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FRAUNHOFER IPM

MEASURING · MONITORING · OPTIMIZING

2014 / 2015

Fraunhofer IPM

FRAUNHOFER-INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM

Measuring · Monitoring · Optimizing

Cover *Fraunhofer IPM develops integrated sensor systems and micromachined components together with corresponding measurement technology for their production.*

- PRODUCTION CONTROL
- MATERIALS CHARACTERIZATION AND TESTING
- OBJECT AND SHAPE DETECTION
- GAS AND PROCESS TECHNOLOGY
- FUNCTIONAL MATERIALS AND SYSTEMS

»Quicker and more precise measurement – to improve efficiency«

Prof. Dr. Karsten Buse, Executive director

Dear customers and partners,

Better and better »resource efficiency« is one of today's central challenges for society. This does not only involve greater energy efficiency but predominantly greater raw material efficiency. There is one problem, however: our demands, our technical facilities and therefore the basic demand for resources are also on the increase – just look at the examples of medical technology and transportation. In these and many other industries, Fraunhofer IPM manages to make a valuable contribution to ensure that ultimately, efficiency improves.

Our mission: To improve resource efficiency

Our measurement systems ensure 100% monitoring of production processes with a high throughput, thus preventing errors and increasing productivity. Our measurement systems help to detect and reduce emissions. And our skills in the field of functional materials help to recycle waste heat. »Resource efficiency« saves money and increases corporate profits. In our market economy that is exactly what is required for technology to become established. The measuring systems built by Fraunhofer IPM are often amortized within a very short period of time, reduce risks for businesses and secure jobs. We have seen dramatic evidence of this on several occasions in the past few months.

Our claim: quicker and more precise measurement

During the meeting of our Advisory Board in 2014, the question was raised as to what makes developments by Fraunhofer IPM stand out compared to those of its competitors and why we are so successful despite the fact that the systems we make often cost 100,000 euros or more each and that globally active enterprises with massive ranges of products are present in the testing and measuring equipment market. There are two good reasons for our success: firstly, we develop and manufacture bespoke special systems tailored to specific applications which would otherwise not exist. Secondly, it became clear during the discussion with our trustees that Fraunhofer IPM systems set world records in terms of their speed and accuracy. Our systems for digital holographic 3D measurement can now record more than 10 million 3D points per second and our laser scanners achieve accuracy levels in the sub-tenth millimeter range, to name but two examples.

Our aim: Customers who keep returning

These unique selling points have led to Fraunhofer IPM continuing to develop very well. Delighted by the performance of our systems and developments, customers have placed follow-up orders and new customers have been acquired who, after many years of fruitless searching for suitable measurement systems, have finally struck gold with us. We are always delighted to receive your enquiries and new challenges.

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

Yours,

Karsten Buse

SAFETY IN FOOD PRODUCTION

Demand for high quality stockfish is rising globally – particularly in Southern Europe. To be able to cover the ever greater demand for this speciality, stockfish production is currently undergoing a transformation from a Viking craft to a high-tech production process. Semi-conductor gas sensors from Fraunhofer IPM play a central role in this process. 40

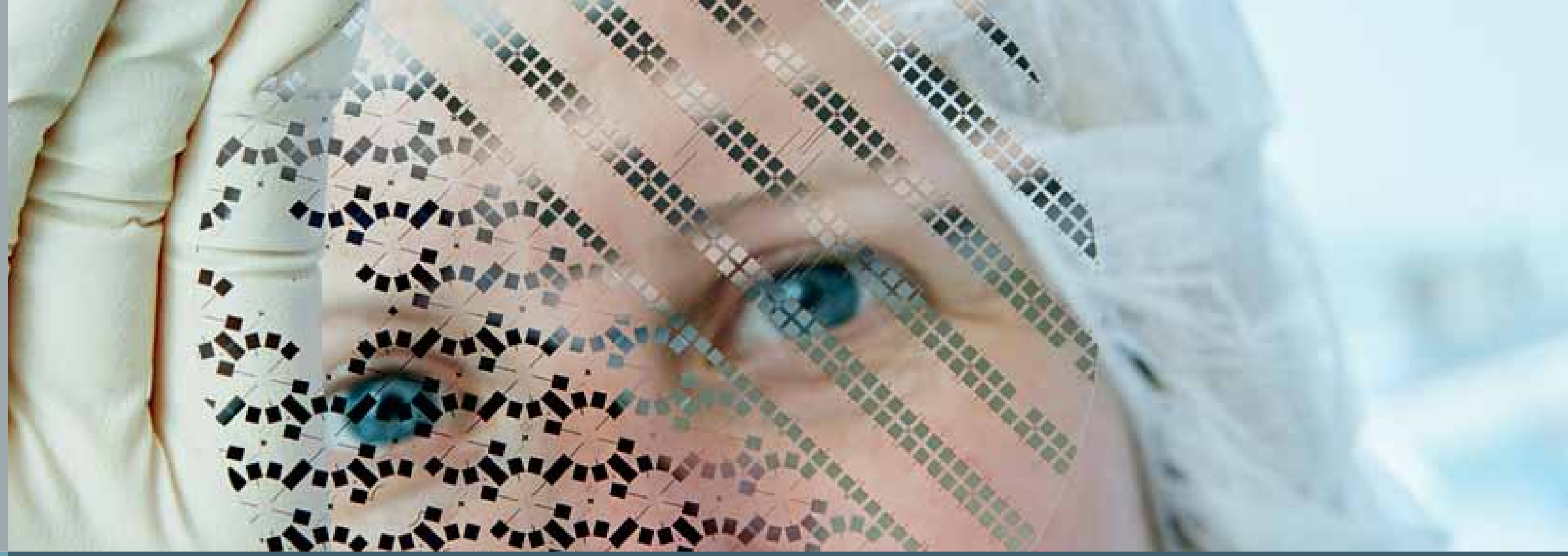
NON-DESTRUCTIVE TERAHERTZ MULTI-LAYER ANALYSIS

To date, the thickness of coatings on non-metallic substrates can only be measured by using destructive or contact methods. Terahertz waves, which lie in the spectrum between infrared and microwaves, enable non-destructive measurement of layers. Terahertz waves are reflected at interfaces at which the index of refraction changes. 30

THERMOELECTRICS IN A COMBINED HEAT AND POWER PLANT

Combined heat and power plants play a major role in the energy transition process. Fraunhofer IPM is developing new thermoelectric generators to increase the electrical efficiency and hence the economy of combined heat and power plants even further. 52

Microstructured measuring structure on transparent substrates.



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Women at Fraunhofer IPM

WOMEN IN SCIENCE EVENT IN FREIBURG

Fraunhofer organized the four-day »Women in Science« event in Freiburg in October 2014 to encourage more women to take up scientific careers. Students of mathematics, engineering, natural science and IT were able to gain deep insight into the application-based research that takes place at all five Freiburg Fraunhofer institutes and to increase their personal and technical skills. Fraunhofer IPM organized the »Science-to-Business« workshop in which the attendees learned how to market scientific results effectively. The next »Women in Science« event will be held in 2015 at Fraunhofer sites in the Cologne-Bonn metropolitan area.

1

2

GIRLS' DAY: DON'T JUST WATCH – GET INVOLVED!

The 14th edition of this special event was held on March 27, 2014 during which Fraunhofer IPM invited year eight schoolgirls to take a tour of its laboratories and workshops. The 18 girls who took part were not only passive spectators but were able to actually do things during the day. The scientists had come up with several exciting experiments for their visitors, such as »Fire and ice«, a thermo-electric test to find out how electricity can be made from fire and ice. The main attraction: Under the heading »Tell the truth!«, the girls were able to build a lie detector.

1 + 2 *Students of mathematics, computer sciences, natural sciences and technics were visiting Freiburg. They witnessed how fascinating applied reseach can be.*

Fraunhofer TALENTA: More women in applied research

Marie-Luise Bauersfeld has been Manager of the »Integrated Sensor Systems« group at Fraunhofer IPM since January 2015. A doctor of microsystems engineering she leads a staff of natural scientists, engineers and technicians working jointly on the development, design, characterization and production of functional surfaces, miniaturized gas sensors and compact gas measuring systems. At the same time, Bauersfeld has been part of »TALENTA speed up« since April 2015, a two-year support and development program for female management staff within the Fraunhofer Society. TALENTA provides female researchers with scope to develop their careers by means of financial support, individual training courses, site and profile reflection and by an opportunity to network with other women at Fraunhofer. The aim is to help female staff to drive forward their careers.

For Bauersfeld the program has opened up lots of new opportunities: »TALENTA enables me to enhance my management potential, expand my group in both thematic and personnel terms by the acquisition of public, national and international projects, build on international joint ventures and networks but also provide support for young scientists by acting as a mentor for students.« And what would the scientist like to concentrate on in the future? »I am looking to develop research topics which are relevant to industry such as supplementing our range of materials and processes with ionizing and gasochromic semi-conductors and highly porous nanostructures. I also want to transfer existing approaches from gas sensor technology into other areas of application such as particle and humidity measuring technology. The focus in this respect is not just on the development of individual components, but also on their integration into compact gas measuring systems. TALENTA is supporting me with these goals and giving me scope to organize my work by providing tailored supplementary program to suit this phase of my life and my career.«

3

3 *Marie-Luise Bauersfeld is manager of the »Integrated Sensor Systems« group at Fraunhofer IPM .*

Awards

»Hugo Geiger Prize« 2014 for Fraunhofer IPM scientist

Jens Kießling won the Hugo Geiger Prize 2014 for his dissertation. The prize is awarded on a yearly basis for outstanding dissertations. Kießling was ranked first among three junior scientists awarded. The young physicist developed and produced a tunable terahertz light source at the Laboratory of Optical Systems at the neighboring University of Freiburg. In his thesis entitled »Non-linear optical production of continuous-wave terahertz waves« Kießling made a major step forward en route to the »laser light at the push of a button«. He developed a new optical-parametric oscillator which converts the light from a single-color pump laser into laser light of any required wavelength in the terahertz range. The new findings of the young scientist led to the development of a product ready for market thanks to the university's good contacts with Fraunhofer IPM. The »C-WAVE« optical-parametric oscillator is the first laser light source for the visible spectral range whose color can be adjusted without components or dyes having to be changed.

1

1 Jens Kießling at the award ceremony of the Hugo Geiger Price 2014 in Munich.

2

2 Markus Schindler (center) receives the award from Chamber of Crafts President Johannes Ullrich (left) and Vice President Christof Burger (right).

MARKUS SCHINDLER BEST YOUNG MASTER CRAFTSMAN 2014

A real success from the Fraunhofer IPM workshop: precision machining master craftsman Markus Schindler was awarded this year's title of Best Young Master Craftsman 2014 by the Freiburg Chamber of Crafts for his outstanding work. The award ceremony was held on December 6 at the Konzerthaus Freiburg. Congratulations!

3

3 President of the Fraunhofer-Gesellschaft Reimund Neugebauer (left) presents the Joseph von Fraunhofer Prize to René Beigang (right) and Thorsten Sprenger (center).

4 The mail scanner »T-COGNITION« detects bombs and drugs in mail shipments without having to open them.

Joseph von Fraunhofer Prize 2014 for »T-COGNITION«

Prof. Dr. René Beigang from Fraunhofer IPM and Dipl.-Ing. Thorsten Sprenger from Kassel-based Hübner GmbH & Co. KG have been awarded one of this year's three Fraunhofer Prizes. They received the award for the development of the »T-COGNITION« mail scanner which identifies hazardous substances in mail shipments without having to open them. Harmless envelope or letter bomb? This is a question which is asked every day in the mail departments of large companies, public authorities, prisons and embassies. »T-COGNITION« delivers a reliable security check for mail shipments while maintaining mail confidentiality. A letter is placed in the unit through a flap. Terahertz waves are then used to screen it. Certain spectral ranges of the waves are absorbed to a greater or lesser extent depending on the substances they strike. The proportions of the waves which pass through the mail unhindered are then collected by detectors. »Within a few seconds, the unit records the spectroscopic fingerprint and identifies a hazardous substance reliably by checking a database,« explains Thorsten Sprenger. If a letter contains explosives or drugs, the system emits an alarm. Low energy terahertz waves penetrate paper, wood, lightweight clothing, plastic and ceramics without any problems. Another benefit is that terahertz waves are non-ionizing and not harmful to humans – in contrast to X-rays. That makes the waves of particular interest for use in mail scanners.

4

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.

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.

Technical University of Kaiserslautern

TECHNISCHE UNIVERSITÄT 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 the basis for functional materials in photonics. Three-dimensional laser lithography is used as a key technology for producing such structures.

1 *Campus of the technical faculty of the University of Freiburg.*

2 *Administrative building of the Technical University of Kaiserslautern.*

Buildings and equipment

3 *The new building in Kaiserslautern was officially opened in April 2015.*

Moving in at Kaiserslautern – Construction preparations in Freiburg

Joy at the Kaiserslautern site: the staff of the »Materials Characterization and Testing« Department moved into their new home at Fraunhofer-Platz number 1 in February 2015. The official opening ceremony for the building was held on April, 14 in the presence of high-ranking guests from the worlds of politics and industry. The growth of this department made the new building necessary and it received total funding of 9 million euros from the EU, the German Federal Government and the State of Rhineland-Palatinate. The modern institute building provides space for 50 staff.

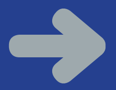
Construction planning has reached a crucial stage: the German Federal Ministry for Education and Research has approved the space requirement and jobs plan, the tender phase for the architects is now underway. The organizers are expecting construction permission to be granted in December 2015, which means that work on erecting the 6,447 m² building can hopefully start in September 2016.

NEW GAS MEASURING STATION

Since 2014, Fraunhofer IPM has had a new gas measuring station. This allows the simultaneous application of test gases, temperature, flow rate and humidity control, and the recording of the resulting signals. The special feature of this new gas measuring station is that it can also handle toxic gases such as carbon monoxide in levels of up to 30%. In addition, various natural gas types can be mixed and bottled in a range of mixing ratios.

