +49 761 8857-549
daniel.carl@
ipm.fraunhofer.de

TOPICS

- Surface analysis
- 100 percent quality inspection
- Inline production monitoring and control

EXPERTISE

- Imaging fluoescence measuring equipment
- Imaging 3D methods
- Digital holography
- Inline microscopy
- High-speed image processing

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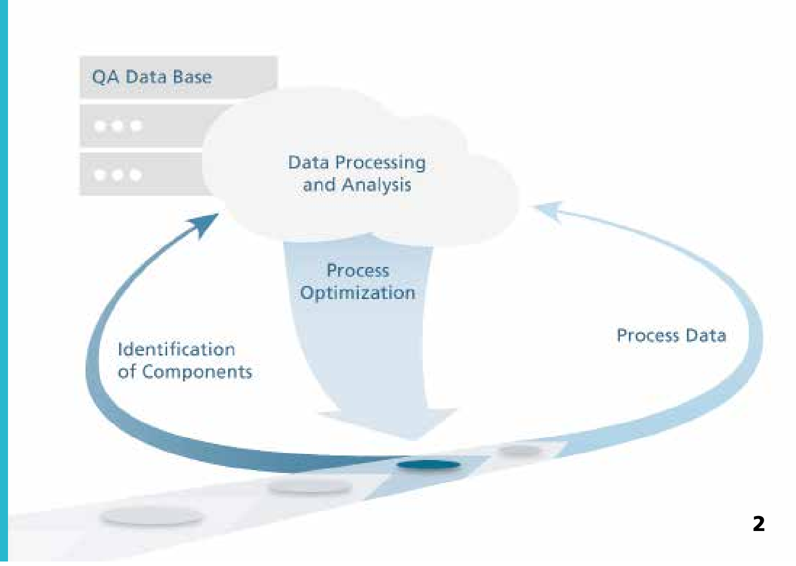

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INLINE MEASUREMENT TECHNIQUES

Tracking everything down to the last screw

Traceability is one of the cornerstones of digitalized production. It enables data collected during production processes to be attributed to individual components and semi-finished products. The concept is the only way in which regularly occurring errors can be analyzed and the results feed back into the manufacturing process. In the »Track4Quality« project, Fraunhofer IPM is working on an innovative tracking procedure for mass-produced parts that identifies individual components on the basis of their surface structure.

The quality of complex industrial products depends on the quality of each and every component. For example, a single faulty connector, even if it is worth only a few cents, may impair the performance and durability of a complex electronic control box in a car. As a consequence, if an assembled component fails its performance test, all the semi-finished parts already fitted are »guilty by association« and the entire product is rejected. This results in companies incurring high costs, often without learning any lessons for the future. The project's goal is therefore to provide even the smallest of components and semi-finished products with a signature so that they can be traced along the supply chain, preferably from the outset. This is the only way of ensuring that in-process inspection systems are capable of detecting and permanently rectifying recurring production errors.

Components identified by product fingerprints

There is one thing that the process of tracing mass-produced parts must not be: expensive. Many established marking methods fail at this first hurdle because they require additional costly production steps. However, this is far from the only drawback of current solutions. Other techniques are not feasible because they affect certain component functions. For example, it is not wise for manufacturers to engrave serial numbers on sealing surfaces or place barcodes on decorative items. Furthermore, while some components are simply too small to be marked, those that can be are at risk of having their markers counterfeited. None of these problems apply to a tracking method being developed by Fraunhofer IPM in collaboration with Hahn-Schickard-Gesellschaft e.V. and industrial partners as part of the »Track4Quality« (T4Q) project. The technique does not require any markers to be added to the component whatsoever, making use of its existing surface structure instead. Viewed under a microscope, almost all technical surfaces reveal incidental characteristics like microstructures or interwoven colors that are as unique as a fingerprint. The T4Q sensor system uses an industrial camera to take high-resolution images of defined areas on the component's surface. The specific structural patterns captured by the image and the way in which they are positioned relative to each other is used to generate a numerical identification code, which is then stored in a database. This entire process can be repeated to identify the component at a later date. If there is a match for a code, users can be certain they have found the component they are looking for. The sensor has been designed to enable a wide range of materials, from smooth plastic to precision-machined aluminum, cast iron and varnished surfaces, to be identified in line with the rate of production using the same hardware.

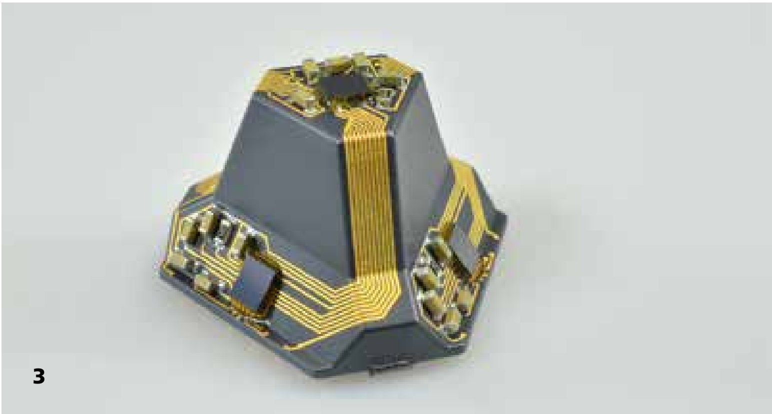
> **»IF MACHINES ARE ABLE TO COMMUNICATE WITH EACH OTHER IN THE FUTURE,** what they actually say will be equally as important as their ability to say it. Measurement techniques will play an important role in this by providing a large part of the data that the machines will share. This data will determine whether the dominance of digital technology in the manufacturing process is actually leading to greater efficiency and better product quality.« – *Daniel Carl*

As part of a study, the T4Q method was tested for practicability in a production chain for molded interconnect devices (MID). Fingerprints from 30 of these three-dimensional injection-molded plastic circuit carriers were produced as a test at the Hahn-Schickard Institute. The test pieces were then subjected to all the steps normally performed as part of the production chain, such as thermal shock tests, laser structuring, CO_2 snow-jet cleaning, wet-chemical cleaning, metal coating, reflow soldering and conductive adhesion. Despite these processes and the addition of conducting paths to a number of the substrates, which resulted in the region of the fingerprint being partially covered, the components could still be reliably identified. Now that the general feasibility and robustness of the T4Q method has been demonstrated, the scientists are working on implementing it in practice. If, by the end of the project, the process is also able to clearly identify components worth only a handful of cents, it will become an essential prerequisite for the long-term improvement of manufacturing processes – in the spirit of sustainable digitalized production.

1 *The quality of components worth just a few cents frequently influences the performance and durability of expensive products.*

3 *The practicability of the tracking method was tested in the production of 3D sensors, manufactured as MID devices.*

2 *A huge amount of measurement and process data is generated during production processes. Clear component signatures are the only way of attributing this data to individual components and of tracing noticeable statistical anomalies to the sources of error.*



3

Dr Alexander Bertz, P +49 761 8857 - 362, alexander.bertz@ipm.fraunhofer.de

1 *The propellant-free Respimat® inhaler uses mechanical pressure to force the medication through a micro-nozzle.*

OPTICAL SURFACE ANALYTICS

Optical inspection improves inhaler safety

With the propellant-free Respimat® inhaler, the pharmaceutical company Boehringer Ingelheim has achieved a technical innovation. This innovation is largely due to a tiny component: a special micro-nozzle for aerosolizing the medication. Fraunhofer IPM has developed an optical in-process inspection system to precisely control the quality of this microfluidic component during production.

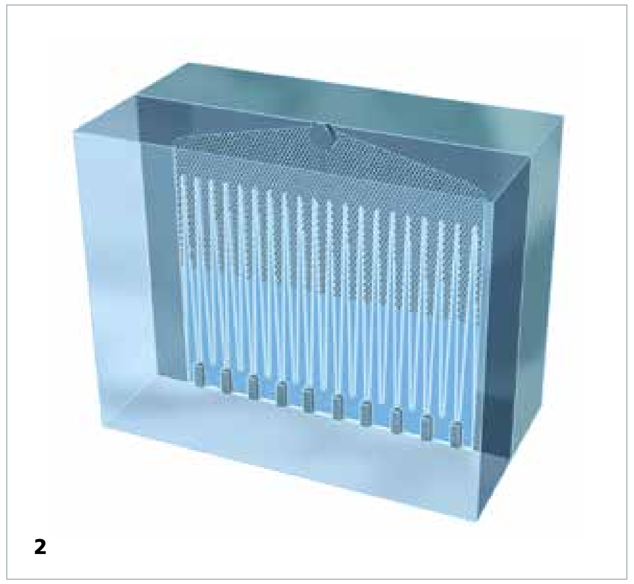
MICROELECTROMECHANICAL SYSTEMS (MEMS) such as the uniblock are components of many state-of-the-art products. They are used as inertial sensors in airbags, as optical actuators in micro mirrors or as microfluidic components in print heads and medical technology products. High-performance in-process inspection technology for the production of delicate components is increasingly in demand.

Optimally aerosolizing the medication in a compact inhaler turns out to be a major technical challenge: Pressing the dose-release button mechanically forces the drug solution through a micro-nozzle called a »uniblock«, where the liquid medication is filtered to form two perfectly dosed jets of liquid. When these two jets converge at high speeds and under a carefully controlled angle, they generate a fine aerosol cloud that is easy to inhale and contains a high fraction of respirable drug particles. In order for this technology to function reliably, the uniblock must be precisely manufactured, and highly thorough inspection is needed to ensure the quality of the components. The Respimat® manufacturer Boehringer Ingelheim microParts (BImP) commissioned Fraunhofer IPM to develop an optical inspection system and implement it in a production environment. This system detects potential structural defects, impurities, scratches, and incorrect external dimensions and does so under clean-room conditions.

Laser scanning microscope detects structures as fine as a micrometer in process

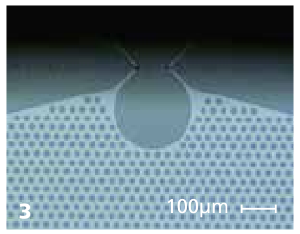
The uniblock is a microstructured, 2 mm × 2.5 mm silicon component with a glass cover and an overall thickness of approximately 1.2 mm. In order to inspect this sort of component, which is series-produced with a high throughput, both a high spatial resolution and a very high scanning rate are needed. The system developed at Fraunhofer IPM checks for various characteristics and potential defects in the uniblock during production: structural defects, in other words deviations in the microstructure from the target geometry and missing structures, impurities, errors in bonding the silicon structure to the glass cover, incorrect external dimensions of the component as the result of sawing errors, and defects and cracks on the edges. In order to reliably inspect even the finest structures, such as the approximately 8 µm wide filter channels, measurement accuracy in the low micrometer range is required. The same is true for typical impurities, which often extend to only a couple of micrometers.

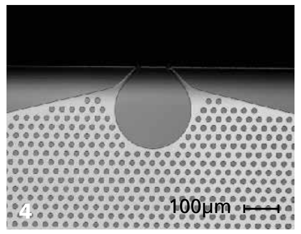
The inspection system uses a laser scanning microscope that conducts all measurements through the glass cover at a cycle rate of 1.3 seconds. A focused laser beam scans the surface of the uniblock. The laser is focused onto a small opening, or »pinhole«, in the microscope, so that light that reaches the detector is almost exclusively from one sample plane. In contrast to a traditional light microscope, the laser scanning microscope can very precisely detect the edge of the uniblock on the plane of the silicon surface under the glass. This makes it possible for the system to check the location of the microstructure relative to the outer edges – an important prerequisite for much of the inspection. But not the only one: In order for the measurement technology to function precisely, the microscope must be optimally integrated into the handling system. The individual uniblocks must be transferred from the magazine to a test chamber under the microscope and then be returned to the magazine following the optical inspection. To make this possible, the exact position of the uniblocks during the infeed and the position of the feeder pockets of the transfer feeder must be identified. The high bulk scattering caused by the plastic that the magazines are made of and the lack of contrast against the relatively dark background make it difficult to detect edges. Fraunhofer IPM has resolved this problem by adjusting the image capture and using specially designed illumination optics. The required repeatability of the position measurement is 30 µm.



