Fraunhofer

IPM

FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES IPM

Measuring · Monitoring · Optimizing

Cover *The wire rod shoots out of the draw plate at a speed of 10 meters per second. At the same time, an optical inspection system detects micro-defects on its surface.*

Prof. Dr. Karsten Buse
Executive Director

Dear colleagues and partners,

Addressing complex measuring assignments with turnkey and certified devices continues to be the special strength of our Institute. Precise measuring technology and adverse operating conditions often appear to represent irreconcilable contradictions. Only the correct choice of method and optimum integration of optics, electronics and mechanics into one system enables these differences to be reconciled.

Measuring systems that enable a 100 percent inspection for defects in the micrometer range can by no means be taken for granted. The same applies to laser scanners that reliably measure signals of only a few hundred photons from trains over the years – in the Brazilian sun and in the freezing cold of Siberia. Success only comes if systems expertise and know-how about the appropriate physical measuring method are fused. Here the system does not only solve the measuring problem, but also addresses the client's specific requirements. Take this example: in 2013, we used ultrasonic measurement technology to determine wear in an environment with a lot of sand, clay and rock – for the first time and with immediate success.

In addition to this, we were once again able to continue developing measuring methods in which we achieve a unique position: the contact-free online multilayer thickness determination is a milestone in the market entry of terahertz technology. We have also shown that terahertz waves are outstandingly suited to characterize super-high-frequency electronics components. By combining thin-film technology with optical detection processes, our integrated sensor systems have made significant advances; and the thermoelectric measuring devices have been integrated to such an extent that they are even able to act as highly sensitive broadband radiometers.

We are researching into and developing new materials to cope with special assignments for which the use of standard materials is not sufficient. In this connection, there are very pleasing advances in the field of thermoelectrics: not only with respect to the materials themselves but also in the construction and bonding technology to produce modules more cost-effectively. Our new field »Technology of Optical Materials« is also gathering speed: the highly sensitive photoacoustic and photothermal absorption measurements have turned out to be »hot sellers« which are not only in demand among external partners for qualifying their own components but are also being used internally – here in particular for constructing optical parametric oscillators, i.e. synthesizers for laser light.

We hope you enjoy reading this report and wish you a stimulating exchange of ideas with Fraunhofer IPM.

Yours

Karsten Buse

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NEWS

FROM FREIBURG AND KAISERSLAUTERN

40 years of Fraunhofer IPM
In July 2013, some 250 invited guests celebrated the 40th anniversary of the Institute. The guest speakers Minister of Finance and Economics Nils Schmid, chairperson of the Bündnis 90/Die Grünen parliamentary group in the state assembly of Baden-Württemberg Edith Sitzmann, Mayor Dieter Salomon, Rector of the University of Freiburg Hans-Jochen Schiewer and Fraunhofer Executive Board Member Alexander Kurz paid tribute to the Institute's achievements and predicted a promising future. The history of the Institute started in 1963, when Professor Karl Rawer founded a working group dedicated to space research in Freiburg. In 1973, the Fraunhofer Institute for Physical Space Research IPW emerged from this group. In the 1980s, the Institute shifted and expanded the spectrum of its research and has since borne the name Fraunhofer Institute for Physical Measurement Techniques IPM. And still today, part of the Institute is devoted to space research even if the main focus of research is now on industrial measurement techniques. Highlights of the event were the interview with Professor Karl Rawer, who has now reached the age of 100 and who reported on aspects of his life and on the beginnings of the Institute, as well as the lecture entitled »Are we heating up our climate?« by the climatologist Prof. Dr. Mojib Latif.

Representatives from science, business and politics congratulated Executive Director Karsten Buse (left) and founder of the Institute Karl Rawer (third from right) on the anniversary: Minister of Finance and Economics Nils Schmid (second from left), Leader of the Bündnis 90 / Die Grünen parliamentary group in the Baden-Württemberg state assembly Edith Sitzmann (third from left), Rector of the University of Freiburg Hans-Jochen Schiewer (second from right) and Fraunhofer Executive Board Member Alexander Kurz (right).