4 *The new gas measuring station handles toxic gases.*

Day to day research



PROJECT: WASTE HEAT ATLAS

The research project »Waste heat atlas: collection, estimation and evaluation of industrial waste heat in Germany – potential and need for research« is looking into the use of waste heat in high energy consumption industries. Data is being collected and evaluated for this purpose throughout Germany. Fraunhofer IPM is mainly involved in the compilation and characterization of waste heat recovery technologies in terms of their operating conditions, such as temperatures, heat flows, carrier media, space and maintenance requirements and efficiency.

Fraunhofer IPM on the Arabian Peninsula

The Qatar Foundation Annual Research Conference QFARC was held in November 2014 in Qatar. The conference is organized by the Qatar Foundation for Education, Science and Community Development whose aim is to secure Qatar's future through education and research. The focal points of this year's conference were four subject areas: »Energy and Environment"« »Computing and Information Technology«, »Health« and »Social Sciences, Arts and Humanities«. Two Fraunhofer IPM thermoelectricity specialists, Jana Heuer and Hans-Fridtjof Pernau, attended the event.

Qatar is one of the driest countries on Earth. Securing water supplies is therefore extremely important for the country and was dealt with in some depth at the conference. For example, Nobel Prize winner and former US Energy Minister Steven Chu presented a paper on »Solar Energy and Water Security«. Fraunhofer IPM took the opportunity to present new ways of improving self-powered sensors to improve water supplies with pipelines that transport water over several thousand kilometers through the desert being fitted with these sensors to check for leaks. Thermoelectric generators mean that they do not need batteries or maintenance, making them ideal for areas which are difficult to access.

Thomas Hinrichs, Workshop-Manager at Fraunhofer IPM.

Interview: »Something new every day«

Fraunhofer IPM's state-of-the-art mechanical workshop manufactures tailor-made precision parts for the systems developed in-house. We spoke to Thomas Hinrichs who has been Workshop Manager since 2005.

1. What are the advantages of an in-house workshop?

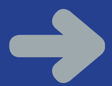
First of all, we are able to respond flexibly to all situations; and we are also quicker than industrial companies which need six to eight weeks to get a job done. That's important because, if a component is required at short notice for a project, it would mess up our entire project schedule having to wait so long for a single part. One of the things to which we owe our ability to respond so quickly is the CAD-CAM Creo Elements Pro software which gives us direct access to the designers' data and allows us to create 3D virtual prototypes. The simulation software permits us to rectify possible subsequent errors as early as the run-up phase. This interim step reduces reject rates and prevents problems during production. The machines can also be programmed directly from the model, so this means that we are already a step ahead of many others who still do this manually. There is a very close spatial proximity between design and production. This means that our staff are capable of processing designers' jobs quickly, flexibly and with high quality.

2. What are your duties as Workshop Manager?

My job is scheduling work and deadlines and I am also responsible for coordinating who does what, when and on which machine. Our schedule is crucial. In order for the Project Managers to be able to plan well, it's important to keep to deadlines and that's what we do.

3. What is a normal working day like in Fraunhofer IPM's workshop?

There's no such thing as a »normal« working day. Some days, a work schedule for the next two weeks will become obsolete within a few hours since we always respond flexibly to new jobs. We squeeze in urgent jobs. Of course, this initially messes up the schedule. But this means that things never get boring. There really is something new every day and it's that which makes working in our workshop very interesting and varied. One other important element of our workshop is training staff as industrial mechanics specializing in precision mechanics and instrument engineering. The Deputy Workshop Manager, Achim Weber, is Head of Training and a member of the Southern Upper Rhine Chamber of Industry and Commerce's Board of Examiners. We take a new trainee every training year and we currently have four of them. That's an awful lot in view of the size of our workshop with a workforce of ten, five of them being apprentices. We also »produce« our apprentices completely ourselves, meaning that we have also trained everyone working here now.

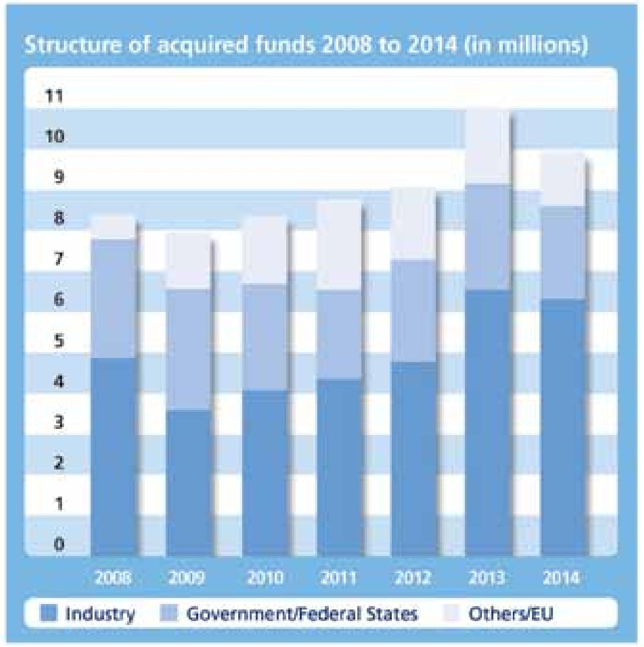


Machine fleet

- **Two Hermle 5-axis machining centers X-Y-Z 600-450-450 mm**
- **One Hermle 3-axis machining center X-Y-Z 800-600-500**
- **One Fehlmann precision milling and drilling machine**
- **Two manual Weiler precision lathes (special-purpose spindle bearing with 2 µm concentricity)**
- **Three three-axis CNC milling machines with line-motion and continuous path control**

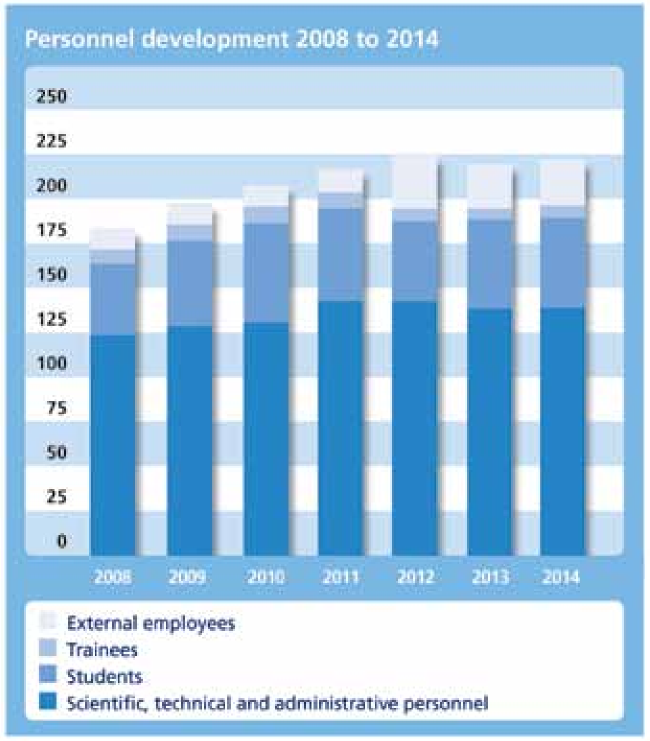
Operating budget

In 2014, the operating budget of Fraunhofer IPM was 14.8 million euros, making it 0.6 million euros lower than in 2013. The operating budget is made up of industry revenues, publicly funded projects and basic funding. The proportion of external funds, consisting of external public funds and industry revenues, was 67.6 percent, or 9.9 million euros (Figure, right). The industrial revenues make up 6.3 million euros of the operating budget or a proportion of 42.9 percent. This is a small increase compared to the previous year of about 0.3 percent.



Personnel

The number of employees hardly changed compared to the previous year. A total of 137 people are employed by Fraunhofer IPM, 18 of them at the Kaiserslautern site. In addition, around 55 students and career entrants work at the Institute, of whom 46 are bachelor's degree and master's degree graduates and 9 are trainees, interns and assistants. In addition, there are around 25 external employees working at Fraunhofer IPM (Figure, right). In percentage terms, the employees are split between three basic areas: around 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.



Our Advisory Board

A committed, competent and widely diversified advisory board provides advice and support for Fraunhofer IPM as regards strategic issues and its future course.

- Reinhard Hamburger, Chairman of the Advisory Board, C-FOR-U Business Coaching
- Dr. Bernd Dallmann, Freiburg Wirtschaft Touristik und Messe GmbH & Co. KG
- Dr. Hans Eggers, Federal Ministry of Education and Research
- Prof. Dr. Thomas Graf, Director Institut für Strahlwerkzeuge IFSW, University Stuttgart
- Dr. Ehrentraud Graw, Ministry of Finance and Economics, Baden-Württemberg
- Siegfried Groß, Keysight Technologies Deutschland GmbH
- Prof. Dr. Jan G. Korvink, Institute for Microstructure Technology, Karlsruhe Institute of Technology
- Prof. Dr. Gunther Neuhaus, University of Freiburg, Vice Rector for Research
- Dr. Volker Nussbaumer, Deutsche Telekom AG
- Dr. Christian Schmitz, Managing Director TRUMPF Laser- und Systemtechnik GmbH
- Dr. Knut Siercks, Managing Director Hexagon Technology Center (CH-Heerbrugg)
- Prof. Dr. Michael Totzeck, Carl Zeiss AG
- Dr. Carola Zimmermann, Head of the Department of Research and Technology at the Ministry of Education, Research, Advanced Training and Culture in Rhineland-Palatine.

»The Fraunhofer Society's fundamental idea is implemented to the greatest possible extent at Fraunhofer IPM. This makes it easy for companies to work with the Institute.«

Dr. Christian Schmitz

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Production Control

»We develop optical measuring systems for production«

TOPICS

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

EXPERTISE

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

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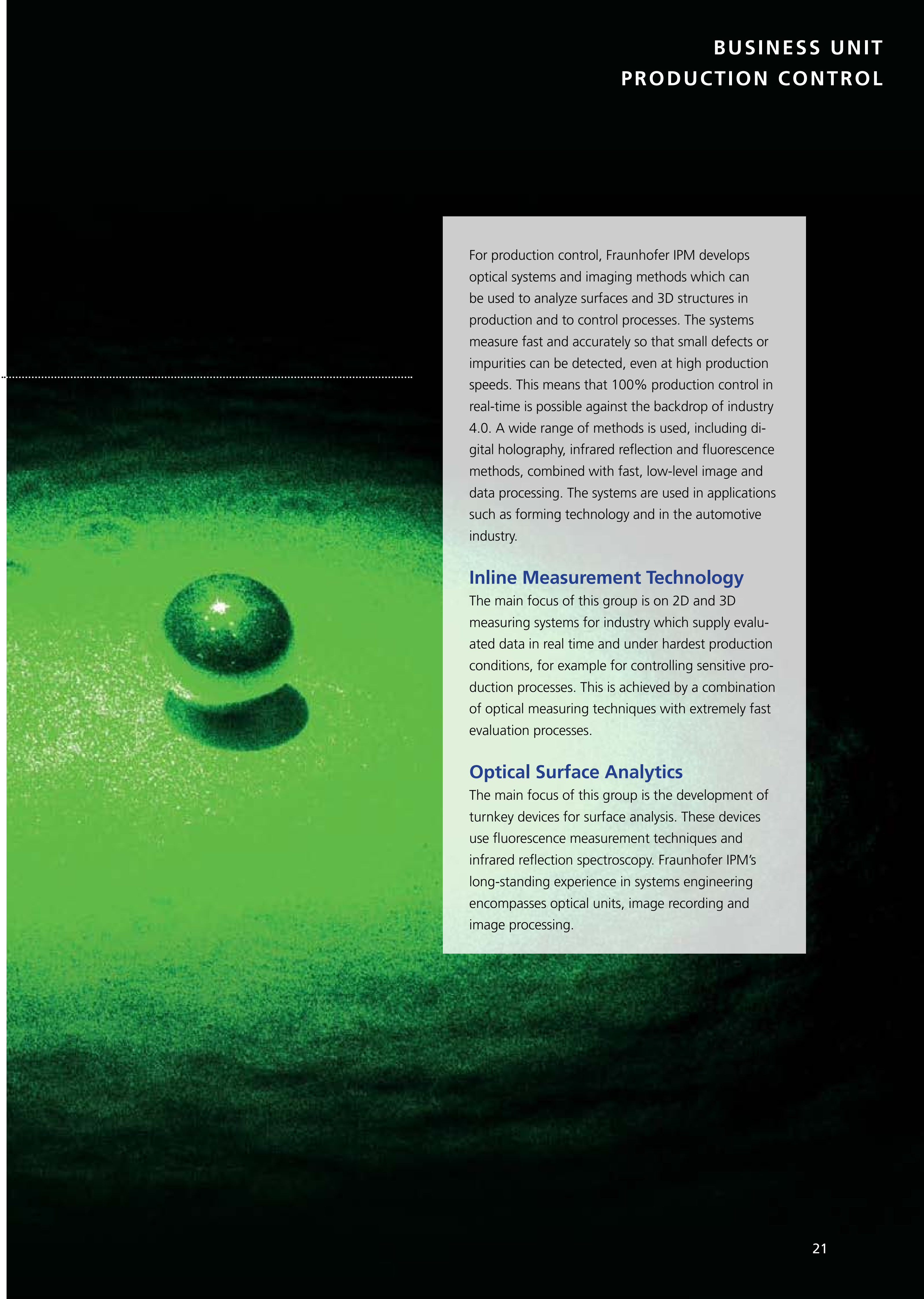


Micro deformation measurement using electronic speckle pattern interferometry.

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% 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 reflection 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 Technology

The main focus of this group is on 2D and 3D measuring systems for industry which 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 and infrared reflection spectroscopy. Fraunhofer IPM's long-standing experience in systems engineering encompasses optical units, image recording and image processing.