2 *In the micro-nozzle, the liquid medication is filtered to form two perfectly dosed jets of liquid that converge at high speeds and a carefully controlled angle to form a fine aerosol cloud. In order for this to function, the component must be very precisely manufactured.*

At its Dortmund site, Boehringer Ingelheim microParts GmbH produces around 44 million Respimat® inhalers annually. Fraunhofer IPM has already integrated several inspection units into the production line there. These units are operating faultlessly and make it possible to reliably detect defective components.





3 + 4 *The structures of the microcomponent are visible through the component's glass cover. However, a traditional wide-field microscope does not depict the edges of the silicon block (3). The position of the microstructure relative to the outer edges cannot be determined. A laser scanning microscope makes this possible (4).*

PD Dr Albrecht Brandenburg, P +49 761 8857-306, albrecht.brandenburg@ipm.fraunhofer.de

Terahertz systems detect the thickness of individual layers of paint on car bodies.

»Our systems measure materials layer by layer.«

Fraunhofer IPM develops measurement systems for practical application in the characterization and testing of materials. To do so, the scientists draw on their expertise in optical systems and measurement technology, spectroscopy, and the development of crystal and semiconductor components. The techniques cover a range from optical coherence tomography (OCT) in the visible spectrum to time-domain spectroscopy in the terahertz frequency range as well as electronic system concepts in the millimeter wavelength range. In materials testing, defects can be identified in ceramics, plastics or fiber-reinforced composites on a non-destructive basis. Fraunhofer IPM's researchers particularly focus on layer thickness measurement, for example in coating processes. Besides OCT, measurement techniques in the terahertz or millimeter wavelength range present alternatives to ultrasound measurements when mechanical contact is not possible or desirable. These techniques can also be used to replace X-ray measurements in situations where ionizing radiation would raise problems. In addition to determining thickness, the measurement systems are able to investigate the material parameters of individual layers and use chemometric analysis methods to identify these characteristics clearly and reliably.

Electronic Terahertz Measurement Techniques

This group focuses on developing customized electronic systems for non-destructive materials testing. Particular emphasis is placed on the lower terahertz spectrum in which many non-conductive materials such as plastics, ceramics or textiles provide good transparency.

Optical Terahertz Measurement Techniques

This group designs and builds turnkey terahertz time-domain systems for generating and detecting broadband terahertz radiation. This includes the production of terahertz emitters and receivers. Areas of application range from robot-mounted layer thickness measurement systems and high spatial resolution spectroscopy to measurement techniques for ultrafast electronics. Extremely fast electro-optical converters and ultrafast optics are combined for this purpose.

CONTACT

Prof Dr Georg von Freymann
Head of Department
P +49 631 2057 40-01
georg.vonfreymann@ipm.fraunhofer.de

TOPICS

- Non-destructive materials testing
- Layer thickness measurement
- Chemical analysis
- Safety applications
- Vector network analyzers

EXPERTISE

- Production of terahertz components
- Spectroscopy systems
- Terahertz imaging
- Ultrafast electro-optical high-frequency measurement techniques
- Optical coherence tomography

ELECTRONIC TERAHERTZ MEASUREMENT TECHNIQUES

Fast, contactless detection of material structures and defects

Electrical insulators such as plastics, ceramics, textiles, and composites are often transparent to low-frequency terahertz waves, making this spectrum ideal for non-destructive materials testing. Fraunhofer IPM develops industry-ready terahertz testing systems. It not only employs its own components and technologies to do so, but also makes use of unusual measurement concepts more commonly seen in communications and radar technology.

The non-destructive materials testing methods of contactless terahertz measurement have two major advantages: Firstly, many electrical insulators are transparent to terahertz waves, and secondly, unlike X-rays, terahertz waves are non-ionizing. Achieving meaningful cross-sectional images of deep material structures is, however, not the only challenge in developing a marketable terahertz test system. Fast signal processing and a system design that facilitates integration into the production environment are equally important.

Terahertz systems that use sensor units to scan test objects pixel by pixel have long proven successful in preliminary investigations and sample testing. Further to this, Fraunhofer IPM has now also significantly expanded its portfolio of fast, industry-ready terahertz testing systems: These range from hand-held single point sensors through rapid scanning systems based on Fraunhofer IPM's extensively tested scanner technology to sensor networks for testing large areas within the quality control process. Contactless terahertz testing typically provides extremely high-contrast images.

From signal to 3D structure

In all system solutions, the signal propagation delay can be controlled by modulating the operating frequency. Analyzing the propagation delay of terahertz signals transmitted by the sensor and reflected by the test object provides the depth information required and allows to pinpoint 3D features in the test object with submillimeter resolution. Single-point sensors are particularly well-suited to carrying out spot-check measurements of thickness and density, for example on tube walls. Rapid line scanners are used for features measuring several centimeters, such as plastic weld seams.

Scaled down terahertz sensor networks

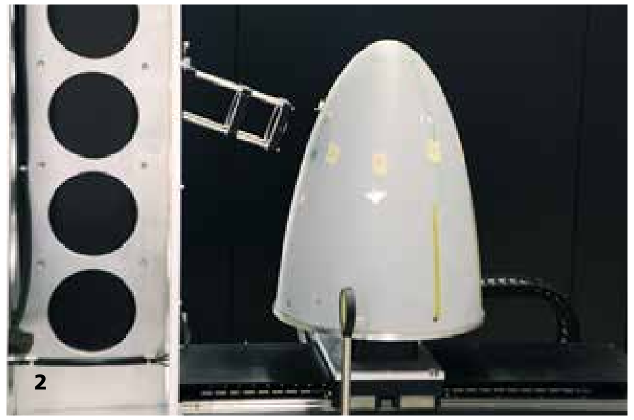
Fraunhofer IPM employs downsized terahertz sensor networks to test large-scale objects with high-depth resolution directly as part of the quality control process. Proven concepts from the field of communications technology are successfully transferred to terahertz imaging systems to enable this. The fundamental measurement principle here involves the individual switching of single transmitter and receiver units to generate a synthetic sensor arrangement. This permits a significant reduction in the number of costly sensor elements and allows the physical configuration of sensors to be customized. Ideally, the total quantity of measurement points will equate to the number of transmitters multiplied by the number of receivers. On the assembly line, a linear configuration of sensors such as this enables test objects to be measured comparatively quickly – for example directly in the production process. Hollow and foam materials with curved/warped surfaces can also easily be analyzed in this way, even if the test samples are only accessible from one side.

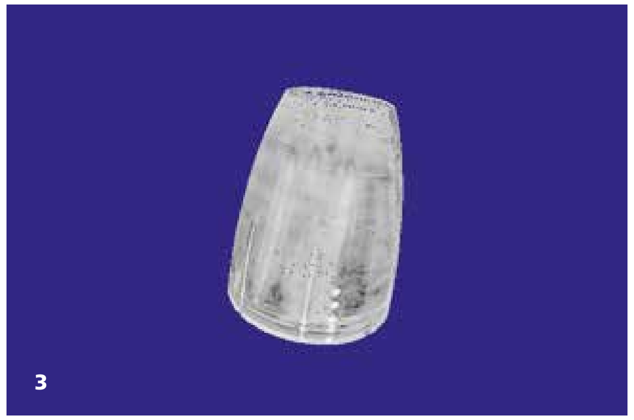
TERAHERTZ TESTING

Complementing ultrasound and X-ray testing, terahertz imaging technology allows dielectric materials to be inspected for internal defects and characteristic features. Contactless terahertz testing typically provides extremely high-contrast images, even for very soft materials and plastic compounds. Deep cross-sectional views similar to those found in ultrasound tomography can also be generated.

1 Using just a few terahertz transmitters and receivers, a terahertz sensor network can plot a vast number of pixels simultaneously. This saves on expensive components while also reducing measurement time.

2+3 Terahertz testing technology is used to scan the internal structure of an aircraft nose cone (radome) and depict it as a 3D tomographic image (source: DOTNAC, FP7-funded project).





Dr Fabian Friederich, P +49 631 2057 40-08, fabian.friederich@ipm.fraunhofer.de

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OPTICAL TERAHERTZ MEASUREMENT TECHNIQUES

Precise measurement, layer by layer

Measurement techniques that depict and analyze the structure of layered systems in a non-destructive way are becoming increasingly important in industry – both in development and quality control. Two complementary methods, terahertz measurement technology and optical coherence tomography, are the new market conquerors.

1 An increasingly frequent requirement of layer analysis is the need to determine the thickness of individual layers.

TOMOGRAPHIC IMAGING is an important measurement method for characterizing and analyzing the internal structures of semi-transparent materials. However, minute structures push established non-invasive tomographic imaging techniques, such as ultrasound and magnetic resonance imaging, to their limits in terms of resolution. This is where optical coherence tomography comes in by being able to reliably resolve the tiniest structures of up to 1 µm in size in partially transparent materials.

Terahertz technology is currently becoming established as a contactless method of layer thickness measurement in many applications, such as automotive coating systems. In contrast to other non-destructive methods of analysis, terahertz waves, which occupy the spectrum between infrared light and microwaves, can be used to analyze even complex multilayer systems with absolute precision. This is because terahertz waves are reflected at every individual interface where the refractive index changes. Differences in propagation delay between the partial waves reflected thus allow the coating thicknesses of multilayer systems to be analyzed with total accuracy – all in a contactless, non-destructive procedure.

Widespread use of coating systems

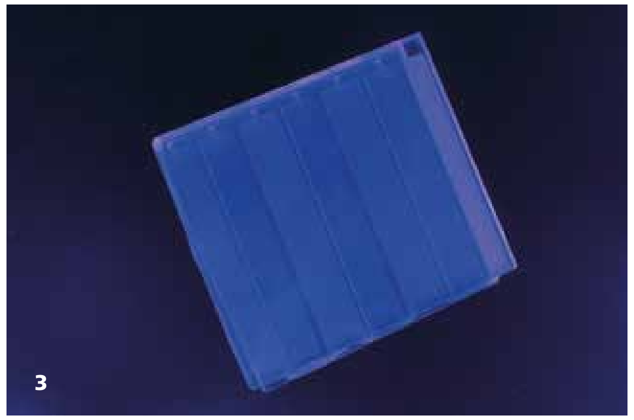
In the past, it was often sufficient to scan the total thickness of a coating in the quality control process. Recently however, monitoring the thickness of individual coating layers within a multilayer system has become a requirement more and more often. This even holds true for standard systems already widely used in industry, such as those employed in auto body spraying. Multilayer analysis on plastic substrates is particularly gaining in importance, since these materials are ever more frequently used to reduce weight and costs. At present, terahertz measurement technology is the only technology of its kind to provide contactless, non-destructive analysis of individual layers in multilayer systems within the relevant thickness range of 10–500 µm. Fraunhofer IPM has demonstrated this in collaboration with different partners in several industries, including the automotive sector. The introduction of this technology in series production is expected for 2016. Initial results in the measurement of soft, structured layers, such as the PVC skins used in automotive interiors, also show a great deal of promise. For physical reasons, however, the scope of application for terahertz multilayer analysis is limited to coating thicknesses of over 10 µm.