New buildings in Freiburg and Kaiserslautern
The Institute building at the Freiburg location is no longer able to cope with the growing number of employees and the demand for new testing rooms and laboratories. As a result of this, a new building in close proximity to the Technical Faculty of the University of Freiburg is in the planning stage. The new building is part of a lighthouse project by the state of Baden-Württemberg and the Fraunhofer-Gesellschaft to strengthen research and development in the fields of sustainable production and utilization of resources and energy. The joint project by Fraunhofer IPM and Fraunhofer ISE is intended to become the »Sustainable Energy Valley« in Freiburg. A sum of 54 million euros is available for the extension of Fraunhofer IPM. At the Kaiserslautern site, too, work is progressing on the new building for the Department of Materials Characterization and Testing. Celebrations for the topping-out ceremony took place on 30 January 2014. By December 2014, the new building is scheduled to be ready for occupation. In future the building will offer space for 50 employees.

Fraunhofer IPM organizes conference on infrared and terahertz research
At the beginning of September 2013, Fraunhofer IPM together with the Technical University of Kaiserslautern welcomed experts from all over the world to the »38th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)« at the Rheingoldhalle in Mainz. The world's most important specialist conference on the subject of long-wavelength radiation takes place every year and is held alternately in Asia, Europe and North America. More than 650 experts met to discuss scientific aspects of infrared, millimeter and terahertz waves. Topics dealt with included the use of these long-wavelength light rays for materials characterization and their application in security technology, communication and biotechnology. In addition, 34 companies presented their innovative products as part of an industry exhibition.

Pictured top right: André Eberhardt (left) secured first place in the »Green Photonics« junior research award with his degree thesis. Dr. Tobias Weiler (right), Managing Director of SPECTARIS, presented the award at Hannover Fair.

Pictured right: Companies presented their innovative products at the international conference IRMMW-THz, which resulted in a lively exchange between the experts.

»Green Photonics« junior research award for Fraunhofer IPM undergraduate
André Eberhardt secured first place in the »Green Photonics« junior research award worth 1,500 euros with his degree thesis conducted at Fraunhofer IPM. The prize is awarded annually by the Fraunhofer »Green Photonics« innovations cluster to a total of eight young researchers whose final dissertations deal with light as the enabler of more sustainability. Eberhardt developed a photometric gas sensor to determine the CO/CO_2 equilibrium in the production of raw iron. By selectively adding gas, it is possible to achieve an optimum gas composition for the melting process. The sensor is intended to permit savings in energy and raw materials and reduce carbon dioxide emissions during the production of iron. The measuring system is a cost-effective alternative to the mass spectrometers usually employed. Supervisor for the work was Prof. Jürgen Wöllenstein, who heads the group on Integrated Sensor Systems at Fraunhofer IPM.