INLINE MEASUREMENT TECHNIQUES

Digital holography for 100% inspection

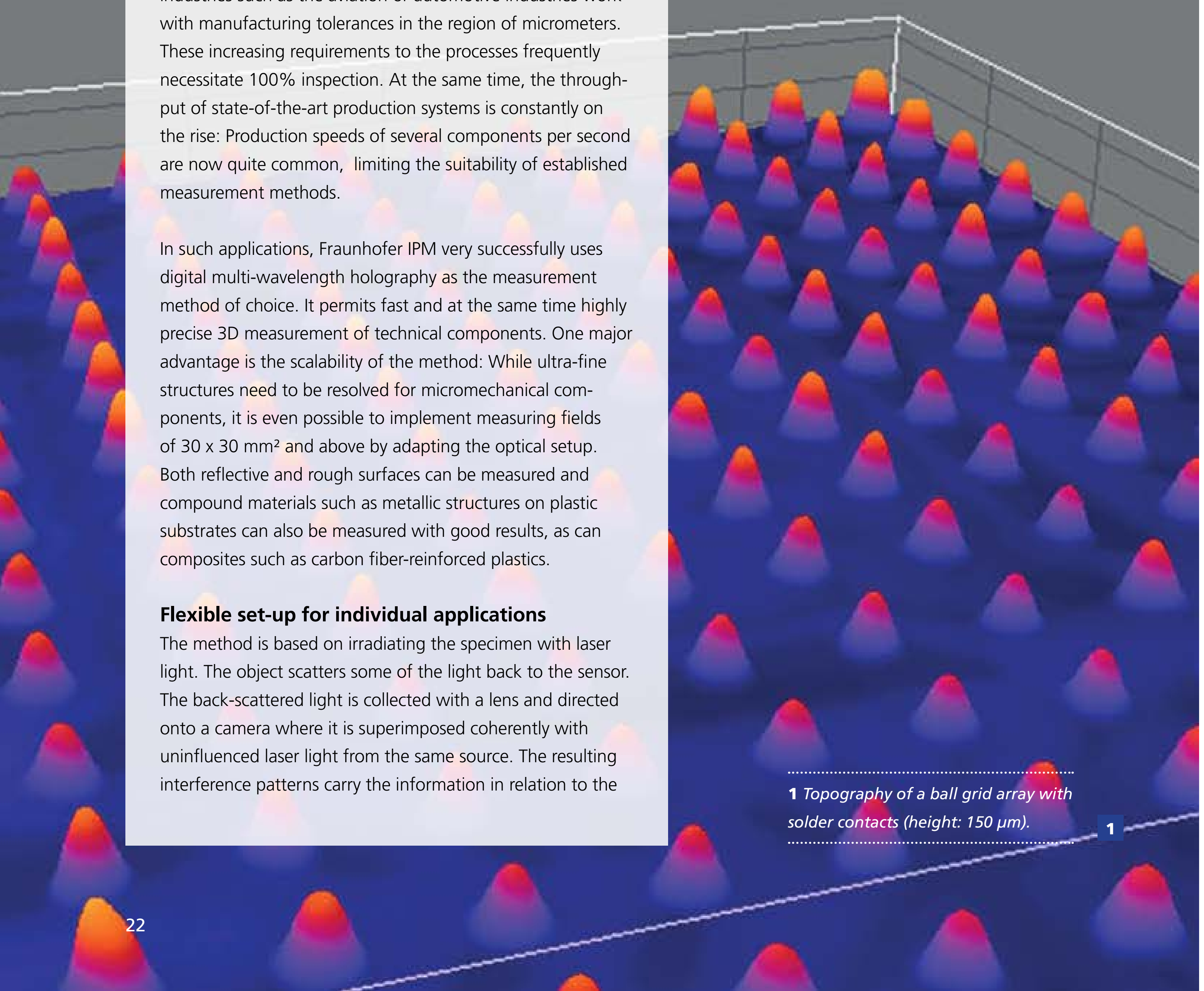
Fraunhofer IPM has brought digital multi-wavelength holography to the production line for the first time. The scientists optimized 3D measurement in order to measure components with micrometer accuracy at production speed.

Requirements to the precision of components and machines are becoming more stringent all the time. Nowadays, hi-tech industries such as the aviation or automotive industries work with manufacturing tolerances in the region of micrometers. These increasing requirements to the processes frequently necessitate 100% inspection. At the same time, the throughput of state-of-the-art production systems is constantly on the rise: Production speeds of several components per second are now quite common, limiting the suitability of established measurement methods.

In such applications, Fraunhofer IPM very successfully uses digital multi-wavelength holography as the measurement method of choice. It permits fast and at the same time highly precise 3D measurement of technical components. One major advantage is the scalability of the method: While ultra-fine structures need to be resolved for micromechanical components, it is even possible to implement measuring fields of 30 x 30 mm² and above by adapting the optical setup. Both reflective and rough surfaces can be measured and compound materials such as metallic structures on plastic substrates can also be measured with good results, as can composites such as carbon fiber-reinforced plastics.

Flexible set-up for individual applications

The method is based on irradiating the specimen with laser light. The object scatters some of the light back to the sensor. The back-scattered light is collected with a lens and directed onto a camera where it is superimposed coherently with uninfluenced laser light from the same source. The resulting interference patterns carry the information in relation to the shape of the object. This information can be obtained from the recorded interference pattern, which are referred to as digital holograms, by means of numeric calculations. The axial measuring range can be increased significantly into the cm range on the basis of the slight differences in measured values achieved by repeating the measurement with several slightly differing laser wavelengths. It is only this evaluation which allows 3D measurement on rough surfaces which is otherwise not possible due to the speckle effect. The method can be adapted individually to various fields of application by selecting the laser wavelengths and the optical setup.

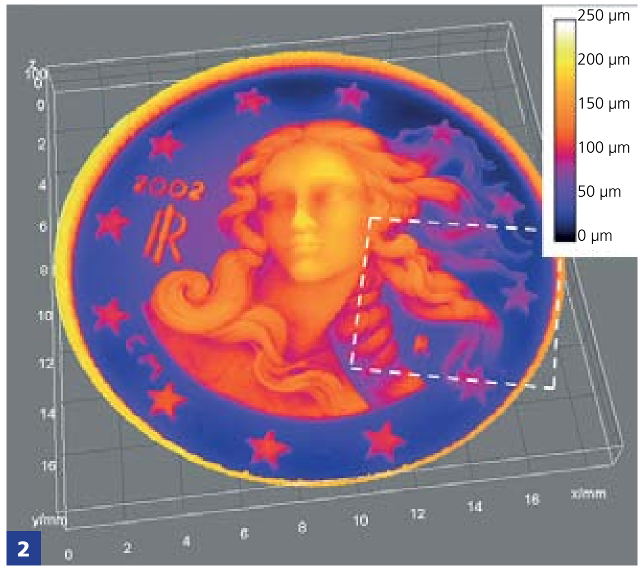


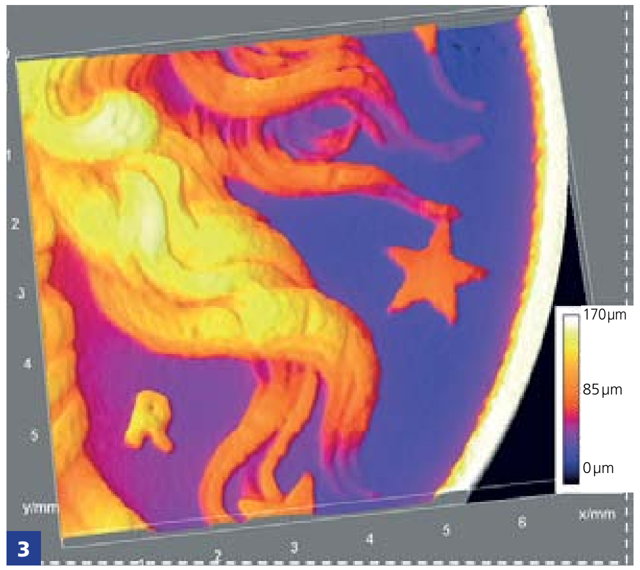
1 *Topography of a ball grid array with solder contacts (height: 150 µm).*

Precise measurement of metal objects

Metal components and semi-finished products such as those produced by deep drawing – a process used to form sheet metal – or produced by other cold-forming processes can be measured very well with digital multi-wavelength holography. A good example for this is the result of measuring the surface of an Italian 10-cent coin. Figure 2 shows a measuring field of around 20 × 20 mm². The measuring field consists of a total of 9 million measuring points. The data acquisition time is 150 ms. The subsequent calculation which produces genuine 3D data from the raw data takes less than 200 ms. High-speed data evaluation is achieved by extremely parallel data processing on state-of-the-art graphics boards. Figure 3 shows an extract of the entire measurement data record. Even the fine details of the measured surface are resolved. The achievable lateral resolution depends on the imaging quality of the lens used and is in the region of a few micrometers in most applications.
Digital multi-wavelength holography is a 3D measurement method with great potential. Whether it be deep drawing, embossing, injection molding, machining or in electronics production: It can be used wherever highly accurate measurement results with high measuring rates are needed and sets a new standard for 3D measurement in the production line.

DENNIS GÁBOR (1900–1979) is best known as the Father of Holography. In 1947, the Hungarian engineer was the first to demonstrate how it is possible to directly extract and record information photographically via the intermediate image phase by layering the object and reference waves. In 1971, Gábor was awarded the Nobel Prize for Physics for his work in this field.





2+3 *Example measurement on an Italian 10-cent coin. The measuring field shown in Figure 2 has a size of around 20 × 20 mm²; Figure 3: marked detailed view from figure 2.*

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1 *Fraunhofer IPM develops special microscopy systems for inline inspection in production processes.*

OPTICAL SURFACE ANALYTICS

Inline-microscopy for demanding measurement tasks

Disposables are generally produced at low cost and at high production rates. But even short-lived products have to meet stringent quality demands, such as in the medical sector. For this purpose, Fraunhofer IPM develops special microscopy systems which monitor production processes fully automatically.

Standard measurement techniques are frequently inadequate for 100% quality inspections in the field of medical equipment production. The measurement tasks and the processes into which the measurements need to be integrated are too complex. Fully documented quality inspection is absolutely essential, particularly in the case of medical devices, since errors here may have direct consequences on people's health. Medical disposables are manufactured in high quantities, but 100% component inspection is indispensable for quality assurance in this sensitive area. This can be achieved only with inline inspection systems which measure down to the micrometer ranges, even with a high throughput.

Reliably detecting structural defects in the micrometer range

For mass production, Fraunhofer IPM develops microscopy systems which are capable of monitoring even demanding production processes reliably and fully automatically. The special microscopes, which are adapted individually, detect structural defects of micromechanical components and impurities on such components in the range of a few micrometers. Besides the size of the components, challenges for the developers include non-flat geometries of the components: These are frequently very small but still geometrically demanding micromechanical objects whose surfaces, for example, are curved or have concealed edges and structures. Compound systems consisting of differing materials also pose a major challenge to precise measurements in this area. Fraunhofer IPM adapts microscopes to these complex geometries and characteristics depending on the scenario.

Individually adapted systems

Wherever possible, the scientists use commercially available microscopes first and then extend these to produce special systems. This means optimizing the illumination, mechanical and electrical interfaces and, not least, data processing software according to the special requirements. This allows them to achieve full documentation and thus traceability of the components which is very important from the point of view of safety, particularly in the sensitive area of medical devices. The Institute has a cleanroom of classes 100 and 1 000 for set-up and in-depth testing. This allows the systems to be developed and tested under medical equipment production conditions and it guarantees that they function correctly, even under very rough, demanding ambient conditions. The systems conduct measurements quickly and precisely and can ultimately be used for inline inspection in production processes. Fraunhofer IPM microscopes are always in demand where standard measurement solutions do not suffice, such as fast inspection of large, flat surfaces for micrometer-sized defects or impurities and for inspecting components with special geometries which require a fit with micrometer accuracy and every second. This allows defective components to be removed from the process in good time and makes production – in particular of disposables – far more efficient and, above all, safe.

2 *Mikrofluidik-LabDisk : HSG IMIT (Institut für Mikro- und Informationstechnik), Freiburg.*

MEDICAL DISPOSABLES, e.g. for modern laboratory analyses, often have minute structures in the range of a few micrometers. At such a scale, even small errors can render results of analyses useless. Manufacturers of such mass-produced plastic parts must therefore be able to prove the dimensional stability of their products.

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Materials Characterization and Testing

»We characterize on a non-contact and non-destructive basis«

TOPICS

- Non-destructive materials testing
- Layer thickness measurement
- Chemical analysis (pharmaceuticals, hazardous substances)
- Safety applications
- Vector network analyzers

EXPERTISE

- Production of terahertz components
- Spectroscopy systems
- Terahertz imaging
- Ultra-fast electro-optical high-frequency measurement techniques

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Terahertz waves detect concealed structures and material defects.

Fraunhofer IPM develops measuring systems that work with terahertz and microwaves for practical application in the characterization and testing of materials. The scientists use expertise from optical systems and measuring technology, spectroscopy and the development of crystal and semi-conductor components for this purpose. Terahertz or microwave measurement technology provides an alternative to ultra-sound measurements if mechanical contact is not possible or desirable, but also to X-ray measurements if ionizing radiation raises problems. These measurement systems can be used to characterize materials through packaging and allow concealed drugs or explosives to be detected. In materials testing, defects can be identified in ceramics, plastics or composites (glass fibers, etc.) on a non-destructive basis. There is particular interest in measuring the thickness of layers, e. g. in coating processes or also in the production of pharmaceutical tablets.