New methods for ultra-thin layers

A solution is also available for measuring ultra-thin layers, namely optical coherence tomography (OCT). This procedure was originally developed to enable depth-resolved visualization of biological and medical materials. Thanks to extensive research, however, the method is now also widely used outside the medical field. High-resolution sample cross sections, which can be generated in real time in an entirely non-destructive manner using visible or infrared light, make OCT an ideal contactless testing technique for many applications. The physical principle underpinning this method is that of interferometry, whereby an infrared beam reflected from different sampling depths is superimposed on a reference beam. The intensity and time lag of the reflected beam allow a sample's depth information to be determined mathematically and depicted as a cross sectional image. Depending on the spectral width, a resolution of between 1 and 20 µm can be achieved.

Optical coherence tomography is suitable for all materials that are at least partially transparent to visible or near infrared light. These include many plastics, compound materials, metals, glass, ceramics, and semiconductor materials. Thanks to OCT, Fraunhofer IPM is now able to tap into the thin layer sector. It has already carried out successful measurements on epoxy resin layers which, for example, are applied to metals as electrical insulators.

2



3

2 + 3 Today, scanning the entire thickness of a coating is no longer sufficient. Individual layers within multilayer systems increasingly need to be of specific thicknesses: epoxy resin layers in a motor (2), coated architectural glass (3).

Dr Frank Ellrich, P +49 631 2057 40-04, frank.ellrich@ipm.fraunhofer.de

A camera combined with special LED lighting enables overhead rail lines to be measured.

»We develop the fastest laser scanners worldwide.«

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.

Laser Scanning

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.

CONTACT

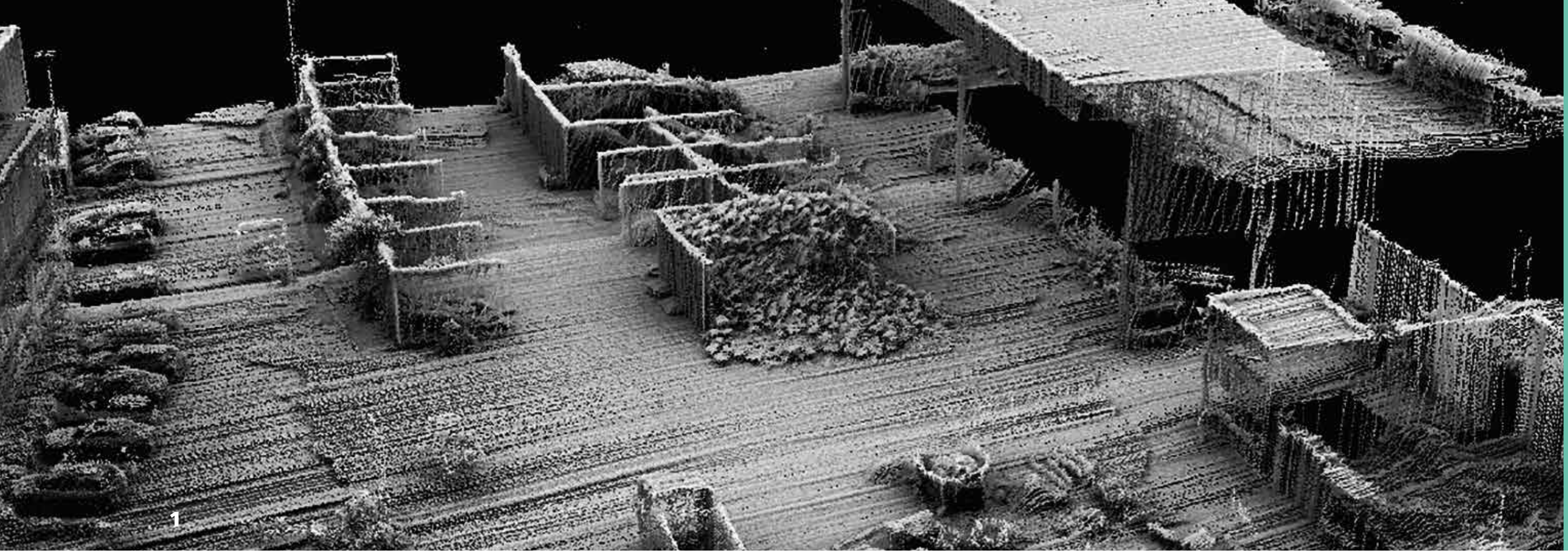
PD Dr Alexander Reiterer
Head of Department
P +49 761 8857 - 183
alexander.reiterer@ipm.fraunhofer.de

TOPICS

- Infrastructure monitoring
- 3D gauging of trains and railway tracks
- Inspection of road surfaces
- Airborne condition monitoring
- Monitoring large underwater structures

EXPERTISE

- Eyesafe 3D laser scanners, camera-based 3D images, 3D data processing
- Capture of object geometries from moving platforms even at high speed
- Rapid image evaluation
- Robust system technology



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LASER SCANNING

Collecting data from the air

From impassable terrain to crisis-hit regions, UAVs (unmanned aerial vehicles) are the number one choice for use in locations where it could be dangerous for people to measure infrastructure. Mounted onto small, flying platforms, measurement systems are able to collect data about large areas and complex structures quickly and efficiently. Fraunhofer IPM has developed an innovative measurement system that enables UAVs to gather local geometry data.

Comprising a variety of modular components, the measurement device is able to position and locate itself locally without the need for external referencing systems like a GNSS (global navigation satellite system). This makes the solution particularly suitable for measuring obstructed and complex structures with little or no GNSS reception. It does so by capturing sequences of images very quickly and by using special algorithms. Depending on environmental conditions, the method has a relative accuracy of a few centimeters. The measuring component used in the system is an eye-safe laser scanner with a working range of 250 m. The scanner is combined with a multispectral camera system to form a powerful multi-sensor unit.

Small, lightweight and energy efficient

Above all, measurement solutions for use in UAVs must be lightweight, which places high demands on the system design. The size, weight and power consumption of the sensors, for example, must be kept within a narrow range. Fraunhofer IPM is continuously striving to optimize these sensors.

The scientists at the Institute are currently participating in two projects concerning the use of measurement systems on UAVs. The objective of the »MulDiScan« project is to better predict natural disasters such as floods, landslides and forest fires, making it easier to introduce preventive measures. This requires scientists to gather high-quality measurement data about vast swathes of land that are sometimes difficult to access, yet may indicate changes to the structural landscape. To achieve this aim, researchers from Fraunhofer IPM have joined forces with academics at the Albert Ludwig University of Freiburg to develop new methods of collecting and interpreting data.

As part of the »MonIs« project, which is being funded by the EU's Eurostars funding program, Fraunhofer IPM in collaboration with partners from Germany, Austria and Spain is developing a system for monitoring infrastructure such as railway tracks, roads and buildings. The measurement solution, which comprises a specially adapted UAV and a sensor system, is able to easily collect data at short intervals in challenging locations.

TIME-DELAY MEASUREMENT OF LIGHT

Collecting data from the air requires highly accurate geometrical measurements to be recorded using the time-of-flight method. This process records the time it takes for light waves or light pulses to travel from a sender to an object and back to a detector. The movement of a laser scanner and measurements taken in rapid succession create a large number of measuring points, which produce a 3D model of the surface under investigation.

Measurement systems fitted to UAVs have enormous potential. From rough or even inaccessible terrain to dangerous environments, they can be used to collect important data whenever it is impossible for measurements to be taken from the ground.

1 *Measuring complex structures from the air. A surface area of several 100 m² can be measured, processed and visualized in less than ten minutes.*

2

2 *A multispectral camera system enables us to determine the vitality of plants, particularly in terms of their water and chlorophyll content. It consists of four cameras that collect data in different spectral ranges.*

PD Dr Alexander Reiterer, P +49 761 8857 - 183, alexander.reiterer@ipm.fraunhofer.de

State-of-the-art gas laboratories at Fraunhofer IPM – for a variety of measurement tasks.

GAS AND PROCESS TECHNOLOGY

»Our measurement systems meet the highest requirements.«

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.

Integrated Sensor Systems

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

Thermal Measurement Techniques and Systems

This group develops bespoke substrates, 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.

Spectroscopy and Process Analytics

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 used for everything from laboratory testing to prototype development to small batch production.

CONTACT

Prof Dr Jürgen Wöllenstein
Head of Department
P +49 761 8857 - 134
juergen.woellenstein@ipm.fraunhofer.de

TOPICS

- Combustion gas measurement
- Detection of fire gases and disaster control
- Air and food quality
- Oil quality control
- Industrial process monitoring (gas composition)

EXPERTISE

- Optical Spectroscopy
- Gas, particle, liquid and thermal sensors and sensor systems
- Microsystem technology
- Simulation of thermodynamics, flow and optics

MINIATURIZED GAS MEASUREMENT SYSTEMS

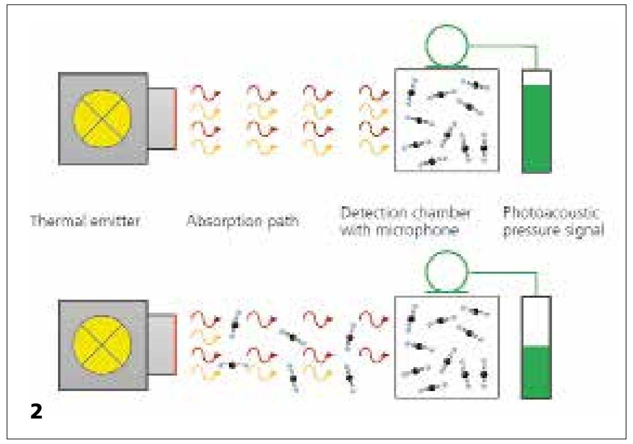
Fraunhofer IPM boasts many years of experience in the development, design, characterization and production of miniaturized sensors and systems for measuring gases. Gas sensors monitor industrial processes, detect leaks or regulate the indoor climate. Thanks to their use of sophisticated technology, the sensors can also collect reliable, precise measurements in challenging conditions.

INTEGRATED SENSOR SYSTEMS

Miniaturized photoacoustic gas measurement systems

Fraunhofer IPM has developed an innovative, compact and inexpensive measurement system based on the principle of photoacoustics for detecting carbon dioxide. It combines a compact measurement and detection chamber with a thermal emitter and a specially enclosed microphone.

1 The air quality inside vehicles can be monitored using photoacoustic gas sensor systems.



2 Principle of operation of the photoacoustic measurement system with a two-chamber design. The ambient air is measured on the absorption path. In the detection chamber, the gas to be measured is used as the gas-selective detector.

From factories and conference halls to cars or trains, the ability to monitor indoor climates is important wherever large numbers of people gather together in an enclosed environment. This is because the effects of so many people exhaling simultaneously may lead to the air quality of a room deteriorating dramatically in just a few minutes. Even a moderate increase in the content of CO_2 in the atmosphere may cause fatigue and impair concentration, while a significant rise leads to dizziness and headaches. For an optimal air conditioning an accurate reading of the concentration of carbon dioxide in the enclosed space is needed. What's more, in addition to maintaining a healthy environment, an efficiently managed ventilation unit saves on heating costs.

Fraunhofer IPM has developed a miniaturized photoacoustic gas measurement system capable of detecting CO_2 indoors. The solution combines a compact measurement and detection chamber with a modulated thermal emitter and a specially enclosed microphone. The user-friendly optical setup and compatible components, such as the MEMS (microelectromechanical systems) microphone from the field of mobile radio technology, enable the sensor system to be used in a range of applications. These mass-produced parts also make the device very cost-efficient. The miniaturization and integration of the system components mean that the sensor consumes very little energy. A further advantage of the solution is its ability to measure gases selectively thanks to its special two-chamber design.