Fraunhofer IPM takes two »Prism Awards«

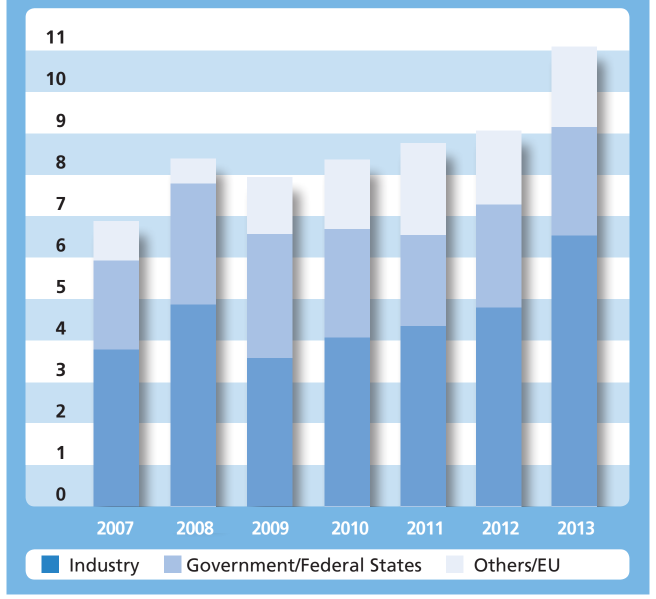
Two optical systems developed jointly by Fraunhofer IPM and the Kassel-based systems supplier HÜBNER GmbH & Co. KG were honored with the prestigious »Prism Award 2014«. The award for novel photonics products is presented annually at »Photonics West«, the world's most important trade fair in this sector. Delivering an impressive performance in the category of security was »T-COGNITION«, a terahertz spectrometer that identifies concealed drugs or explosives in postal deliveries. »T-COGNITION« thus contributes to security in post centers, penal institutions or other sensitive establishments such as embassies. The optical parametric oscillator »C-WAVE« won in the category of scientific lasers. For the first time »C-WAVE« provides an optical parametric oscillator that continuously emits laser light across the entire visible range of the spectrum. Cooperation between the Chair for Optical Systems at the University of Freiburg, Fraunhofer IPM and HÜBNER GmbH & Co. KG has made it possible for a laboratory setup to develop into the award-winning product »C-WAVE« within the space of a year.

Excellent atmosphere at the presentation of the »Prism Awards« at Photonics West in California. Employees of Fraunhofer IPM, the University of Freiburg and the industry partner HÜBNER GmbH & Co. KG celebrate the success of »T-COGNITION« and »C-WAVE«.

Hands-on research at the science market

In July 2013, the Freiburg Science Market took place on the city's Cathedral Square under the motto of »Wissen – Staunen – Mitmachen«, encouraging visitors to »Discover – marvel – get involved«. More than 10,000 visitors were able to experience science at close quarters at 60 stands organized by the University of Freiburg, the University Medical Center and the regional universities and research establishments. The five Fraunhofer Institutes in Freiburg also presented examples of their research. Using the »Thermoelectric Railway« and the »Talking Coffee Pot«, Fraunhofer IPM demonstrated how surplus heat can be converted into electrical current. This is achieved by thermoelectric modules that are developed at Fraunhofer IPM. The »Talking Coffee Pot«, for example, generates enough electricity from the heat dissipated by the coffee to measure the coffee temperature and the level of coffee in the pot, send this information to a laptop computer and thus order more coffee when required.

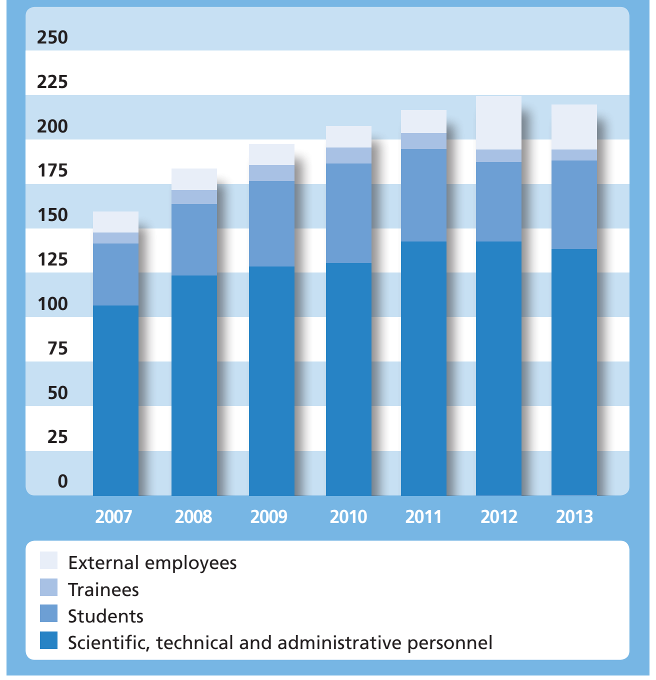
Structure of acquired funds 2007 to 2013 (in millions)



Operating budget

The operating budget of Fraunhofer IPM was 15.3 million euros in 2013 and hence 1.6 million euros higher than in 2012. The operating budget is made up of revenues from industry, publicly financed projects and the basic funding. Of this figure the proportion of external funding consisting of external public funds and revenues from industry amounts to 72.2 percent or 11.1million euros (Fig. left). Revenues from industry at 6.5 million euros account for 42.6 percent of the operating budget. This represents a remarkable increase on the previous year (35.3 percent or 4.8 million euros).