Electronic Terahertz Measurement Techniques

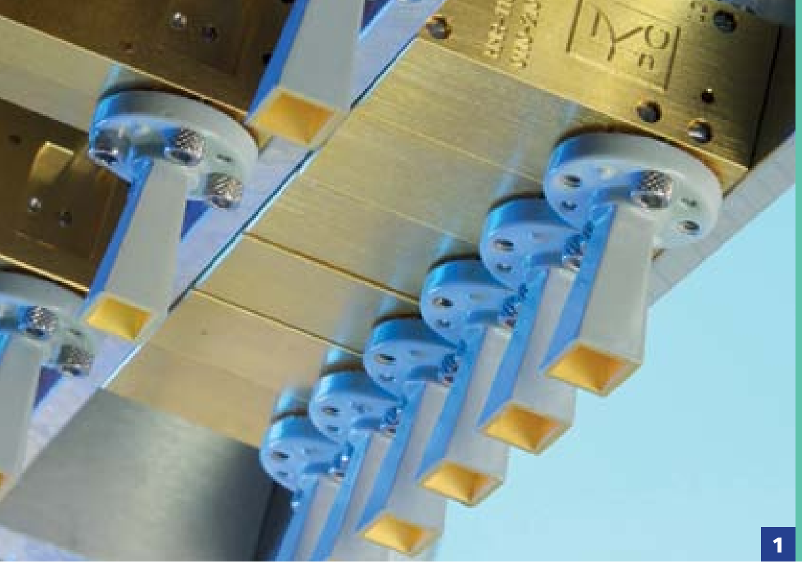
The main focus of this group is the development of application specific terahertz systems for non-destructive material testing. For this purpose the lower terahertz spectrum is of interest, since here many non-conductive materials such as plastics, ceramics or textiles provide a good transparency.

Optical Terahertz Measurement Techniques

This group designs and builds turnkey terahertz time domain systems for generating and detecting broadband terahertz radiation. The team is involved in the production of terahertz emitters and receivers and conducts research into non-destructive materials characterization. This includes applications in the safety sector and thickness analyses of multi-layer coating systems almost independent of the substrate.

Terahertz Opto-Electronics

The main focus of this group is the development of measuring equipment for ultra-fast electronics extending into the terahertz frequency range, e. g. for characterizing electronic HHF circuits. Extremely fast, electro-optical converters and ultra-fast optics are combined for this purpose.



1 + 2 *A MIMO terahertz system can record up to 144 pixels simultaneously using just twelve terahertz transmitters and receivers. Not only does this reduce the number of expensive components but also drastically reduce the measuring time.*

ELECTRONIC TERAHERTZ MEASUREMENT TECHNIQUES

Fast volume inspection using terahertz waves

Low-frequency terahertz waves are ideal for non-destructive materials testing. This is because electrically non-conductive materials such as plastics, ceramics, textiles or even complex composites are often transparent in this spectral range. For the development of volume inspection systems with industrial maturity, Fraunhofer IPM is now using measurement concepts from communication and radar technology.

In the field of non-destructive testing, contactless terahertz measuring technology has received great attention. There are two main reasons for this: Firstly, the high transparency of many electrically non-conductive materials to terahertz waves and secondly, the fact that unlike X-ray radiation, terahertz waves have no ionizing effects. But there are some other relevant points for the attractiveness of a measuring method from the point of view of industry: does the inspection system's measuring speed match the speed of the process? Is the system flexible enough to be adjusted to various tasks? In other words, the challenges for the development of a ready-to-market terahertz volume inspection system are not just focused on a decent representation of internal material structures by depth cross-sectional imaging. High-speed signal processing and an overall system design which is suitable for use in a production environment are just as important. To achieve this, Fraunhofer IPM not only uses its outstanding expertise in terahertz measuring technology but also benefits from alternative measuring concepts adopted from communication and radar technology.

New concepts of terahertz imaging for material testing

In communication technology, the use of multiple transmit and receive antennas is known by the acronym »MIMO« (Multiple Input Multiple Output). This form of signal processing has proven very effective in communication technology. Fraunhofer IPM has now successfully transferred this concept to the terahertz imaging technology. The newly developed MIMO terahertz system provides a specially thinned array with multiple terahertz emitters and receivers combined with a very-high-speed computer-based image reconstruction system. This new approach of terahertz imaging is interesting to industry since it enables high-speed volume inspections of large-area objects with high depth resolution directly during the production process. The MIMO imaging technology used for this purpose is based on a multistatic synthetic aperture radar (SAR). The method requires computer-intensive image reconstruction. The measurement principle involves the individual switching of single transmitter and receiver units to generate a synthetic sensor arrangement. This allows the

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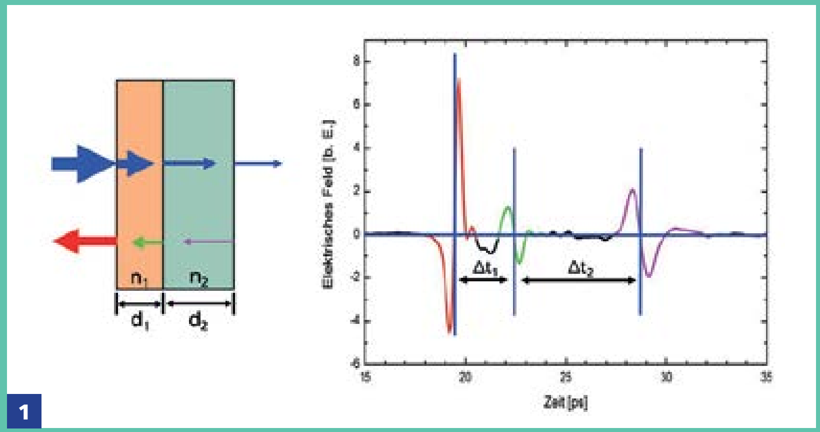
»MIMO« (MULTIPLE INPUT MULTIPLE OUTPUT) is the term to denote a signal evaluation method which uses multiple transmit and receive antennas. The concept was originally used in communications technology. MIMO allows the application of special signal modulation techniques, which take advantage of both temporal and spatial information.

required number of expensive sensor elements to be drastically reduced and the physical sensor arrangement adjusted flexibly to meet the needs of the application. Ideally, the total number of measuring points is equal to the number of emitters multiplied by the number of receivers.

Fewer components – greater capacity

In the initial implementation of the idea, twelve terahertz transmitters and receivers were arranged over a length of 60 cm (see figure). If the operating frequency is then modulated between 75 GHz and 110 GHz to determine the signal time delay, the result can be used to inspect the volume of large-area objects with a resolution of 144 individual measuring points per line. The depth information can be obtained by the time-of-flight of the terahertz signals transmitted by the sensors and reflected back off the object, which allows the three-dimensional localization of features within the measurement object. Previous systems which scanned the object pixel by pixel using a single sensor unit have proven ideal for initial inspections and random measurements. When combined with a conveyor belt, the line-type sensor arrangement of the new MIMO terahertz system now makes it possible to inspect the object during in-process inspection procedures. In addition, it restricts both the use of expensive sensor elements and the complexity of the overall system to use only those components which are really necessary.



1

OPTICAL TERAHERTZ MEASUREMENT TECHNIQUES

Non-destructive multi-layer analysis on a second-by-second basis

The thickness of coatings on non-metallic substrates is generally measured using destructive methods. Terahertz waves, which lie in the spectrum between infrared light and microwaves, are frequently a better alternative: they are reflected at interfaces at which the index of refraction changes. The layer or coating thickness can then be determined from the differences in propagation time of the partially reflected waves – even and above all in the case of complex multi-layer systems.

Why is it so important for industry to know coating thicknesses? Here is one example: nowadays, aircraft are successively coated with several layers of lacquer: first with a primer which is applied directly to the component, and then with the base coat. Finally, the clear coat is applied. At the end of the process, a large commercial aircraft has to carry up to half a ton of lacquer. These coatings also add to the weight of the aircraft and increase fuel consumption. This is why to date aircraft components have to be weighed before and after lacquering. If too much lacquer has been applied by mistake, this not only takes up valuable production time but, above all, it also costs money.

Multi-layer analysis is crucial

The solution is non-destructive, contactless terahertz multi-layer analysis. It allows the coating thickness on virtually every material to be monitored – as early as the lacquering stage. This method determines the thickness of every individual layer of lacquer coating so precisely that the lacquering system can be controlled on the basis of these parameters.

To date, it was generally adequate to detect the total thickness of a coating. But demands for thickness monitoring of the individual coating layers within a multi-layer system are more and more frequent. Complex multi-layer lacquer coatings are used primarily in aircraft construction and automotive engineering. Over and above this, many other products are now finished with coatings. This includes such different things as rotor and turbine blades, ships' hulls and also pharmaceutical tablets. In all these contexts, industry has a great interest in a measurement technique which detects individual coating thicknesses in multi-layer coating systems with the aim of quality control and preserving resources. Multi-layer analysis on plastic substrates in particular is becoming more and more important since such substrates are being used increasingly in order to reduce both weight and costs. Terahertz measurement technology works in the 10 to – 500 µm thickness range, which is important for the industrial sector, and is currently the only measuring method that can detect individual layers in multi-layer coating systems non-destructively and without physical contact. This has already been demonstrated by Fraunhofer IPM in cooperation with various industrial partners including those from the automotive sector.

Terahertz multi-layer analysis

In coating thickness measurement with terahertz time-domain spectroscopy, Fraunhofer IPM utilizes the fact that the incident terahertz beam is reflected at material transitions. In the simplest case, two reflections are obtained: one from the air-coating transition and a second from the coating-substrate transition. The time difference between the two reflections and knowledge of the index of refraction allow us to then determine the coating thickness. If the coating consists of several layers, further reflections, which also allow analysis of complex multi-layer coating systems, appear between the two reflections described above. However, in practice, the user does not notice a great deal of the evaluation process. A user-friendly software package performs the entire process of evaluation. Defined reference samples are used to calibrate the system. The measurement result is available within one second and the measurement is evaluated in parallel with the subsequent measurement. This means that one second is available both for measurement and for evaluation. The achievable measurement accuracy is around ±1 µm depending on the coating system. This is already optimal for many applications.

1 *Left: Examining a two-layer system with Terahertz waves (blue arrow), the waves are partially reflected at the interfaces owing to the difference in index of refraction (n1≠n2) (left). The coating layer thicknesses d1 and d2 can be determined from the differences in propagation time ∆t1 and ∆t2 (right).*

2 *Fraunhofer IPM develops and produces terahertz emitters and receivers for non-destructive multi-layer analysis.*

EVEN COMPLICATED COATING SYSTEMS with a very high number of layers can be analyzed reliably using terahertz measuring technology. Metals, plastics but also carbon fiber composites are ideal for use as a carrier substrate for the coatings being measured.

2

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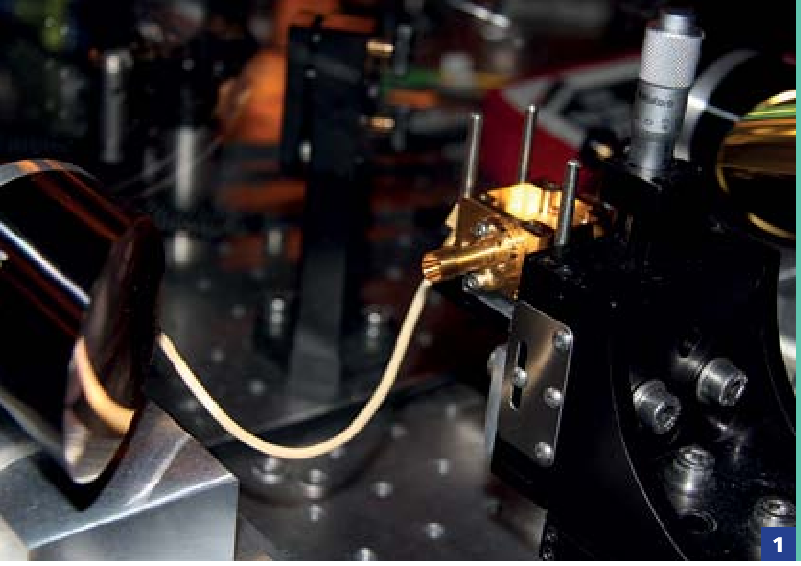
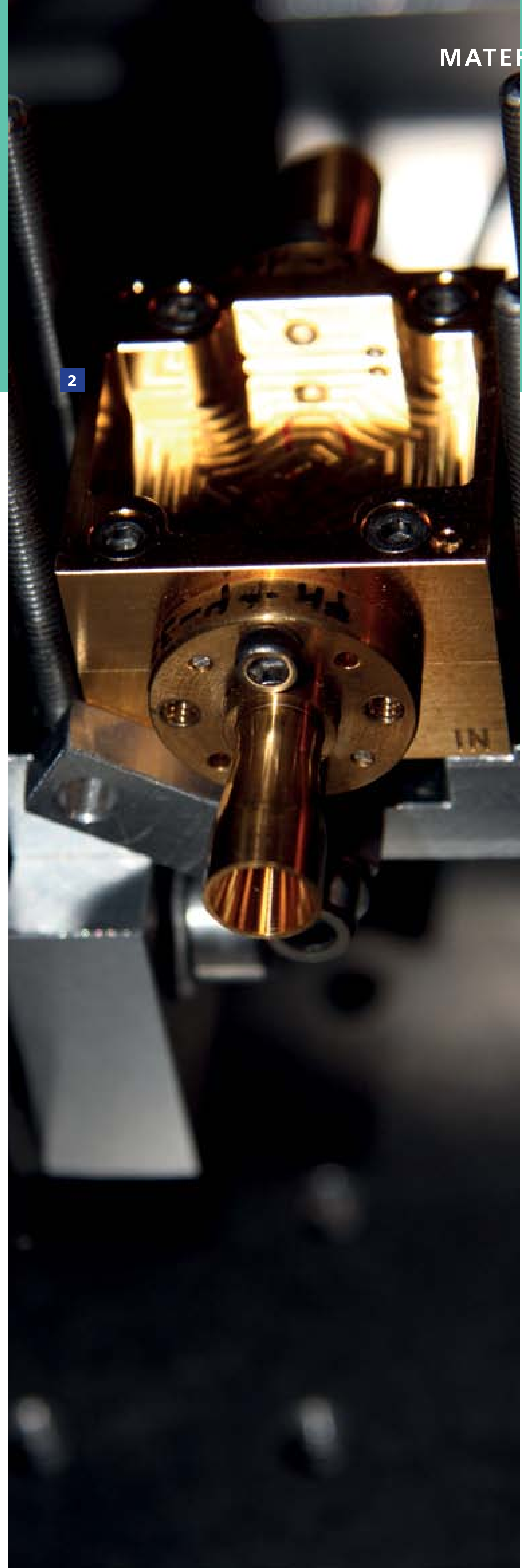




1 + 2 With »Tera-VNA« terahertz pulses can be transferred to the component under investigation through a waveguide.