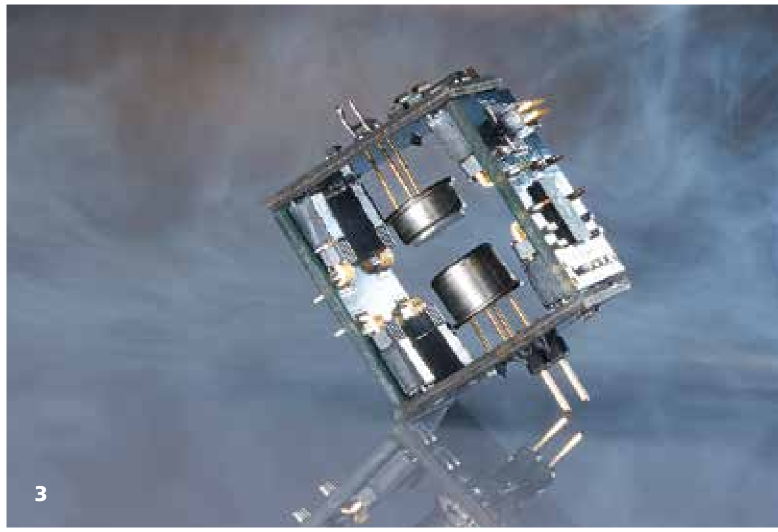
Converting light into sound

The measurement system is based on the photoacoustic effect, which was first explained by Alexander Graham Bell, the inventor of the telephone. The effect describes the conversion of light energy into sound as a result of it being absorbed by gas molecules. During the photoacoustic measurement method, the absorption of electromagnetic radiation by molecules is measured directly using a pressure transducer that detects the increase in pressure arising from the absorption. This means that, in contrast to other infrared measurement systems, the radiation itself does not require detection. The formation of the photoacoustic signal can be divided into a number of stages. Firstly, the electromagnetic radiation is absorbed by the molecules at very specific wavelengths. The resulting increase in energy causes the molecules to move more quickly, which leads to a rise in pressure in the system. The elevated pressure can then be detected as a sound wave using a microphone in a closed chamber. This is made possible as a result of the light energy having been converted into sound.

Ideal measurement principle for compact systems

Conventional indoor air monitoring units are expensive and sensitive to temperature. Replacing the radiation detector with a standard, commercially available microphone, the solution developed by Fraunhofer IPM is significantly less expensive than other systems. The distances between the components and, as a result, the optical path are considerably shorter in photoacoustic sensors than in comparable absorption measurement methods. Inexpensive miniaturized photoacoustic measurement systems, manufactured in large quantities, can be used for a diverse range of applications. In addition to ensuring a healthy environment in conference halls, their small size makes them ideal for maintaining a safe atmosphere in any enclosed space where CO_2 may form. Examples include bar taps, refrigeration and freezer units, wine cellars, medical equipment and industrial production lines, where overly high concentrations of CO_2 present serious health risks.

3 High CO_2 concentrations impair the climate, indoors as much as outdoors. A compact, low-cost CO_2 sensor by Fraunhofer IPM is based on the principle of photoacoustics.



Dr Marie-Luise Bauersfeld, P +49 761 8857 - 290, marie-luise.bauersfeld@ipm.fraunhofer.de

THERMAL MEASUREMENT TECHNIQUES AND SYSTEMS

Electronic tongues can taste the difference

By recognizing patterns in the various sensory signals that the tongue transmits in fractions of a second, the human brain can intuitively distinguish between thousands of different foods. The same approach can also be applied to measurement technology: With the appropriate evaluation methods, a combination of thermal and electrical impedance spectroscopy makes it possible, for example, to reliably recognize the characteristics of liquids used in processes.

At first glance, human sensory capacity and information processing during eating may seem somewhat trivial: The tongue identifies the taste, temperature and quality of food and drink. By combining this information with the sensory impressions provided by the olfactory cells and the visual cells in the retina, humans can reliably distinguish between an incredible number of different foods – those with a practiced palate can even identify individual components of a dish without difficulty. Only upon closer examination does the remarkable performance of the sensory cells and the brain become clear. In order to identify the taste of a food, the brain must combine and evaluate a broad range of sensory signals in a proce ss both highly complex and efficient.

The electronic sensors commonly used today are downright simple in comparison. Fraunhofer IPM is currently developing new sensor concepts based on combined electrical and thermal impedance spectroscopy, which would allow the measuring principle of recognizing materials by taste to be applied to monitoring technical processes.

Measurement techniques acquire a sense of taste

Electrical impedance spectroscopy is a proven tool for measuring the characteristics of liquids that depend on electrical conductivity. However, there is a problem: Due to their size, the measurement structures used are very sensitive with respect to undesirable deposits, which can separate the measurement structures from the liquid. In real processes, such deposits are generally impossible to avoid, which is why Fraunhofer IPM is trying a new approach: Drawing on additional sensors for thermal impedance spectroscopy, these deposits are registered as a change in the thermal contact between the measuring tongue and the liquid.

Combining measurement data creates clarity

But that’s not all. Thermal impedance measurement can additionally be used to detect changes in the thermal characteristics of a liquid. Such characteristics are directly linked with other characteristics, such as viscosity. Combining several thermal measurement structures also makes it possible to measure flow rate and direction.

IMPEDANCE SPECTROSCOPY is used to examine a wide range of materials and conductivity mechanisms. In electrical impedance spectroscopy, impedance depends on the frequency of the alternating current. If the thermal conductivity rather than the electrical conductivity of a material is examined, this is known as »thermal impedance spectroscopy«. Combining both methods makes it possible to make more reliable statements about the characteristics of liquids used in processes.

1 *Electronic tongues are designed downright simple if compared to the human tongue.*

Scientists at Fraunhofer IPM are currently developing innovative measurement concepts that combine a wide range of sensors to measure the aging of oils as well as sooting and other processes in chemical reactors. In addition, some measurement structures are being specially furnished with reactive coatings. As with the human brain, the focus is on analyzing and linking the individually detected sensor signals. Because what is true for the human tongue is equally true for the electronic tongue – in order to reach the right conclusion, it is necessary to combine various information about taste. Whether the conclusion is: Yes, the soup has been over salted. Or: Yes, the hydraulic oil needs to be changed.

2 *Novel sensor concepts based a combination of thermal and electrical impedance spectroscopy reliably detect characteristics of liquids.*

Martin Jägle, P +49 761 8857 - 345, martin.jaegle@ipm.fraunhofer.de

SPECTROSCOPY AND PROCESS ANALYTICS

Infrared spectroscopy facilitates highly accurate analysis of combustion gases

Major fluctuations in the quality of natural gas are now widespread in Germany, making the regular and reliable analysis of gas composition increasingly important. Fraunhofer IPM has developed the »EcoSpectro« measuring system for RMA Mess- und Regelungstechnik GmbH & Co KG, which quickly and accurately detects the quality of natural gas.

Fluctuations in gas composition and therefore in the quality of natural gas are growing ever larger. This is due to the fact that various suppliers are feeding gases of different quality into the German natural gas grid. 90 percent of the natural gas consumed in Germany comes from abroad, with the majority originating in Russia, Norway and the Netherlands. This mix is supplemented with the feed-in of biogas and in the future will also be supplemented with hydrogen, which serves as temporary storage for excess power from volatile energy sources such as wind and photovoltaic plants in accordance with the power-to-gas principle.

Calorific value is a significant factor in determining gas quality. For customers, the gas price is calculated based on the volume of gas supplied and the calorific value. The latter is not constant and varies depending on gas composition – after all, natural gas is a natural product. Previously, the calorific value of gas was determined through combustion in a calorimeter. Today, distribution points on the gas grid and industrial consumers rely on gas chromatography, a method with many drawbacks: Not only are gas chromatographs expensive to purchase and complicated to use, they are also relatively slow and require carrier gases.

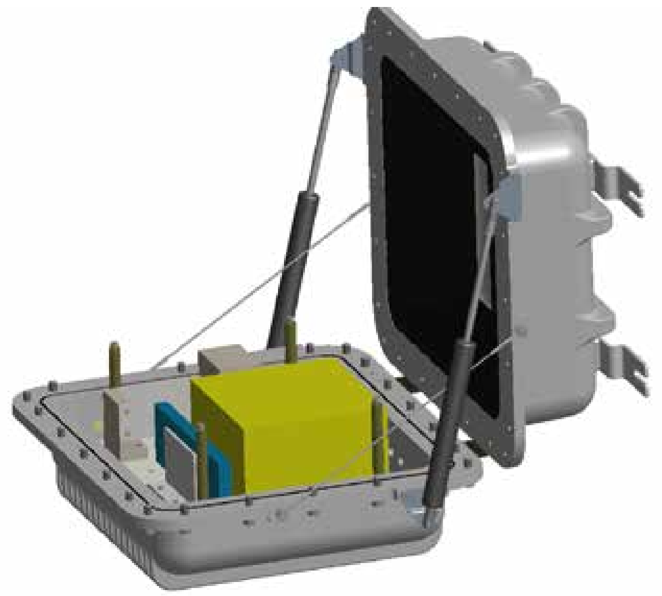
Spectral measurement – chemometric analysis

Fraunhofer IPM has developed an innovative combustion gas measurement system based on infrared spectroscopy that offers many advantages over traditional gas chromatographs. The »EcoSpectro« measurement system, developed for RMA, is capable of analyzing the quantity of hydrocarbons up to C6+, CO_2, N_2, and also offers options for detecting hydrogen and oxygen. Any gases in the mixture that are not infrared active are detected by additional integrated sensors. Other advantages of the system: The »EcoSpectro« measures gas quality at one minute intervals, and because it does not need carrier gases, it is much cheaper to maintain than a gas chromatograph.

The system uses an innovative chemometric process to automatically evaluate the spectra. This process also makes it possible to very accurately and automatically detect higher hydrocarbons up to hexane in the spectra. With extensive measures to stabilize the infrared spectrometer, spectra with a good signal-to-noise ratio are recorded and it is possible to use the mathematical algorithms to determine the high dynamic of gas concentrations. They range from more than 70 percent (methane) to only 100 ppm (higher hydrocarbons such as pentane and hexane) in individual spectra. The various hydrocarbon isomers multiply the number of gases to be detected, for example pentanes can be present as n-pentane, isopentane or neopentane, so that spectroscopic detection of more than ten different gas components is necessary. Fraunhofer IPM has been using chemometric processes in spectroscopy for many years to create exact mathematical models of the composition of substances – even with very large amounts of data.

A new generation of gas measurement technology

As scientists at Fraunhofer IPM have repeatedly noted in recent years, gas is the key to the economic and environmental success of the energy transition. Systems for the continuous analysis of gas composition and gas quality such as »EcoSpectro« are important elements of sustainable, economic gas supply.