3 Comparative measurements of the scattering parameter S_{21} on a power amplifier (MPA) in the range 220–330 GHz. The red curve was measured with a commercial vector network analyzer (VNA) and the blue curve was measured with the »Tera-VNA« based on the principle of time domain spectroscopy (TDS).

TERAHERTZ OPTO-ELECTRONICS

A broad application but a precise result: »Tera-VNA« network analyzer

The field of high-frequency electronics is developing all the time – advances in communication technology above all are very fast indeed. Fraunhofer IPM ensures that the required measuring systems can keep up with the high speed of development. The newly developed »Tera-VNA« Terahertz network analyzer operates in a far broader frequency range than conventional network analyzers – and it operates very precisely.

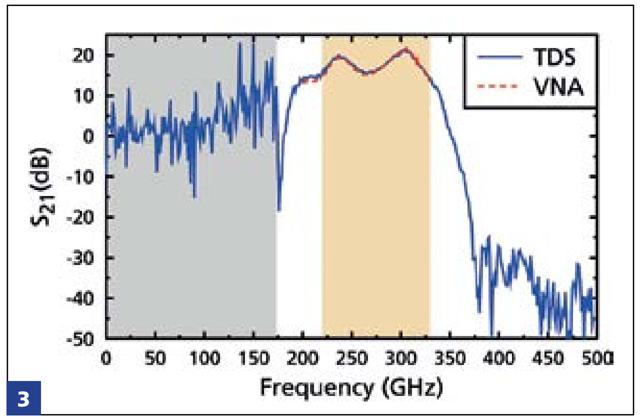
Electronics engineers require reliable information on the so-called scattering parameters (S parameters) which should be as precise as possible for the purposes of optimum dimensioning and calculation of electronic systems. These parameters describe the behavior of linear electrical elements, components and networks using wave quantities. Commercially available network analyzers measure these values in the frequency range. It has been possible to boost the bandwidth of such units up to 1.1 THz in recent years. But this does not suffice by far: nowadays, electronic components operate in such high frequency ranges that conventional measuring systems reach their limits. Fraunhofer IPM has now doubled the achievable frequency range with the »Tera-VNA« terahertz network analyzer. The trick to it is that »Tera-VNA« does not measure the required S parameters in the frequency range but in the time domain.

Measurement in the time domain

As the name already suggests, »Tera-VNA« is based on terahertz time domain spectroscopy. The system was further developed so that the terahertz pulses can be transferred to the component under investigation through a waveguide for the purposes of this application. After the pulses have passed through the component, they can then be detected optically in the time domain. After the data which has been obtained in this way has been transferred to the frequency range, it is then possible to determine the required vectorial S parameters of the component under investigation. This has been demonstrated for frequencies from 100 GHz to 2 THz. The new technology affords many advantages by comparison with classical network analysis in the frequency range.

Advantages of the method

Terahertz time domain spectroscopy permits working with very high bandwidths at relatively low-cost system prices compared with electronic network analyzers commonly used today. One other advantage of the »Tera-VNA« is that only the waveguide components or the probes in each case need to be changed for shifting between various frequency bands. Instead, it is frequently necessary to use quite different measuring instruments for different frequency bands on electronic network analyzers.



The »Tera-VNA« Terahertz network analyzer is able to measure at far higher frequencies than network analyzers commonly used today. Moreover, it is even possible to determine the propagation times of the pulses through a network directly. It is thus possible to detect invisible flaws or discontinuities in the network directly and identify their positions directly. This opens up new possibilities in development of new high-frequency electronics.

VECTOR NETWORK ANALYZERS (VNA) are required to develop electrical circuits or for use as testing equipment in production environments. In high-frequency electronics, they are used to detect the scattering parameters (S parameters) of components or networks so as to be able to describe their properties using wave sizes.

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Object and Shape Detection

»We scan quickly, precisely and safe for the eyes«

TOPICS

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

EXPERTISE

- 3D laser scanners, 3D cameras, 3D data processing
- Capture of moving objects even at high speed
- Rapid image evaluation
- Robust system technology

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In the »Object and Shape Detection« Business Unit, we detect three-dimensional geometries and the location of objects in the surrounding area. For this purpose, not only do we develop laser scanners but also custom-tailored lighting and camera systems. These devices take measurements at high speed and with high precision, particularly from moving platforms. We focus specifically on 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 the 10-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 and in water.

Laser Scanning

The main focus of this group is the development of optical measuring systems based on time-delay measurement of light, which enable the distance and geometry of objects to be measured at high speed and with great precision. The developed systems are employed worldwide and in a variety of applications.

Laser scanners detect the clearance gauge of railway tracks – fast and accurately.

LASER SCANNING

Exact rail gauging by laser

Laser scanners afford many advantages over camera systems when it is necessary to gauge rail infrastructure. The Rail Track Scanner RTS is the first scanner to supply a highly detailed image of rails, railhead, sleepers and track bed.

1 *The Rail Track Scanner detects changes in topography with a measurement uncertainty of less than one millimeter.*

FRAUNHOFER IPM develops optical systems for measuring overhead line wear, overhead line position, clearance profile, mast position, and to record the geometry of moving trains.

The rail infrastructure is checked regularly for damage so that traveling by train remains safe. This is not an easy task: Germany has Europe's longest rail network with over 40,000 kilometers of track.

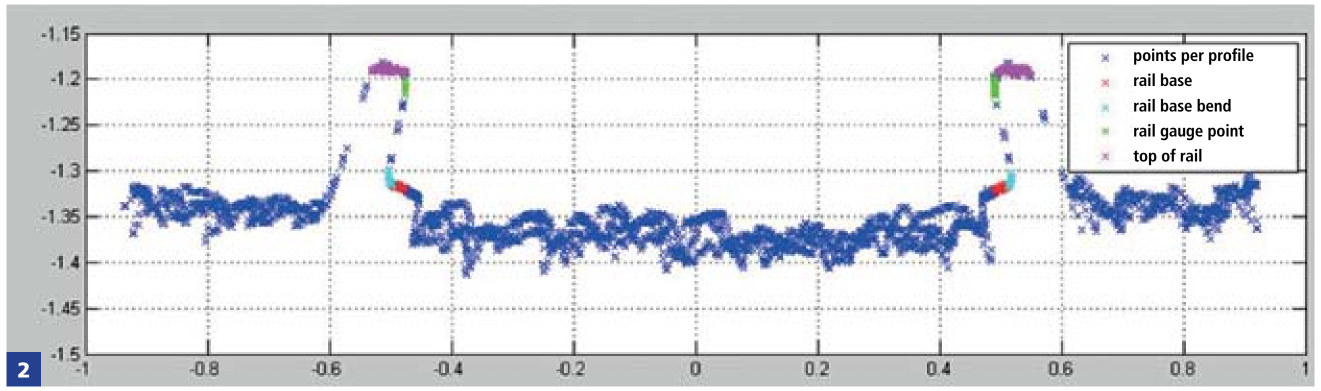
Nowadays, points, sleepers and rails are generally gauged with camera-based systems. This has certain disadvantages: the systems function correctly only if there is adequate ambient lighting or artificial lighting. This means that the systems mainly measure during the daytime, i.e. when the capacity of the rail network is being heavily used anyway and when test trains also make timing more difficult. The new Rail Track Scanner operates independently of ambient lighting. It detects the geometry of rails, railhead, sleepers and track bed and permits automated data evaluation – quickly, reliably and with the required level of precision.

The laser scanner detects even minute irregularities which may become dangerous. Rail tracks are subject to tension and could crack abruptly thus producing a domino effect – the worst-case scenario being that rail tracks and railway sleepers break over large distances.

Measurement with uncertainties of less than one millimeter

A special optical configuration allows the shoebox-sized scanner to be mounted on any rail vehicle only 1.2 meters above the track bed. The laser scans the rails transversely to the forward motion of the vehicle over a width of approximately 1.7 meters. Two million measurements per second and 800 profiles form the basis for a very detailed, three-dimensional image of the rail tracks and the infrastructure directly linked to it. Suitable algorithms allow parameters such as distance, height and inclination of the rail track or the railhead geometry to be extracted from the point cloud generated in this way and to be compared with target profiles. The scan frequency can be adapted flexibly to the relevant task. Topographical structures and changes are detected reliably with a measurement uncertainty of less than one millimeter. Another major advantage is that the RTS operates with an eye-safe infrared laser and can thus be used unrestrictedly in the public sector as well.

Fraunhofer IPM presented the Rail Track Scanner in September 2014 as a world first at the Innotrans trade fair in Berlin. The RTS is now being used for the first time for metrological assessment of narrow gauge tracks in Switzerland.



2 *Result of a test run. The clearance from the rail axis is plotted on the horizontal axis. The corresponding height profile which, at the same time, also represents the shape of the track bed and the rails, is plotted on the vertical axis. The two rails with the corresponding railheads and, between them, the rough surface of the ballast bed can be seen excellently. The various objects are shown color-coded. The low gauging noise and the large number of measuring points can be seen clearly.*

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Gas and Process Technology

»We take accurate measurements – even under extreme conditions«

TOPICS

- Gas measurement techniques
- Particle measurement techniques
- Thermal measurement techniques
- Robust complete systems

EXPERTISE

- Spectroscopy from EUV to MIR, laser spectroscopy
- Gas sensors
- Thermal sensors
- Microsystem technology
- Simulation

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A compact infrared spectrometer monitores the proliferation of extinguishing gas in fire extinguishing units.

In its »Gas and Process Technology« Division, 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 under extreme conditions. The expertise in the business unit comprises laser spectroscopic methods for gas analysis, energy-efficient gas sensors, particle measuring technology as well as thermal sensors and systems. The scope of applications is very broad – extending from flue gas analysis and transport monitoring of food to sensors and systems for measuring very small temperature differentials.

Integrated Sensor Systems

The main focus of this group is the development, design, characterization and production of functional surfaces, miniaturized gas sensors and compact gas measuring 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.

1 The sensor system developed by Fraunhofer IPM measures the escaping volatile organic compounds, relative humidity, temperature, weight change and the color of the external fish skin.

INTEGRATED SENSOR SYSTEMS

Safety in food production

Demand for high quality stockfish is rising globally – particularly in Southern Europe. To be able to cover the ever greater demand for this specialty, stockfish production is currently undergoing a transformation from a Viking craft to a high-tech production process. Semiconductor gas sensors from Fraunhofer IPM play a central role in this process.

Drying fresh fish is an ancient form of food conservation. The Vikings used the cold wind on the coast of Northern Norway to dry fresh cod on wooden frames and to preserve it in the form of stockfish. However, this procedure is not very efficient: the fish can only be dried in the months of February to May. In addition, up to 40 percent of the animals are spoiled by insect infestation. When the weather starts to get warmer, the risk of insects laying eggs in the fish rises. Furthermore, during the drying process it is possible that undesirable bacteria growth will take place on the fish resulting in nasty odors. If the »wrong« bacteria get into the fish, they can render it inedible.

In the »SafeTrackFood« project funded by the EU, Fraunhofer IPM together with partners from research and industry are developing a new, industrial drying process for fish. The process will be independent of the weather, faster, and therefore more efficient than the existing process. Furthermore, it should also ensure uniform quality and therefore drastically less waste.

To achieve this objective, the natural stockfish drying process has been relocated to the factory. The fish is dried there at a temperature between 4° C and 8° C. Fraunhofer IPM has developed a twin-unit sensor system for monitoring quality at the various stages of the drying process – the sensor unit is inside the drying oven and measures the escaping volatile organic compounds, relative humidity, temperature, weight change and the color of the external fish skin. The evaluation and control unit is located outside the climate chamber and records the data. This is then transferred to an online platform.

Semiconductor gas sensors monitor the drying process

The complex structure which consists of metal oxide gas sensors and many other sensors is capable of determining the drying stage of the fish very precisely. The system also detects the escape of volatile compounds which are generated during the maturing process and determines their quality and quantity. These escaping gases provide information on whether the drying process is running smoothly so that the fish does not spoil during the maturing process. On the basis of the detection of a certain gas composition, the system can state precisely when the fish is ready to be eaten.

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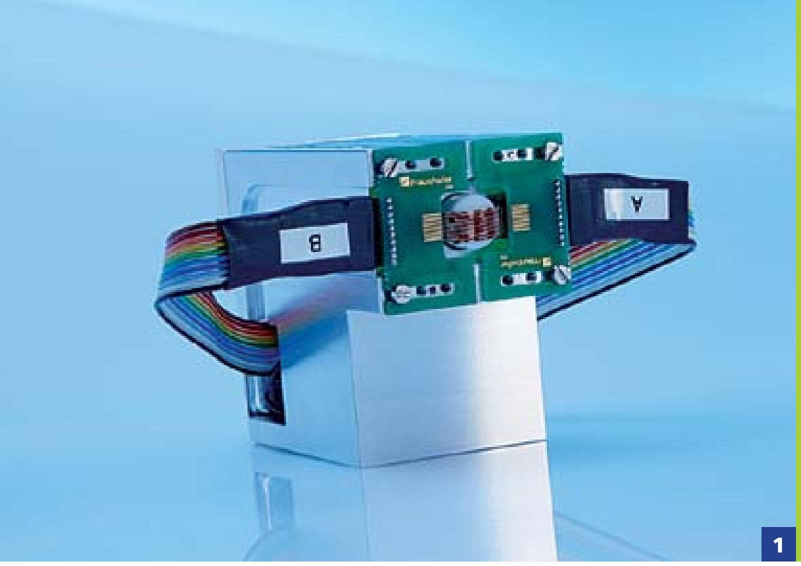
2 The Vikings used the cold wind on the coast of Northern Norway to dry fresh cod on wooden frames.