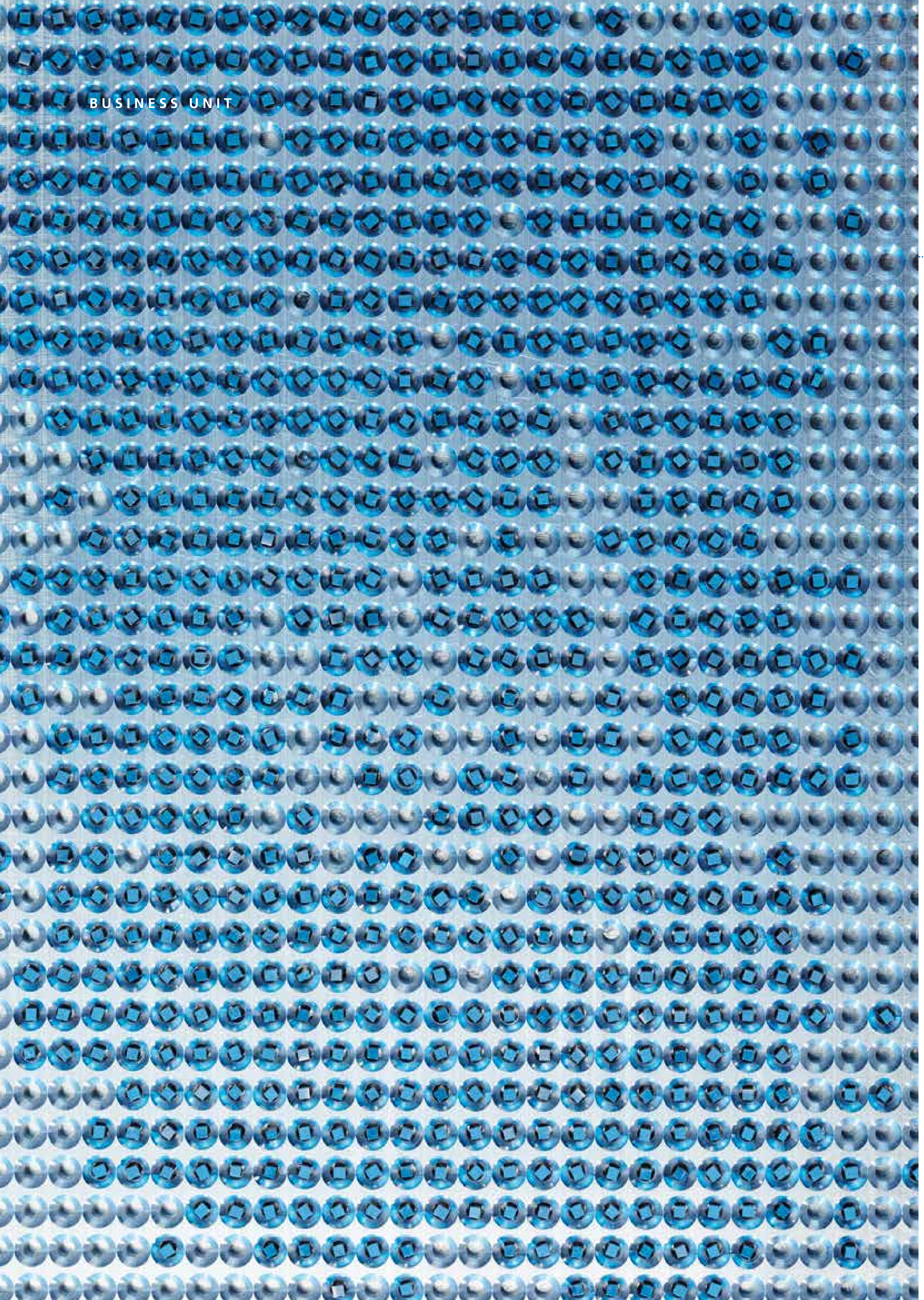
2

1 *Natural gas from various sources is fed into the natural gas grid. The calorific value of gas fluctuates depending on its composition.*

2 *»EcoSpectro« analyzes concentrations of hydrocarbons, nitrogen, carbon dioxide, hydrogen and oxygen in gas mixtures at one minute intervals.*

WHAT IS OUR NATURAL GAS MADE OF? Natural gas is a natural product. It is 70 to 90 percent methane and also comprises ethane, propane, butane and other hydrocarbons. Natural gas typically contains nitrogen and carbon dioxide. One of the clear advantages of natural gas over crude oil or coal is its significantly lower pollutant emissions during combustion as well as its lower CO_2 emissions. After mineral oil, natural gas is the second most important primary energy source in the German energy mix.

Dr Raimund Brunner, P +49 761 8857-310, raimund.brunner@ipm.fraunhofer.de



FUNCTIONAL MATERIALS AND SYSTEMS

»We make more of materials.«

The »Functional Materials and Systems« business unit manufactures and optimizes materials with special physical properties, developing them into systems. The materials include: *nonlinear optical materials,* e.g. for the development of novel lasers with adjustable wavelengths; *thermoelectric materials* for the direct conversion of waste heat into electricity; *magnetocaloric and electrocaloric* materials for efficient refrigerant-free heat pumps and cooling systems

Nonlinear Optics

The »Nonlinear Optics« group focuses on developing innovative laser sources and detectors based on nonlinear optical materials. These materials enable various light wavelengths to be added or subtracted so that different variable wavelengths can be formed. This creates widely adjustable laser light sources and sensitive infrared detectors that can be used, for example, in highly sensitive spectroscopy systems. By measuring even the lowest levels of residual absorption in highly transparent materials, the group is able to characterize important system components for high-power lasers and nonlinear optics.

Thermoelectrics

The »Thermoelectrics« group focuses on conditioning new thermoelectric materials and develops thermoelectric modules. These modules can be used to harvest waste energy, to supply self-powered sensors or as high-performance Peltier coolers. The group uses simulations and its knowledge of systems to develop, construct and field test prototypes of complete electricity generation plants or thermal management solutions for critical hardware components. It further specializes in optimizing bespoke thermoelectric materials and modules for research and industrial development purposes.

Magnetocalorics and Electrocalorics

The »Magnetocalorics and Electrocalorics« group concentrates on developing innovative cooling systems based on magnetocaloric and electrocaloric materials. These heat up or cool down when exposed to magnetic or electric alternating fields. The new materials can be used to produce cooling systems that do not require refrigerants, making them more efficient and much more environmentally friendly than conventional compressor-based cooling techniques.

TOPICS

- Widely tunable laser light sources for spectroscopy
- Characterization of optical materials and semiconductors
- Conversion of waste heat into electricity
- Self-powered sensors and systems
- Measurement systems for determining thermal and electrical material characteristics
- Efficient cooling systems without refrigerants

EXPERTISE

- Conditioning and characterization of functional materials
- Frequency conversion for light generation and detection
- Measurement of very low absorption rates
- Thermal management (heat pipes, Peltier elements)
- Special electrical and thermal contacting
- FEM simulations
- System design and development

CONTACT

Dr Heinrich Höfler
Head of Department
P +49 761 8857 - 173
heinrich.hoefler@
ipm.fraunhofer.de

Picture *Feed stock with thermoelectric legs.*

1 *Silicon camera with an »active« lens.*

NONLINEAR OPTICS

Silicon camera for the mid-wave infrared region

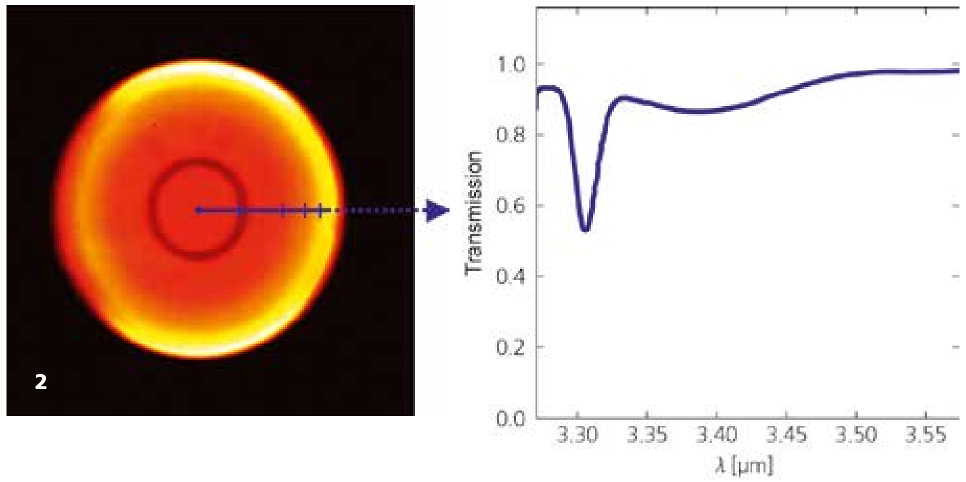
Fraunhofer IPM has developed a special camera lens capable of transforming low-cost silicon-based digital cameras into sensitive, fast infrared cameras. The scientists' work draws on the process of frequency conversion.

NONLINEAR FREQUENCY CONVERSION
Under certain circumstances, exposing suitable nonlinear optical materials to radiation creates light with new wavelengths. A typical example of this is the generation of light with a doubled frequency, i.e. half the wavelength of the incident light. For example, the green light projected by a laser pointer (532 nm) is generated by frequency doubling the output of a laser that actually emits infrared light with a wavelength of 1064 nm.

Nowadays, conventional infrared cameras for the mid-wave (3 – 5 µm) and long-wave (8 – 12 µm) spectrums are frequently used to take measurements during technical processes and in the safety technology field. However, in comparison with silicon-based cameras for use in the visible spectrum, infrared cameras are still significantly inferior in terms of sensitivity and temporal resolution. What's more, the special semiconductors found in infrared cameras require cryogenic cooling, making them complex and expensive. As part of the LITRAN project, Fraunhofer IPM has joined forces with three other Fraunhofer Institutes to develop a new generation of fast cameras for the mid-wave infrared (MWIR) region that do not require special semiconductors. The new devices comprise conventional, silicon-based cameras fitted with a special »active« lens.

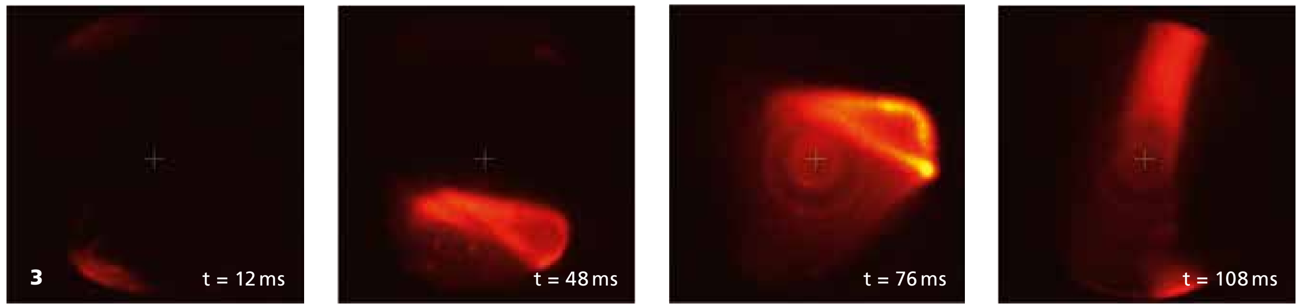
From MWIR to NIR

The centerpiece of this »active« lens is an MWIR-NIR converter. The MWIR signal is converted into the NIR spectrum (700 – 900 nm) by means of sum-frequency generation using laser pumping. The unusual idea behind this technique is that of making the light »fit« for the camera as opposed to making the sensor »fit« for the light. Although scientists have long been familiar with the process of frequency conversion, until now the technique had been much too inefficient to be used in practice. However, thanks to novel materials for the pump laser and conversion crystal, conversion efficiencies in the percentage range have now been achieved, opening up new areas of application. The converted NIR photons can be detected quickly and with a high level of sensitivity using silicon-based image sensors available on the market – without the need for expensive cryogenic cooling. The camera's strengths come especially to the fore during spectrally resolved infrared imaging. The physical properties of the conversion ensure that the active lens can act as an adjustable, narrow-band infrared filter. This makes it possible for wavelength-selective measurements with a high contrast to be collected in the mid-wave infrared region. Since the level of dark noise in NIR detectors is lower by several orders of magnitude, these devices also have the potential for extremely low-noise, sensitive imaging. Alongside its partners, Fraunhofer IPM has discovered potential uses for the new camera, such as the remote detection of methane emissions or inspection procedures in the plastics industry. Rapid and sensitive measurement techniques coupled with the ability to dispense with expensive infrared image sensors are opening up new potential uses of image analysis in the infrared region.