THE OBJECTIVE OF THE EU'S »Safe Track Food – Development of a novel Industrial Fish Drying and Maturing Process to secure Seafood Safety, Traceability and Quality« is to develop an industrial drying process for fish which will ensure uniform quality and therefore considerably less waste. www.safetrackfood.eu

One of the main challenges for the sensor system is the detection of the fish smell created during the drying process. The system must deliver precise measurements and must not suffer any saturation effects even if the process creates considerable odors leading to the escape of gases such as ammonia. In addition the ambient temperature, high humidity and mechanical stress are major challenges for the sensor system.

Experts in food inspections

Fraunhofer IPM used its long-standing experience and competence in the fields of microsystems engineering and gas sensor technology in the development of this new miniaturized odor and gas measurement system. The scientists at the Institute regularly develop small, lightweight, flexible sensor systems for all those sections of the food industry where continuous monitoring is required for quality controls.



1 *The measurement head can be tailored individually to the material to be measured.*

THERMAL MEASUREMENT TECHNIQUES AND SYSTEMS

Measuring with pressure: a stamp simplifies material measurement

Measuring thermal and electrical conductivity at the same time – without sample preparation. This is made possible by a new foil-based measuring concept for which a measurement head makes contact with the surface of the material by simply pressing it onto the sample.

Fraunhofer IPM has been working on the development of flexible sensors for many years. The flexibility of the new generation of sensors applies in two ways: they can be adapted to suit the measuring task in hand and are also pliable. Various electronic sensors on flexible plastic substrates such as polyamide or PET foils have already been developed. These »measuring plasters« are essentially capable of determining a wide range of physical variables simultaneously: from simple temperature measurements, measurements of electrical or thermal conductivity, and heat capacity through to determining parameters such as the Seebeck coefficient, a Lorenz number or porosity of adequately smooth surfaces of solids. In liquids, flexible »electronic tongues« can measure the pH value, density or viscosity by simply immersing them.

Measuring by pressing

The latest development in the field of flexible measurement technology is a material measuring stamp. The measurement structures are integrated in a flexible plastic foil made of polyimide (kaptone) and are made using thin-film technology. An insulation layer also made of polyimide is used to electrically insulate parts of the measurement structure and the sample.

2 *The sensor measures the electrical and thermal conductivity by simply pressing it on top the smooth surface of a workpiece.*

FLEXIBLE SENSORS measure physical parameters such as temperature, electrical and thermal conductivity, heat capacity, Seebeck coefficient, Lorenz curve or porosity.

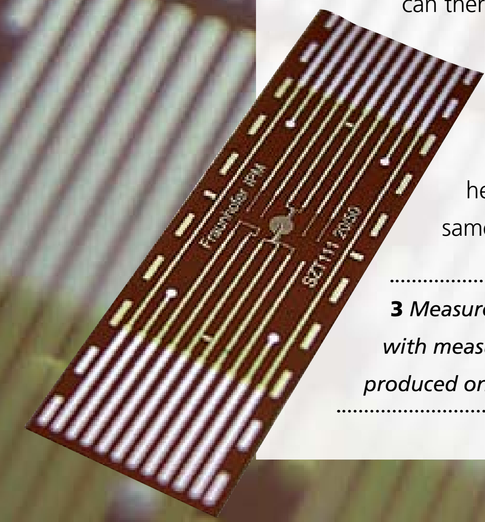
Mounted on a flexible measurement head support, the sensor measures electrical and thermal conductivity without any sample preparation by simply pressing it on top the smooth surface of a workpiece. Unlike conventional measuring methods, the workpiece does not have to be machined for this purpose and therefore remains intact. By replacing the foil measurement head support, it is possible to determine other parameters such as type of charge carrier, Seebeck coefficient or the thermal and electrical capacity of a material. The measurement head can be tailored individually to the material being measured, specific measurement parameters and the properties of the workpiece depending on the application.

»Thermal ultrasound«

A variable which is very difficult to measure, such as thermal conductivity, can therefore be checked on workpieces without having to stop the process. Scientists rely on the so-called 3-omega method. A heater structure encased in the measurement foil is charged with an alternating current with a frequency of omega. Pressed on to a body, this then feeds heat waves of double this frequency into the material. The penetration depth of these waves differs depending on the frequency, material and material thickness. The temperature increase this causes depends on the thermal material properties and the frequency and can be measured from the change in the resistance of the heater structure.

If the workpiece being measured is made up of several layers of different materials or of a composite material, this allows a sort of »thermal ultrasound picture« to be generated as long as the thermal conductivity of the various components is different. Air inclusions and delaminated layers can also be detected. The 3-omega method is not restricted to the measurement of solid materials but can also be used for measuring gases or liquids.

The measurement head itself is around the size of a pen and can therefore very easily be flanged on to a robot arm. If the integration of all the required measurement structures is not possible for a multi-parameter measurement using one head, several measurement heads can be used on one workpiece at the same time. Flexibility is the key in this case, too.



3 *Measurement chip made of plastic foil with measurement structures. The chips are produced on a wafer base and then separated.*

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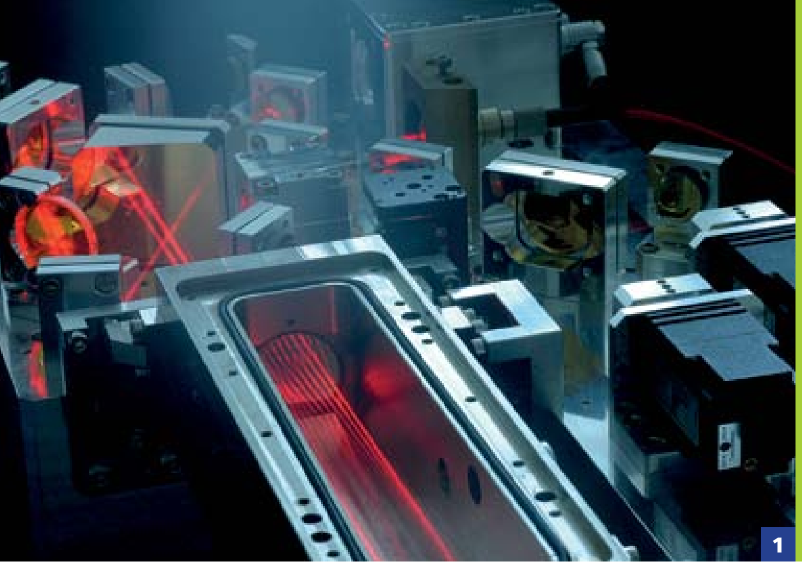

1 *Fraunhofer IPM's QCL analyzer detects laughing gas with a very high degree of sensitivity.*

SPECTROSCOPY AND PROCESS ANALYTICS

Quantum cascade lasers for rapid exhaust gas analytics

European emission legislation is becoming more and more stringent both for industry and for the automotive sector. Climate protection can work only if air pollution by vehicle exhaust gases is reduced constantly. Fraunhofer IPM has developed a reliable exhaust gas measurement system for development of reduced-emission engines. In particular, it can also be used to detect laughing gas, a gas which has a particularly negative impact on the environment. The system is based on infrared absorption spectroscopy using quantum cascade lasers as the light source in conjunction with a specially designed sampling system.

As early as in past decades, more stringent exhaust gas legislation led to the introduction of a whole number of new technologies for reducing emissions. Exhaust gas treatment has also become increasingly more complex. Admittedly, it was possible to achieve major success with the first three-way catalytic converters, but the emission of undesirable gases still continues to preoccupy both scientists and automobile manufacturers alike – in particular in the field of engine development. During the course of this development process, demands on measuring accuracy are becoming ever-more stringent: the call for detection limits in the region of 10 ppb are no longer a rarity (ppb = 1 part per billion).

New technology for extreme measuring requirements

Current legislation relating to greenhouse gases for example already requires measurements of laughing gas (N_2O) in very low concentrations of below 1 ppm (ppm = 1 part per million). The gas, also referred to as nitrogen monoxide, is mainly produced during decomposition of mineral nitrogen fertilizer in the soil, but is also generated when combusting fuel in internal-combustion engines. Conventional technologies which have been used to date for measurements of N_2O – such as non-dispersive infrared technology (NDIR) or electrochemical gas sensors – are either too insensitive for today's measuring requirements or they demonstrate excessive cross-sensitivities.

An optical spectrometer based on quantum cascade lasers (QCL), developed by Fraunhofer IPM jointly with an industrial partner, now, for the first time, permits exhaust gas measurement which meets the more stringent requirements. The gas analyzer is capable of reliably detecting laughing gas in very low concentrations, in the range of 10 ppb to 100 ppm (4 decades). The QCL analyzer applied is highly selective in relation to the other components in the particular gas matrix such as that typical of the exhaust gas from internal-combustion engines.

Quantum cascade lasers are semi-conductor lasers for wavelengths in the medium infrared range (MIR). Unlike other lasers which emit in the MIR range, the QCL has a comparatively high output power and also operates at room temperature – a complex and expensive cooling system is no longer required. The laser temperature is stabilized and consequently the emission wavelength is also stabilized using a conventional Peltier element with a corresponding ventilation system. The control system is designed for laser operating points between –30 °C and +30 °C.

Industrial systems for automobile manufacturers

Fraunhofer IPM was able to take recourse to its many years of experience in the field of exhaust gas measurement systems when developing the N_2O exhaust gas measurement system: as early as 2002, Fraunhofer IPM developed an industrial measurement system for high-speed, high-sensitive and selective detection of carbon monoxide, nitrogen monoxide and nitrogen dioxide with the QCL-based exhaust gas analyzer DEGAS (Dynamic Exhaust Gas Analyzer System) for a major automobile manufacturer. DEGAS permits simultaneous measurement of the concentration of various exhaust-gas components with a time resolution of five milliseconds at up to four measuring points on the exhaust gas system. The new QCL analyzer which has now been developed is intended for instrument cabinet applications and is thus designed as a substantially more compact unit; in addition, the next expansion stage is to be able to detect two gas components simultaneously. The QCL analyzer is not only already being used successfully in research and development but also to an increasing extent for certification measurements on reduced-emission engines.

FRAUNHOFER IPM primarily conducts research in the field of gas and process technology and uses a wide range of spectroscopic methods for this purpose. In addition to laser spectroscopy, the expertise of the institute also extends to many classic methods such as Fourier transform IR spectroscopy (FTIR), photometry, filter, UV and Raman spectroscopy and photoacoustics.

2 *Developing engines producing less emissions is a major challenge for today's scientists and for the industry.*

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Functional Materials and Systems
»With us, material makes the difference«

TOPICS

- Efficient cooling without refrigerants
- Converting waste heat into electricity
- Self-powered sensors and systems
- Widely adjustable laser light sources for spectroscopy
- Characterization of optical materials and semi-conductors
- Thermal analysis of thin-layer systems and solid materials
- Development of measurement systems and contract measurements for determining thermal and electrical material characteristics

EXPERTISE

- Functional materials:
  – magnetocaloric and electrocaloric
  – nonlinar optical
  – thermoelectric
- FEM Simulations
- Thermal management (heat pipes, Peltier)
- Special electrical and thermal contacting
- Frequency conversion for light generation and detection
- Measurement of very low absorption rates
- System design and development

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Thermoelectrics
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High-purity optical crystals are necessary for state-of-the-art photonic technology.

Materials with special physical properties are manufactured, optimized and developed into systems in the »Functional Materials and Systems« Division. These include the following:

- Magnetocaloric and electrocaloric materials for efficient heat pumps and cooling systems which do not use coolants.
- Nonlinear optical materials such as for the development of new lasers with adjustable wavelengths.
- Thermoelectric materials for the direct conversion of waste heat into electric power (in cars and industrial processes) and for operating small self-powered sensor systems

Magnetocalorics and Electrocalorics

The group »Magnetocalorics and Electrocalorics« is involved in the development of innovative cooling systems based on novel magnetocaloric and electrocaloric materials. Compared to conventional compressor-based cooling systems, more efficient and ecological systems can be realized – entirely without coolants.

Nonlinear Optics

The main focus of this group are materials and methods in the field of nonlinear optics. Highly sensitive spectroscopic techniques are being developed and used for the measurement of residual absorption in highly transparent optical materials for high-power lasers and nonlinear optics. Many years of experience with nonlinear frequency conversion form the basis for creating widely tunable laser light sources and sensitive infrared detection systems.

Thermoelectrics

The main focus of this group is the development of new thermoelectric materials and components for various applications – from thermopile detectors and thermogenerators to high performance Peltier coolers. In addition to material research, the spectrum of the group also includes the development of thermoelectric modules and systems, their simulation and the development of bespoke thermoelectric measuring equipment.

1 Refrigerant-free cooling is a good alternative in cars or aircrafts, where the use of substances highly flammable or harmful to health poses problems.

MAGNETOCALORICS AND ELECTROCALORICS

Cool: magnetic cooling without harmful refrigerants

More and more air-conditioning systems are being installed the world over. They generally operate with refrigerants which are harmful to the environment and also require a great deal of energy. Magnetocaloric cooling technology could make far more energy-efficient and refrigerant-free cooling systems possible in future.