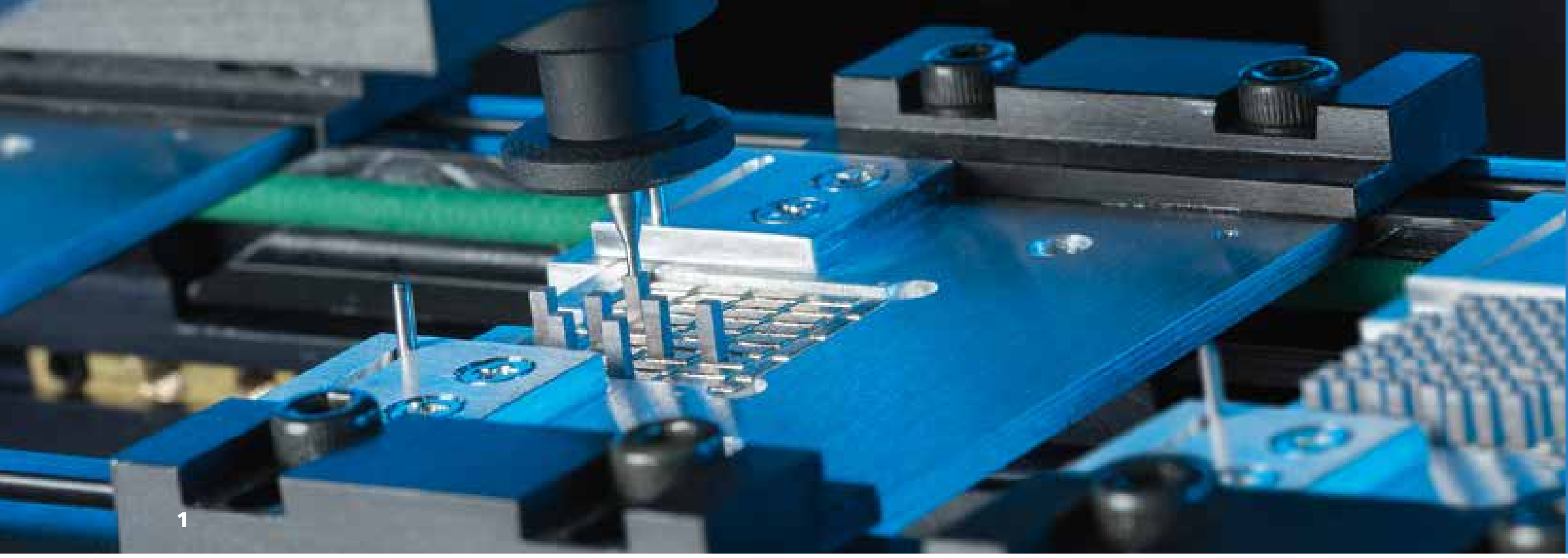


2 *The LITRAN image converter in use as a spectrometer: The LITRAN camera captures an image of light passing from a thermal emitter into a gas cell flooded with methane. The camera image is then converted into a spectrum. The ring pattern can be used to determine the wavelength and the level of methane absorption.*

3 *The LITRAN image converter in use as a fast camera: Infrared images (at approximately 3 µm) of the formation of a lighter gas flame. The thermal glow from the hot water vapor surrounding the flame can be seen around the edges of the flame. This emits infrared radiation with individual wavelengths that are visible as a ring pattern.*



Dr Frank Kühnemann, P +49 761 8857 - 457, frank.kuehnemann@ipm.fraunhofer.de



THERMOELECTRICS

High-temperature modules – on the path to industrial production

Thermoelectric modules are high-tech products, which are still fabricated primarily by hand. Fraunhofer IPM has developed a laboratory process for the semi-automatic fabrication of high-temperature modules, which marks the first step towards industrial module production.

The global demand for thermoelectric modules has increased significantly in recent years. The market for high-temperature modules, which can use waste heat at temperatures of far above 250 °C, is showing particular promise. Fraunhofer IPM boasts one of the world's leading research groups for this type of module. Thanks to major advances in research and development, thermoelectric materials are now available for use at these high temperatures and can be produced on a large scale. Examples include half-Heusler compounds, skutterudites, and silicides. Fraunhofer IPM is using these new materials to manufacture thermoelectric modules that can be integrated into both stationary units like combined heat and power plants or mobile systems such as vehicles. Many of the steps needed to produce high-temperature modules are still performed by hand. To date, efforts to automate the fabrication of thermoelectric modules have been limited to modules operating at room temperature, which have been commercially available for decades. Fraunhofer IPM has now become the first to automate the production of new thermoelectric high-temperature modules to a certain extent.

Dexterity and concentration

Thermoelectric modules consist of n- and p-type conducting materials. Known as thermoelectric legs, they are connected thermally in parallel and electrically in series. The waste heat is converted by means of a heat flux that passes through the modules and generates electricity due to the so called Seebeck effect. For this to happen efficiently, the legs are connected to a material with the highest possible level of electrical conductivity. Modules are sandwiched between thin ceramic plates, which form their exterior. The module production process comprises the following main steps: Firstly, cylindrical blanks are lapped to size and cut into legs. These are then joined to the electrodes by means of soldering, brazing or welding.

Dexterity and a high level of concentration are crucial, especially when positioning the legs by hand. Under a microscope, tweezers are used to position up to 80 legs, each with an edge length of around 1 mm, onto the electrodes of each module. N- and p-type legs, which in terms of their appearance are scarcely distinguishable from one another, must be arranged in a checkerboard pattern. It only takes one leg to be positioned incorrectly for the completed module not to function. Positional accuracy of around 0.1 mm is needed for the modules to work. It is therefore vital that each step is performed with the utmost precision. This means that the entire contacting process, including the joining temperature, quantity of solder or braze and processing steps, must be reproducible and carried out precisely.

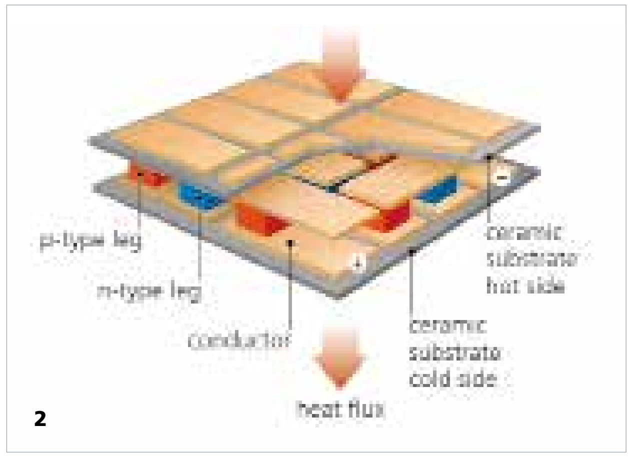
USING »ENERGY HARVESTING« TO BOOST ENERGY EFFICIENCY

Thermoelectric modules convert heat into electricity. As robust and low-maintenance energy converters, they are ideal for generating electricity from waste heat in combustion engines, power stations and industrial plants. Since most of this energy is currently unexploited, thermoelectric energy harvesting will help to significantly increase energy efficiency in these areas.

Automation and measurement techniques

The module fabrication process put into operation by Fraunhofer IPM at the start of 2016 has now automated many of the production steps. An automatic precision saw ensures the legs are manufactured precisely, while a positioning machine is responsible for arranging the legs. An automated joining unit developed at the Institute regulates the brazing process precisely and efficiently. Special measurement techniques are used to monitor various stages of the fabrication process with respect to quality assurance. For example, particular procedures are employed to measure the electrical conductivity and Seebeck coefficient of the blank, inspect the shape of the legs after sawing, and test completed modules for desired electrical properties like internal resistance. The majority of these processes are performed using measurement systems developed by Fraunhofer IPM. This ensures real-time 100 percent control on request.

1 The positioning robot precisely places the legs on the ceramic plate. A module comprises up to 80 legs. These are made from n- and p-type thermoelectric materials and are arranged in a checkerboard pattern.

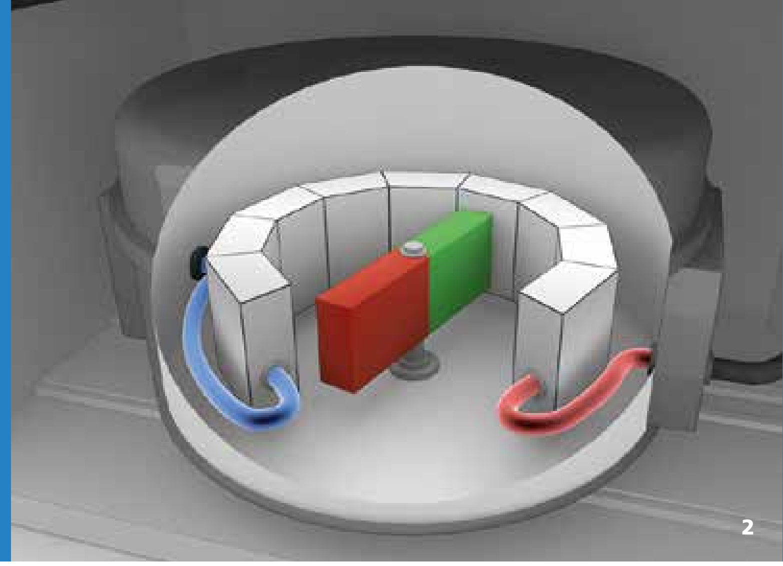


2 Setup of a thermoelectric module.

By starting up the semi-automated batch production line on a laboratory scale and increasing production capacity to several thousand modules a year, Fraunhofer IPM has taken a significant step towards establishing industrial module production and lowering module prices for innovative high temperature modules.

Dr Jan D. König, P +49 761 8857-329, jan.koenig@ipm.fraunhofer.de

1 + 2 *CAD model of a magnetocaloric cooling system. A rotating permanent magnet generates a magnetic field that heats and cools the series-connected magnetocaloric segments.*



MAGNETOCALORICS AND ELECTROCALORICS

Efficient heat transfer in magnetocaloric cooling circuits

Magnetocaloric cooling technology is a promising candidate for efficient and environmentally friendly cooling technology. The future market viability of this technology depends on its ability to transfer heat between a magnetocaloric material and a heat exchanger as efficiently as possible. To this end, Fraunhofer IPM has developed a new concept based on so-called heat pipes.

In terms of cooling technology, the industry relies almost exclusively on compressor-based systems; however the refrigerants needed to operate these systems pose a danger to the environment and/or health and are therefore increasingly regulated or even prohibited across the EU. In the future, magnetocaloric cooling cycles could make cooling systems up to 30 percent more efficient. These systems are generally quiet and low-maintenance, and operate without using controversial refrigerants.

Increased material efficiency

Magnetocaloric (MC) materials heat up when exposed to a magnetic field and cool down again once this field is removed. To implement a cooling cycle, a magnetic field is applied to the MC material, and the heated material is connected to a heat sink in order to transfer the heat produced. If the magnetic field is removed, the MC material cools down again, reaching a lower temperature than at the start of the cycle. The material is then connected to the system to be cooled and can absorb heat until it returns to its starting temperature. Magnetocaloric cooling circuits were first implemented in the 1970s. Due to the increasing efficiency of MC materials, today magnetocaloric heat pumps can achieve a pump capacity of several kilowatts. As part of the »MagCon« project (Magnetocalorics: Development of refrigerant-free, highly efficient heat pumps for heating and cooling), scientists at the Institute are collaborating with colleagues at Fraunhofer IFAM to develop a prototype for a magnetocaloric cooling circuit with a new, patented heat transfer concept that functions on the heat pipe principle. The goal is to develop the world's first refrigerant-free cooling system with a heat pump capacity of 300 W, a temperature change of 35 K and a coefficient of performance of > 5.