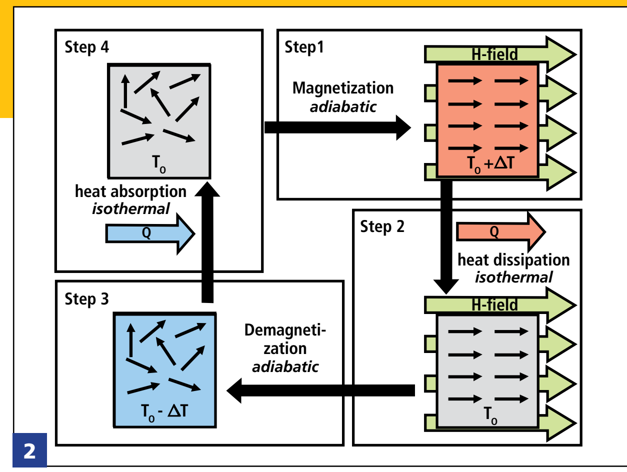
Cooling technology is a fast growing market with a high energy demand. Over 72,000 GWh of electrical power per annum is consumed for cooling even in Germany, which is a relatively cool country. This corresponds to 14 percent of the entire electrical power demand. Every year, over 50 million new air-conditioning systems are added worldwide. Regardless of whether cooling systems are installed in buildings, in motor vehicles or as refrigerators – virtually all these systems available today operate on the basis of the compressor principle, whereby the heat is dissipated via the changed physical state of a refrigerant. The problem with this is that all refrigerants have a global warming potential to a greater or lesser extent; some of them, such as ammonia, are directly harmful to health. Sooner or later, as the refrigerant circuit's leakage rates increase, the refrigerants escape and need to be replaced at great cost. Other disadvantages are that compressors require a great deal of space, are loud and need to be serviced.

Promising cooling technology

It is possible to develop particularly energy-efficient cooling systems that operate entirely without refrigerants on the basis of the magnetocaloric effect. They are based on what are called magnetocaloric (MC) materials. MC materials are magnetizable materials which heat up when exposed to a magnetic field and accordingly cool down again when the field is removed. This is how it is possible to implement a cooling cycle: The heated MC material is connected to a heat sink so that heat can be dissipated. If the magnetic field is removed, the material cools down again and is at a lower temperature than at the start of the cycle. The MC material is now connected to the system to be cooled and is able to absorb heat. Magnetocaloric cooling systems can achieve up to 30 percent higher efficiencies by comparison with compressor-based systems. Dispensing with refrigerants simplifies use in mobile systems such as cars, trains and aircraft where the use of substances highly flammable or harmful to health is problematic. It is an additional advantage that the systems operate without a great deal of servicing and, moreover, operate very quietly.

MAGNETIC COOLING – THE PRINCIPLE:
The magnetocaloric material is heated (Step 1) by applying a magnetic field (H field). In Step 2, the MC material is connected to a heat sink so that the heat produced (Q) can be dissipated. If the magnetic field is removed (Step 3), the MC material cools down again and is at a lower temperature than it is at the start of the cycle. The MC material is now connected to the system to be cooled and can absorb heat (Q) (Step 4).

THE MAGNETOCALORIC EFFECT was discovered as early as 1881 by the German physicist Emil Warburg.



2 The principle of magnetic cooling (for a detailed description of the process see left).

System design makes a crucial contribution to cooling performance

Magnetic cooling systems are still a long way off. But their outlook is promising: Magnetocaloric materials have become far more efficient and better value for money in recent years. However, it must be possible for them to be manufactured on a large scale, and it will be necessary to develop a system for material shaping and system development for structuring cooling systems in order for them to be suitable for use on an industrial scale.

System design makes a crucial contribution to cooling performance. When designing thermal systems and thermal coupling of components, Fraunhofer IPM takes recourse to its experience in the field of thermoelectrics. Scientists at the Institute research into the optimization of heat transfer from magnetocaloric material to the medium to be cooled or heated. The techniques used achieve up to 1,000 times higher heat transfer rates than would be possible, for instance, by pure thermal conductivity of copper. Consequently, at given temperature differences, it is basically possible to achieve far higher cooling rates. These heat-transfer techniques are the central topic of the MacCool Project in which a magnetocaloric heat pump for energy-saving, refrigerants-free temperature stabilization of electric vehicle batteries is being developed.

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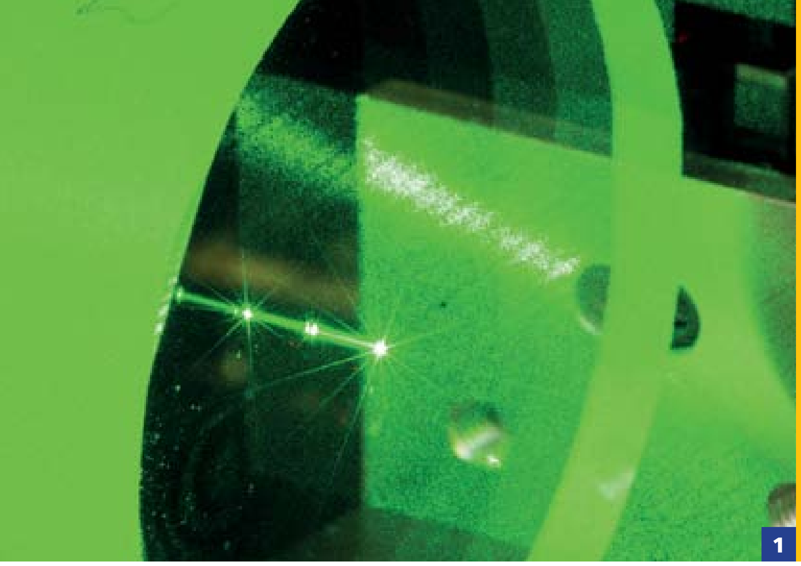


1 + 2 Highly sensitive photoacoustic and photo-thermal measurement techniques are a valuable tool for quality control of optical materials.

NONLINEAR OPTICS

Pure optics: precise measurement of residual absorption

Fraunhofer IPM has optimized two methods to measure the purity of optical lenses – and is therefore conducting research in the original area of Joseph von Fraunhofer, who took giant strides in production and processing techniques for optical lenses over 200 years ago.

For a long time, scientists thought it impossible to transfer light pulses over long distances using glass fibers since absorption due to impurities in the material caused high attenuation. Only with the development of much more transparent glass fibers did low-loss data transfer become possible. Today, the question of purity is also applicable to short optical components since more powerful laser sources place high requirements on their quality. In contrast to glass fibers, it is not so much the attenuation of the light power which is important, but the thermal effects since the absorbed light is converted almost completely into heat. As the temperature changes so does the index of refraction of the material and with it, the optical properties. These thermo-optical effects may result in undesirable fluctuations of laser power or, for example in laser welding, in a displacement of the focus position. Frequently, the optical components themselves may be damaged.

Precise, reproducible and non-destructive

It is therefore very important for the development of optical materials to know the absorption coefficient of a material. Manufacturers of optical materials and coatings require measurement methods to determine bulk and surface absorption. The measurement results should be precise and reproducible while the measurement method itself should ideally be contactless, at least non-destructive. This is the only way to optimize production processes.

Transmission spectrometers, which are normally used to measure absorption, are not sensitive enough for the low absorption coefficients of optical materials. Highly sensitive indirect measurement methods, which use the heat generated in the specimen by the absorbed energy, are therefore mainly used to determine the residual absorption in optical materials.

Precision by combination: photoacoustics plus photo-thermal interference measurement

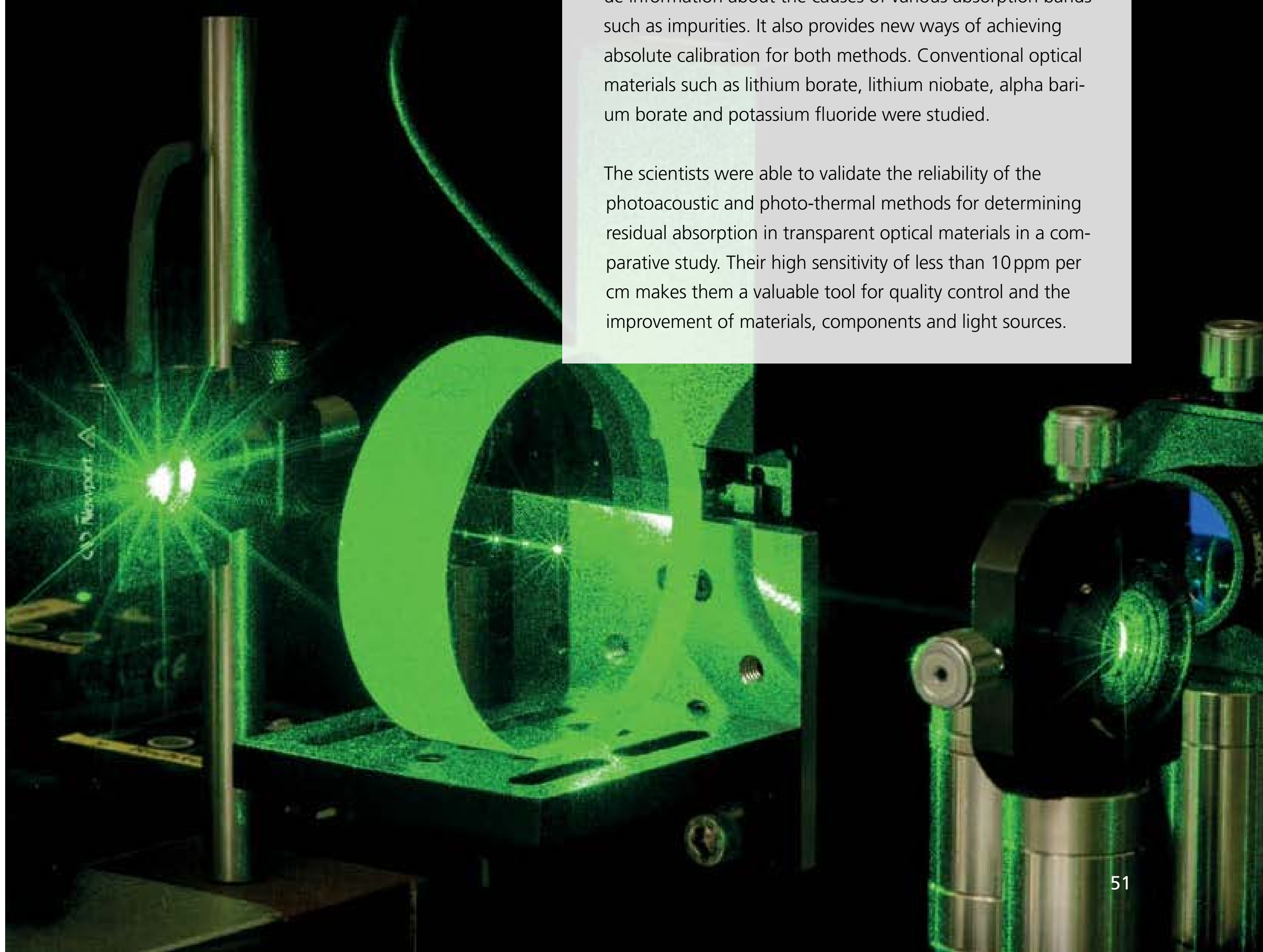
Photoacoustic measurement methods detect absorption on the basis of the thermal expansion of the material. In the case of pulsed light, acoustic waves are created which may be detected using a piezo sensor. The absorption coefficient can be derived from the amplitude of the sound waves. A photoacoustic spectrometer which has been recently developed by scientists at Fraunhofer IPM is the first to allow measurement of absorption spectra in 1 mm thick samples over the entire wavelength range from 212 to 2,500 nm with detection limits of up to 10^{-5} cm^{-1}. Photoacoustic measurements are ideal for materials with large coefficients of thermal expansion. Photo-thermal common path interferometry (PCI) is an alternative measurement method which has been developed particularly for materials with high thermo-optical coefficients. The local heat generation caused by radiation absorption forms a »thermal lens«. The detection beam recognizes this as inhomogeneity. Using a photo diode, the self-interference of the detection beam provides information about the absorbed light power. This method has already become established with glass and crystal manufacturers at single wavelengths. Scientists at Fraunhofer IPM have for the first time combined this method with a tunable light source to measure spectra of residual absorption in the near and medium infrared wavelength range.

Sensitive measurements over large wavelength ranges provide information about the causes of various absorption bands such as impurities. It also provides new ways of achieving absolute calibration for both methods. Conventional optical materials such as lithium borate, lithium niobate, alpha barium borate and potassium fluoride were studied.

The scientists were able to validate the reliability of the photoacoustic and photo-thermal methods for determining residual absorption in transparent optical materials in a comparative study. Their high sensitivity of less than 10 ppm per cm makes them a valuable tool for quality control and the improvement of materials, components and light sources.

FOLLOWING IN JOSEPH VON FRAUNHOFER'S FOOTSTEPS

Joseph von Fraunhofer managed to determine the absorption lines in the solar spectrum primarily as a result of the improved quality of the glass prisms he used.



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CONVERTING WASTE HEAT INTO ELECTRICITY, many researchers throughout the world are working flat out on this project. This form of »Energy Harvesting« lends itself to many combustion processes. Prerequisites for this are efficient thermoelectric materials and optimal manufacturing processes.

THERMOELECTRICS

Thermoelectric generators in a combined heat and power plant

Combined heat and power plants play a major role in the energy transition process. They are more efficient than conventional power plants. Fraunhofer IPM is developing new thermoelectric generators to increase the efficiency and economy of combined heat and power plants even further.

Combined heat and power plants (CHPPs) are so promising because they are capable of converting energy very efficiently. CHPPs generate heat and power at the same time: thanks to its cogeneration, a CHPP is also capable of using waste heat in addition to generating high-quality electric power while the majority of this waste heat is not used in conventional power plants.

But it is possible to achieve even more: Fraunhofer IPM, a global leader in thermoelectrics, plans to install new thermoelectric generators (TEG) in the heat exchanger of a CHPP which can drastically increase its economy and power yield. Whilst conventional CHPPs to date have only been able to heat utility water, the new TEGs installed in the heat exchanger are capable of converting part of the waste heat from the flue gases straight into high-quality electric power.