Heat pipes facilitate fast heat transfer

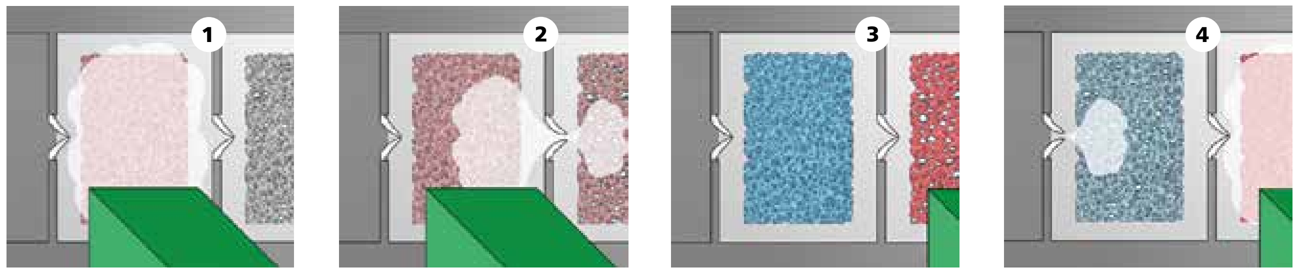
The efficient transfer of heat between the MC material and the heat exchanger is a decisive factor in the overall efficiency of the magnetic cooling cycle. Previous prototypes are based on the concept of »active magnetic regeneration« (AMR), in which a fluid is pumped through the MC material to transfer heat. A low heat transfer coefficient and the resulting low cycle frequency as well as the large amount of pumping energy required make AMR concepts inefficient overall. The heat pipe concept for heat transfer developed by Fraunhofer IPM facilitates passive heat transfer through the evaporation and condensation of a fluid in a hermetically sealed volume. Such heat exchangers, also known as thermosiphons, are used as solar collectors or in computer cooling. The heat pipe concept is an innovative method for implementing a magnetocaloric cooling cycle.

The whole system is efficient and fast: By evaporating a fluid such as water or ethanol at the heat source and subsequently condensing it at the heat sink, it is possible to achieve heat transfer coefficients that are several orders of magnitude higher than those achieved in traditional heat transfer by means of thermal conduction or convection. Simulated calculations have shown that transporting thermal energy from one magnetocaloric segment of only a few centimeters in size to the next occurs in a matter of milliseconds, making it fundamentally possible to establish cooling cycles with a frequency of more than 10 Hz. Fraunhofer IPM has developed heat pipes which are thermal diodes and only allow heat to flow in one direction only.

Efficient, refrigerant-free heat pumps based on the magnetocaloric cycle have the potential to revolutionize cooling technology. The best part: Magnetocaloric heat pumps can also be used for heating, making them an important element of the HVAC technology of the future.

MAGNETOCALORIC COOLING CIRCUITS

The heat is »driven forward« in only one direction according to the principle of a thermal diode: The heat generated by the magnetic field causes the fluid in the MC material to evaporate (1), increasing the pressure in the segment. The pressure relief valve opens, allowing the vapor to flow into the adjoining element (2). Once the magnet has been switched off, the MC material cools down below the starting temperature (3) and the vapor pressure drops. A vacuum develops in relation to the previous segment. Gaseous fluid flows in and heat from the previous segment is absorbed (4).



Dr Kilian Bartholomé, P +49 761 8857-238, kilian.bartholome@ipm.fraunhofer.de

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 67 institutes and research units. The majority of the nearly 24,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.1 billion euros. Of this sum, more than 1.8 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 Länder 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.

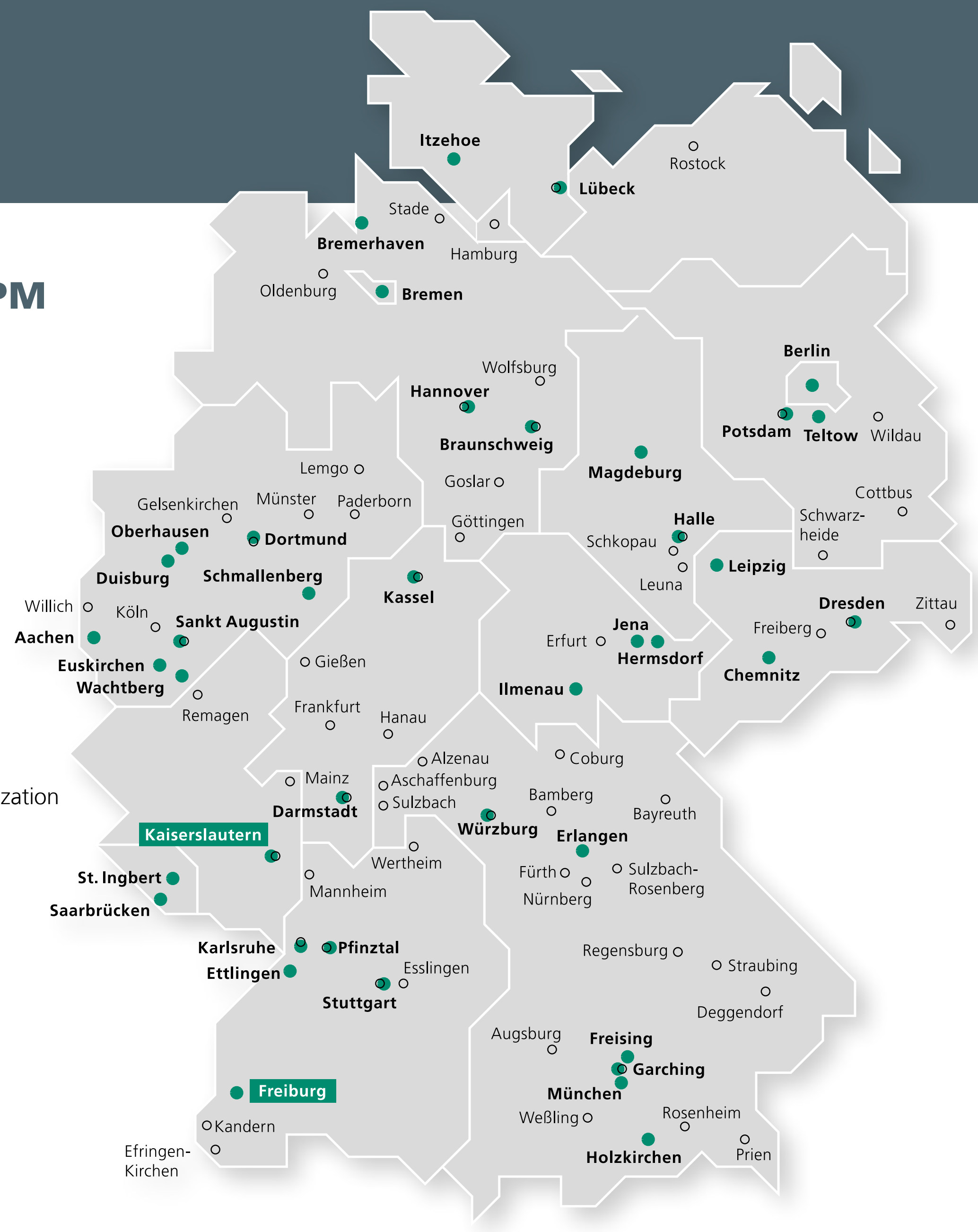
www.fraunhofer.de

FRAUNHOFER IPM

Freiburg
Fraunhofer Institute for Physical Measurement Techniques IPM
Heidenhofstraße 8
D-79100 Freiburg
P +49 761 8857-0
F +49 761 8857-224
info@ipm.fraunhofer.de

Kaiserslautern
Fraunhofer Institute for Physical Measurement Techniques IPM
Department Materials Characterization and Testing
Fraunhofer-Platz 1
D-67663 Kaiserslautern
P +49 631 2057 40-00
F +49 631 2057 40-03
info@ipm.fraunhofer.de

www.ipm.fraunhofer.de/en



Main locations ●
Other locations ○

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 Food Chain Management Alliance
- Fraunhofer Cleaning Technology 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
- LIA – Laser Institute of America
- MRS – Material Research Society
- OSA – Optical Society of America
- SPIE – International Society for Optics and Photonics

Germany

- AMA Fachverband für Sensorik
- Arbeitskreis Prozessanalytik der GDCh und DECHEMA
- Biovalley Deutschland e.V.
- BBA-BW – Brennstoffzellen- und Batterie-Allianz Baden-Württemberg
- CAST e.V. – Competence Center for Applied Security
- CNA Cluster Bahntechnik e.V.
- DGZfP – Deutsche Gesellschaft für Zerstörungsfreie Prüfung
- DPG – Deutsche Physikalische Gesellschaft e.V.
- DTG – Deutsche Thermoelektrik Gesellschaft e.V.
- DTZ – Deutsches Terahertz-Zentrum e.V.
- FAIM – Forum Angewandte Informatik und Mikrosystemtechnik e.V.
- LR BW – Forum Luft- und Raumfahrt Baden-Württemberg e.V.
- GDCh – Gesellschaft Deutscher Chemiker
- Green City Freiburg Regional Cluster
- Strategische Partner - Klimaschutz am Oberrhein e.V.
- microTEC Südwest e.V.
- Nano-Zentrum Euregio Bodensee e.V.
- Draht-Welt Südwestfalen – netzwerkdraht e.V.
- Optence e.V. Kompetenznetz Optische Technologien Hessen und Rheinland-Pfalz
- Photonics BW Innovationsnetz für Optische Technologien
- SPECTARIS – Deutscher Industrieverband für optische, medizinische und mechatronische Technologien e.V.
- Science Alliance Kaiserslautern e.V.
- VDI/VDE – GMA Gesellschaft für Mess- und Automatisierungstechnik
- VDMA – Photovoltaik-Produktionsmittel; E-Batterie
- VDSI – Verband für Sicherheit, Gesundheit und Umweltschutz bei der Arbeit e.V.

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DE102014201800

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DE102013101610

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DE102013218842

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DE102014105139

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DE102013107265

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DE102013214515

TRADE FAIRS

Control
International Trade Fair for Quality Assurance
Stuttgart, May 5 – 8, 2015
»Fraunhofer-Allianz Vision« booth
We presented systems for 3D object measurement in production environments, image-based inline detection of residual contamination and inline layer thickness measurement using terahertz waves.

E-MRS Spring Meeting
European Materials Research Society
Lille, May 12 – 14, 2015
At the spring meeting of the European Materials Research Society, Fraunhofer IPM collaborated with Quick-Ohm Küpper & Co. GmbH to present measurement systems for materials characterization.

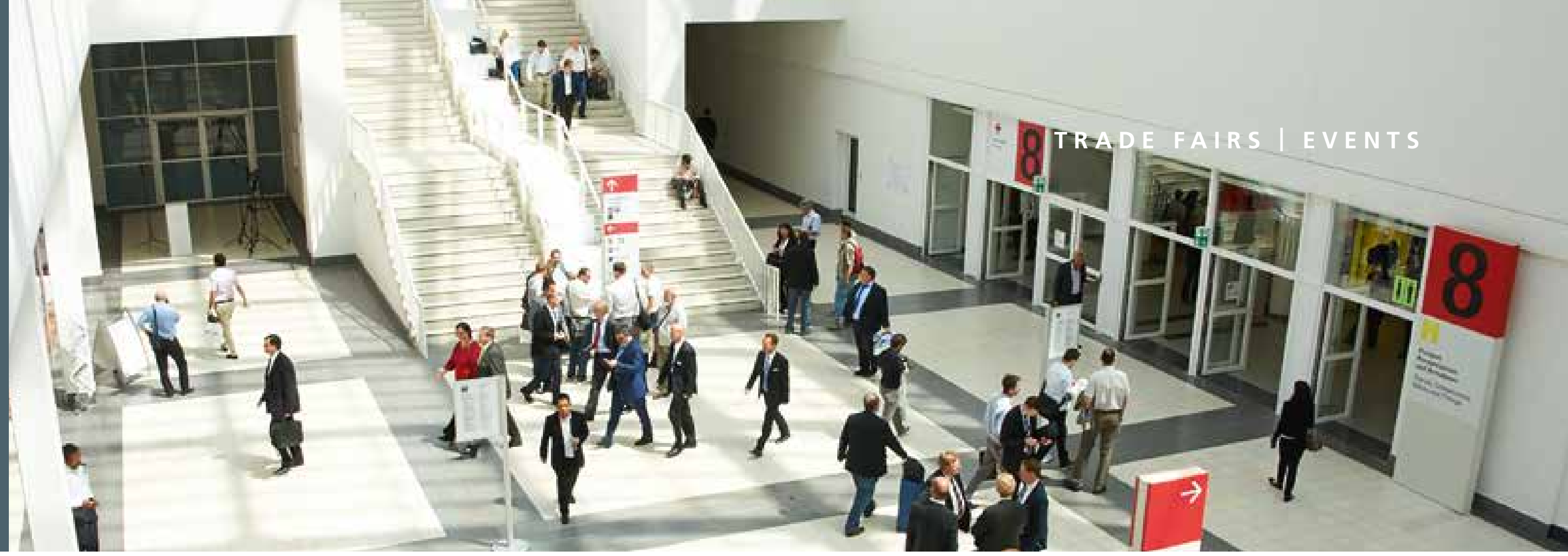
Sensor + Test
The Measurement Fair
Nuremberg, May 19 – 21, 2015
»Frauenhofer-Gesellschaft« booth
Frauenhofer IPM presented mechanically flexible gas, liquid and solid-state sensors for different applications in areas such as food chain management, automobiles, process control or biotechnology.

Parts2Clean
Leading International Trade Fair for Industrial Parts and Surface Cleaning
Stuttgart, June 9 – 11, 2015
»Frauenhofer-Gesellschaft« booth
Residual contamination on components – such as oils, photoresists or cleaning agents – often remains undetected, but can disrupt the subsequent processing of components. Fraunhofer IPM presented a laser-based scanning measurement system that uses autofluorescence to check component surfaces for residues.

Achema
World Forum and Leading Show for the Process Industries
Frankfurt, June 15 – 19, 2015
Fraunhofer IPM presented systems for emissions analysis in engine test benches, remote gas detection, and terahertz spectroscopy. Employees of the Institute were involved in four presentations at the Achema 2015 congress.

Intergeo
Conference and Trade Fair for Geodesy, Geoinformation and Land Management
Stuttgart, September 15 – 17, 2015
The Clearance Profile Scanner CPS and the Modular Lightweight Measurement System MLM were exhibited at Intergeo 2015. The CPS is the fastest laser scanner in the world for the detection of geometries in the surrounding area. The modular MLM is a small, lightweight laser scanner developed for detecting infrastructure and for use on aerial vehicles.

Deburring Expo
Trade Fair for Deburring Technology and Precision Surfaces
Karlsruhe, October 13 – 15, 2015
»Frauenhofer-Gesellschaft« booth
Fraunhofer IPM served as a cooperation partner at the expert forum of the inaugural DeburringExpo. The booth showcased a measurement system for 100% inspection that uses digital-holographic, multi-wavelength interferometry to quickly measure the burr on die cast metal components with millimeter precision.



EVENTS

Kick-Off of Sustainability Center Freiburg
Freiburg, June 3, 2015
The Sustainability Center is a cooperation between the University of Freiburg (Albert-Ludwigs-Universität Freiburg, ALU), Freiburg's five Fraunhofer institutes and industry.

Opening ceremony for the new Fraunhofer IPM building in Kaiserslautern
Kaiserslautern, Fraunhofer IPM, April 14, 2015
Official opening of the institutional building at the Fraunhofer Center in Kaiserslautern.

Girls' Day
Freiburg, Fraunhofer IPM, April 23, 2015
In 2015, Fraunhofer IPM once again participated in the annual Girls' Day for students in grades 5 through 10, providing insight into jobs in technology, information technology, the trades and the natural sciences.

Children's Afternoon to mark the International Year of Light
Freiburg, Fraunhofer IPM, July 3, 2015
At the center of the Children's Afternoon were a series of experiments involving light, which the Institute organized as part of the International Year of Light.

Freiburg Science Market
Freiburg, Münsterplatz, July 10 – 11, 2015
Fraunhofer IPM joined together with the Fraunhofer Institutes of Freiburg to present »Hands-on Science« on Freiburg's Münsterplatz.

EUROSENSORS XXIX 2015
Freiburg, Konzerthaus, September 6 – 9, 2015
Fraunhofer IPM collaborated with the Department of Microsystems Engineering IMTEK in Freiburg to organize EUROSENSORS XXIX 2015. EUROSENSORS is an international forum for scientists, students and engineers dedicated to the topics of sensors, actuators, micro- and nanosystems. Approximately 550 visitors participated in the event.

8. Fraunhofer Vision Technology Day
Stuttgart, Fraunhofer IPA, 8. Fraunhofer Vision Technology Day
Workshop with accompanying exhibition. Fraunhofer IPM presented a 3D sensor for production environments.

Sustainability Summit 2015
Freiburg, Konzerthaus, October 19 – 20, 2015
Kick off for a conference series of the Sustainability Center Freiburg, focusing on the topics energy, materials, resilience and transformation.

Optical 3D measurement techniques for quality assurance in production
Jena, Fraunhofer IOF, November 25 – 26, 2015
Seminar and practical session. Lecture by Dr Tobias Beckmann on the topic of digital-holographic 3D measurement techniques.

1 Prof Dr Jürgen Wöllenstein (left), Fraunhofer IPM, and Prof Dr Gerald Urban, Department of Microsystems Engineering IMTEK, chaired the EUROSENSORS conference.

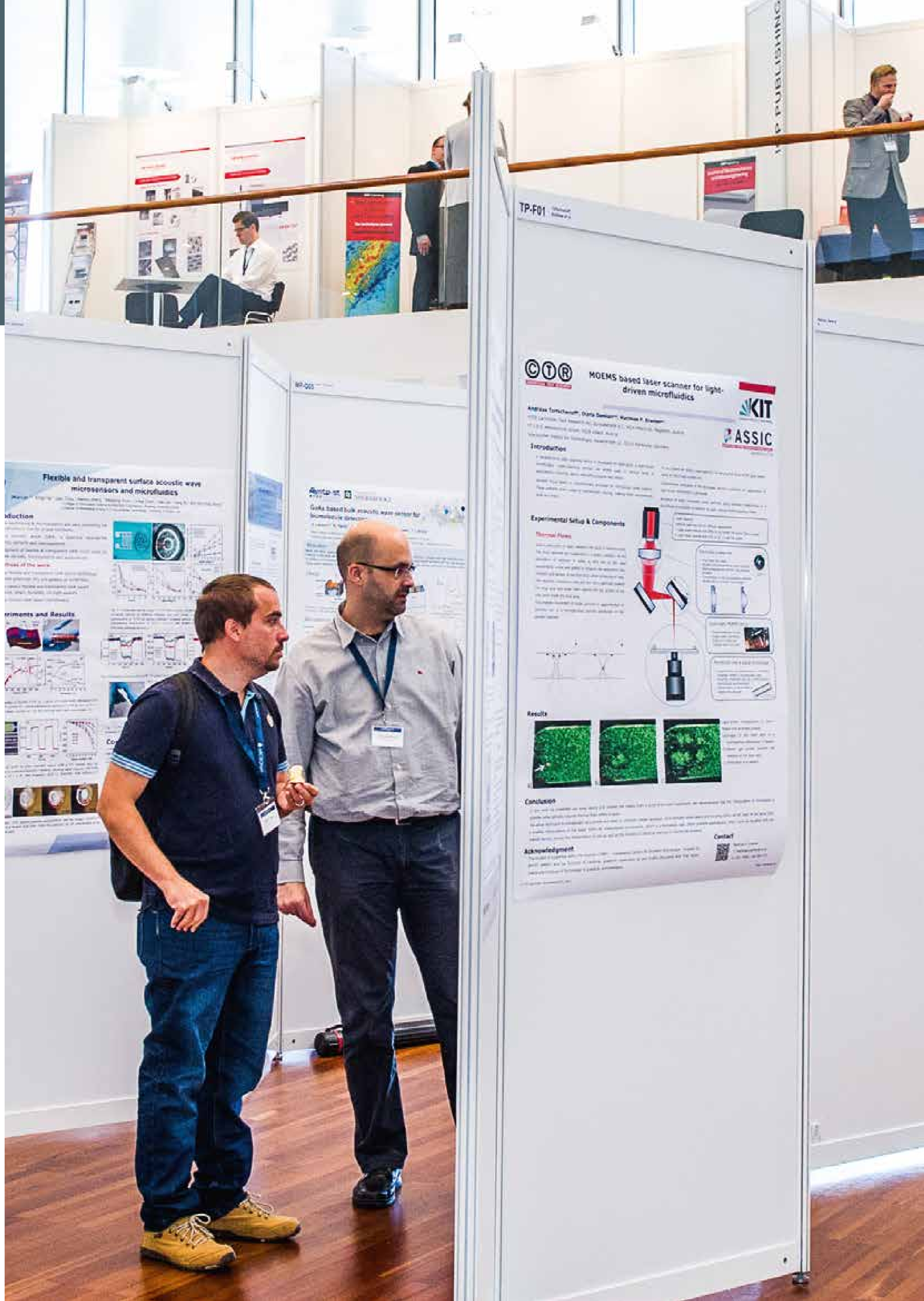
WORKSHOPS AT FRAUNHOFER IPM

Gas Sensor Workshop
Freiburg, Fraunhofer IPM, September 10, 2015
Intelligent technologies for gas measurement: Application-oriented workshop for science and industry.

Expert Workshop »Non-destructive Testing of Composites«
Kaiserslautern, Fraunhofer IPM, September 10, 2015
Workshop for representatives from industry and science on the latest technology and trends in non-destructive testing and production of composites.

Contactless Moisture Measurement Techniques
Freiburg, Fraunhofer IPM, October 8, 2015
Application-oriented workshop for representatives from science and industry.

QLC in Industry – From the Laboratory to Processing
Freiburg, Fraunhofer IPM, November 12, 2015
Application-oriented workshop for experts and other interested parties from science and industry.



In 2015, Fraunhofer IPM organized the international EUROSENSORS conference (picture) and four workshops.

Fraunhofer IPM

Freiburg
Fraunhofer Institute for
Physical Measurement Techniques IPM
Heidenhofstrasse 8
D-79110 Freiburg
P +49 761 8857-0
F +49 761 8857-224
info@ipm.fraunhofer.de

Kaiserslautern
Fraunhofer Institute for
Physical Measurement Techniques IPM
Department Materials Characterization and Testing
Fraunhofer-Platz 1
D-67663 Kaiserslautern
P +49 631 2057 40-00
F +49 631 2057 40-03
info@ipm.fraunhofer.de

www.ipm.fraunhofer.de/en

Editorial Address
Fraunhofer Institute for
Physical Measurement Techniques IPM
Press and Public Relations
Holger Kock
Heidenhofstrasse 8
D-79110 Freiburg
P +49 761 8857-129
holger.kock@ipm.fraunhofer.de

Editorial Team
Holger Kock, Anja Strobel, Iris Erbach, Isabell Wiedle

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Rea Naber

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