Thermoelectrics: high-tech for protecting the environment

The additional power generation significantly increases the electrical efficiency of a CHPP, currently by up to 3 percent. This additional energy efficiency is of great importance for operating a combined heat and power plant economically. The higher the proportion of generated electrical energy, the longer the operating time of such power plants and the greater their contribution to the protection of environment and climate.

The harvesting of waste heat using thermoelectric generators is one of many exciting areas of research in thermoelectrics, whether it be in power plants, industrial processes or in motor vehicles. The specially developed thermoelectric generators are based on materials which can convert a heat flow between a warm side and a cold side into an electric current. In contrast to many other conversion mechanisms, TEGs do not need any moving components – they operate silently and do not require maintenance. In addition, they are extremely durable which makes them sustainable in the truest sense of the word.

Low-cost and efficient

Most of the generators available in the past on the market are generally only suitable for use in temperatures of up to 200 °C. Fraunhofer IPM is the first to develop modules which operate reliably at temperatures of up to 550 °C. The experts also managed to reduce the amount of material used in the manufacture of these modules by around one-half without compromising their capacity. The modules are therefore considerably lighter, cheaper and more attractive for industrial use. In fact, Fraunhofer IPM is currently working with industrial partners on the industrialization of this promising technology.

1

1 *Fraunhofer IPM is the first to develop modules which operate reliably in temperatures of up to 550 °C.*

2

2 *The efficiency of a combined heat and power plant can be significantly increased by the use of thermoelectric generators.*

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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 more than 23,000 staff are qualified scientists and engineers, who work with an annual research budget of 2 billion euros. Of this sum, more than 1.7 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.

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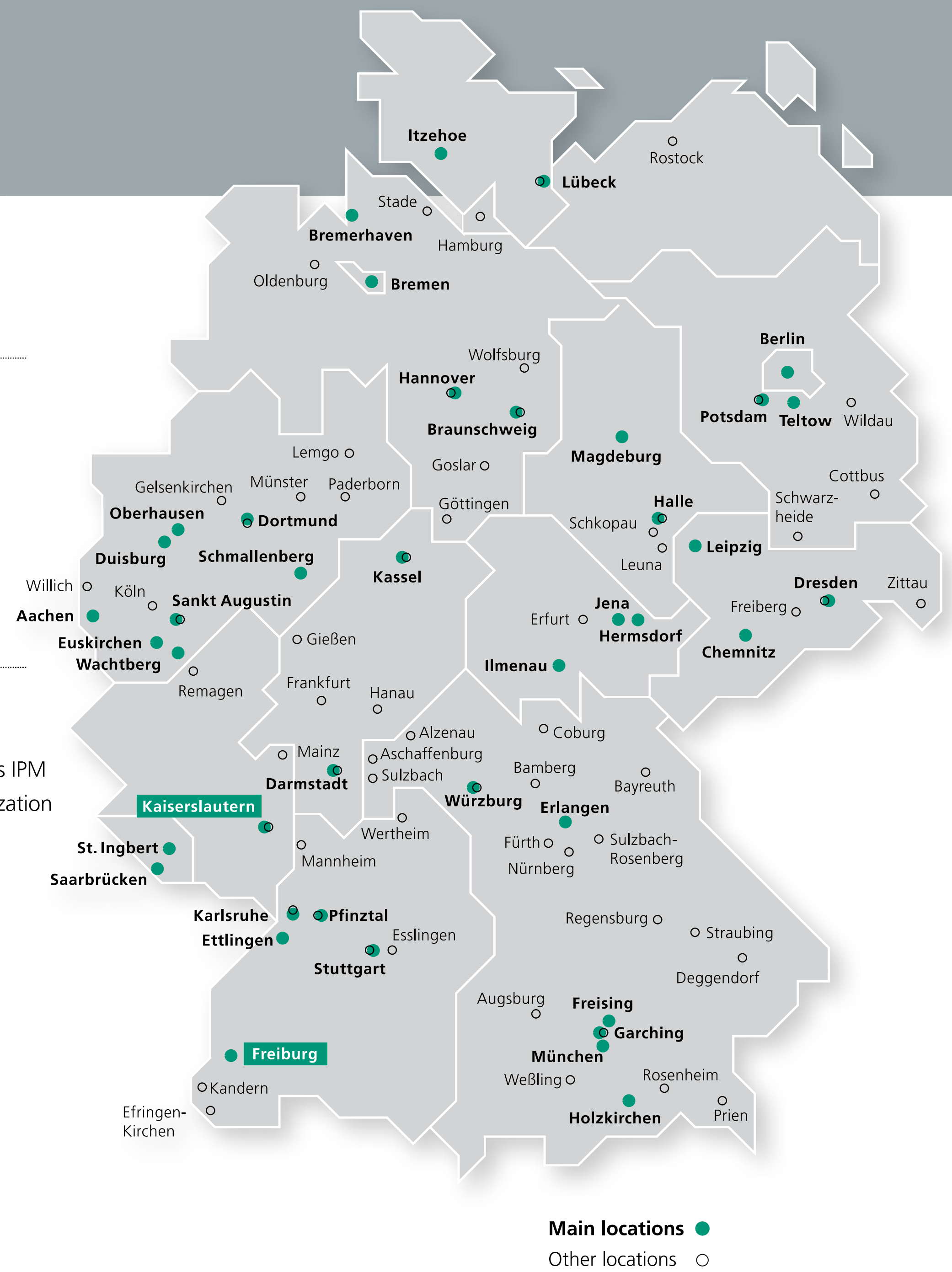

Partners and Networks

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

Fraunhofer-Gesellschaft

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

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
- 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.
- GDCh – Gesellschaft Deutscher Chemiker
- Green City Freiburg Regional Cluster
- MST BW – Mikrosystemtechnik BW
- Netzwerkdraht e.V.
- Optence e.V.
- Photonics BW
- SPECTARIS – Deutscher Industrieverband für optische, medizinische und mechatronische Technologien 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.

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

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Novel approaches to optical activity measurements

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Verfahren zur Herstellung eines thermoelektrischen Bauelements und thermoelektrisches Bauelement

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Verfahren zur Herstellung einer Fügeverbindung und Vorrichtung

Brandenburg, Albrecht
Vorrichtung zur optischen Detektion von Substanzen in einem flüssigen oder gasförmigen Medium

Ellrich, Frank
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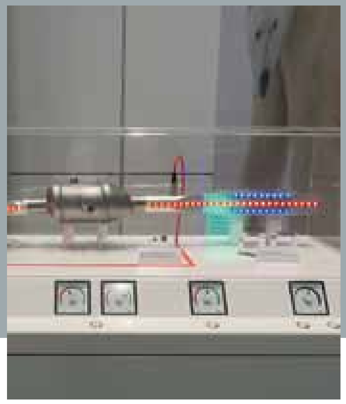

Exhibition demonstrator for flexible measurement techniques.

Energy 2014, Hanover Exhi-bi-tion Center; Fraunhofer -Allianz Energy booth.

TRADE FAIRS

- **SPIE Photonics West 2014**
  Laser, Photonics, Biomedical Optics Conference and Exhibition San Francisco, USA February 4 - 6, 2014
  The »C Wave« and »T Cognition« for which there were two »Prism Awards« were presented at the Hübner company's booth.

- **Wire 2014**
  International Wire and Cable Trade Fair
  Düsseldorf, April 7 – 11, 2014
  »Netzwerk-Draht« joint booth
  Fraunhofer IPM presented the WIRE-AOI inspection system which fully inspects the wire surface during production and detects flaws in real time at speeds of up to 10 m/s at the Wire and Cable Trade Fair.

- **Energy 2014, Hanover Exhibition Center**
  Leading International Trade Fair for Renewable and Conventional Energy Generation and Energy Supply, Transmission, Distribution and Storage
  Hanover, April 7 – 11, 2014
  »Fraunhofer-Allianz Energie« booth
  Fraunhofer IPM presented different systems for raising energy efficiency in combustion processes, among them fast measurement systems for optimization of motors as early as the development phase, smart gas sensors and thermoelectric generators for electrical power generation from exhaust gas heat.

- **Control 2014**
  28th Control – International Trade Fair for Quality Assurance
  Stuttgart, May 6 – 9, 2014
  »Fraunhofer-Allianz Vision« booth
  We presented inline detection systems for micro-deformation measurement, wire inspection, measu-rement of large-area residual contamination and measurement of coating-thickness with Terahertz waves.

- **E-MRS Spring Meeting of the European Materials Research Society**
  Lille, May 27 – 29, 2014
  »Quick-Ohm GmbH« booth
  The Quick-Ohm GmbH company and Fraunhofer IPM presented turn-key measuring systems for bulk and thin-film materials.

- **SENSOR+TEST 2014**
  The Measurement Fair
  Nuremberg, June 3 – 5, 2014
  »Fraunhofer-Gesellschaft« booth
  We presented a foil based sensor array combined with a measurement punch system for measurement of thermal and electrical material characteristics.

- **Lasys 2014**
  International Trade Fair for System Solutions in the Field of Laser Metalworking
  Stuttgart, June 24 – 26, 2014
  »Photonics BW« booth
  Fraunhofer IPM presented a measurement system for optimized seam quality in laser welding processes by real-time control.

- **Parts2Clean**
  12th Leading International Trade Fair for Industrial Parts and Surface Cleaning
  Stuttgart, June 24 – 26, 2014
  We exhibited a measuring instrument for determining residual contamination on large components by way of spatially resolved fluorescence measurement techniques

- **InnoTrans 2014**
  International Trade Fair for Transport Technology Innovative, Components, Vehicles, Systems
  Berlin, September 23 – 26, 2014
  »Fraunhofer-Allianz Verkehr« bootht
  Fraunhofer IPM showcased the most recent develop-ments in the field of rail measurement systems – the Rail Track Scanner RTS and the Sector Profile Scanner SPS.

At the InnoTrans 2014 visitors were able to convince themselsves of the precision of our laser scanners.

Workshop: gas technology in the energy transition

Although public debate relating to the energy transition centers on the subject of electricity, the significance of the gas market for energy policy is systematically underestimated. This was the view of gas technology experts at a workshop held on June 26, 2014 by Fraunhofer IPM. The »community« all agreed that the technical facilities of the existing gas infrastructure had not nearly been exploited for the energy transition. The experts made the case for elec-tricity and gas infrastructures to be better networked. Technologies such as power-to-gas, which converts surplus electricity into gas, will allow energy to be generated and used anywhere and at any time.

»The technical facilities of using gas more widely for the energy transition have by no means been exploited fully«, said Institute Director Karsten Buse and demanded investment in innovations rather than subsidies in the energy sector. »The gas industry must stop being the puppet in the energy sector. It must actively drive innovations forward.« This must be supported by politicians providing adequate research funding according to the experts who set out the findings in a position document to be submitted to politicians.

Workshops offer the opportunity for identifying new research topic together with experts from different branches.

WORKSHOPS AND CONGRESSES

- **Expert Workshop – Certification of Mobile Mapping Systems for 3D Data**
  Freiburg, IPM, February 5, 2014

- **Applied Research for Defence and Security in Germany**
  Berlin, Hotel Maritim proArte, February 3–5, 2014
  Talk and posters in relation to applied security research by way of example of detection of hazardous substances. Incoming-mail inspection with terahertz waves, for instance in prisons; spatially resolved measurement of gaseous hazardous substances and fumes, e. g. in emergencies.

- **6th International Workshop onTerahertz Technology and Applications**
  Kaiserslautern, Fraunhofer IPM, March 11–12, 2014
  One of the aspects which we focused on at the »International Workshop on Terahertz Technology and Applications« was application of quantum cascade lasers (QCL) and metrology.

- **Girls' Day**
  Freiburg, Fraunhofer IPM, March 27, 2014

- **Fraunhofer Annual Convention**
  Freiburg, Fraunhofer IPM, May 22, 2014

- **Gas Technology in the Energy Transition, Research and Development Potentials**
  Freiburg, Fraunhofer IPM, June 26, 2014
  Research and Development Potentials

- **Workshop Laser-Based Process Analytics**
  Freiburg, Fraunhofer IPM, September 25–26, 2014
  An introduction to the fundamentals of optical process analysis and focused in-depth on laser-based measuring methods for online and inline analysis.

- **2014 German Road and Transport Congress Road and Transport Exhibition**
  Stuttgart, September 30–October 2, 2014
  Fraunhofer IPM presented the Pavement Profile Scanner at this event. This scanner generates 3D images of the roadway surface with a degree of precision unparalleled to date.

- **International Student Conference on Micro Technology 2014**
  with industry exhibition and contact exchange for students of engineering sciences and natural sciences in their final years of study in addition to young Ph.D. students
  Freiburg, IMTEK, October 6–10, 2014

- **Science Campus 2014**
  Women in Science
  Workshop »Science to Business«
  Freiburg, Fraunhofer IPM, October, 6–9.2014

- **MoLaS 2014**
  Technology Workshop Mobile Laser Scanning
  Freiburg, Fraunhofer IPM, 26.–27.11.2014

- **4th Thermoelectrics IAV Conference**
  Waste Heat Utilization in Transport and Industry
  Ellington Hotel Berlin, December 10–12, 2014

The world in 3D: workshop on the subject of mobile object detection

MoLaS
Mobile Laser Scanning | Technology Workshop

More than 100 people from 14 countries attended the »MoLaS – Technology Workshop Mobile Laser Scanning« which Fraunhofer IPM staged for the first time in November 2014. The group led by Alexander Reiterer thus managed to attract the interest of the mobile laser scanning community for a workshop concept focused on the technology for the mobile 3-D mapping of objects. Various European universities, research facilities and companies gave presentations on the latest technological trends in mobile laser scanning. The program comprised four sessions with the themes of sensors, calibration, data processing and applications. There were also some very concrete products on show, including a rucksack-based laser scanner which allows measurements to be taken on rough terrain. During the breaks, a poster session and an industry exhibition provided an opportunity for talks between experts. In the future, MoLaS will be held every two years at Fraunhofer IPM.

www.molas-workshop.org

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