Personnel development 2007 to 2013



Personnel

The number of employees has barely changed in comparison with the previous year. A total of 136 employees are scientific, technical and administrative personel, of whom 13 are at the Kaiserslautern location. Some 54 students as well as school and college leavers work at the Institute, of whom 46 are students on various degree courses, while 8 are apprentices, on work experience schemes or hold posts as assistants. Approximately 25 external employees are also engaged at Fraunhofer IPM (Fig. left). In percentages, the employees are spread across three basic categories: roughly 50 percent of employees work as research assistants, 35 percent as engineers and technical staff and 15 percent are employees in the field of infrastructure and workshops.

IDEALLY CONNECTED

Fraunhofer IPM enjoys excellent connections through associated chairs with the local universities in Freiburg and Kaiserslautern. We are therefore in direct contact with basic research and have access to the latest research findings. A total of some 45 post-doctoral researchers, postgraduates and Master students are engaged at the university departments.

University of Freiburg
Department of Microsystems Engineering – IMTEK

Laboratory for Optical Systems
Prof. Dr. Karsten Buse
Main areas of research are nonlinear optical materials and whispering gallery resonators. One aim is to miniaturize optical parametric oscillators. An optics colloquium has been founded together with other university optics groups and »Photonics« is now offered as a specialization option within the Master's course in Microsystems Engineering. Group manager Dr. Ingo Breunig supervises the research work.

Laboratory for Gas Sensors
Prof. Dr. Jürgen Wöllenstein
The laboratory develops gas-sensitive materials, sensors and sensor systems. At the focus of the research are miniaturized, energy-saving gas measuring systems.

Campus of the Technical Faculty of the University of Freiburg.

Technical University of Kaiserslautern
Faculty of Physics

Administrative building of the Technical University of Kaiserslautern.

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.

Chair Ultrafast Photonics and Terahertz Physics
Prof. Dr. René Beigang
Work focuses on procedures for producing and detecting THz radiation, terahertz time-domain spectroscopy and applications of terahertz technology.

Our Advisory Board

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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 – Association for Sensor Technology
- Arbeitskreis Prozessanalytik der Dechema
- Biovalley
- BBA – Batterie- und Brennstoffzellenallianz BW
- CAST – Competence Center for Applied Security
- Cluster Green City Freiburg
- CNA – Center for Transportations & Logistics Neuer Adler e.V.
- DGZfP – German Society for Non-Destructive Texting
- DPG – Deutsche Physikalische Gesellschaft
- DTG – German Thermoelectric Society
- DTZ – Deutsches Terahertz-Zentrum e.V.
- FAIM IMTEK – Forum Angewandte Informatik und Mikrosystemtechnik
- GDCh – Gesellschaft Deutscher Chemiker
- LRBW – Forum Luft- und Raumfahrt BW
- MSTBW – Mikrosystemtechnik BW
- Optence e.V.
- Photonics BW
- SPECTARIS – German Hightech Industry Association
- VDI OPTAM Optical Analysis Technology
- VDI/VDE – Gesellschaft für Mess- und Automatisierungstechnik
- VDMA German Engineering Federation – Photovoltaic Means of Production; E-Battery
- VDSI – Verband Deutscher Sicherheitsingenieure

International
- 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 Optical Engineering

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BUSINESS UNIT
PRODUCTION CONTROL

TOPICS

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

EXPERTISE

- Imaging fluorescence measurement techniques
- Imaging 3D-techniques
- Digital holography
- Inline microscopy
- Rapid image processing

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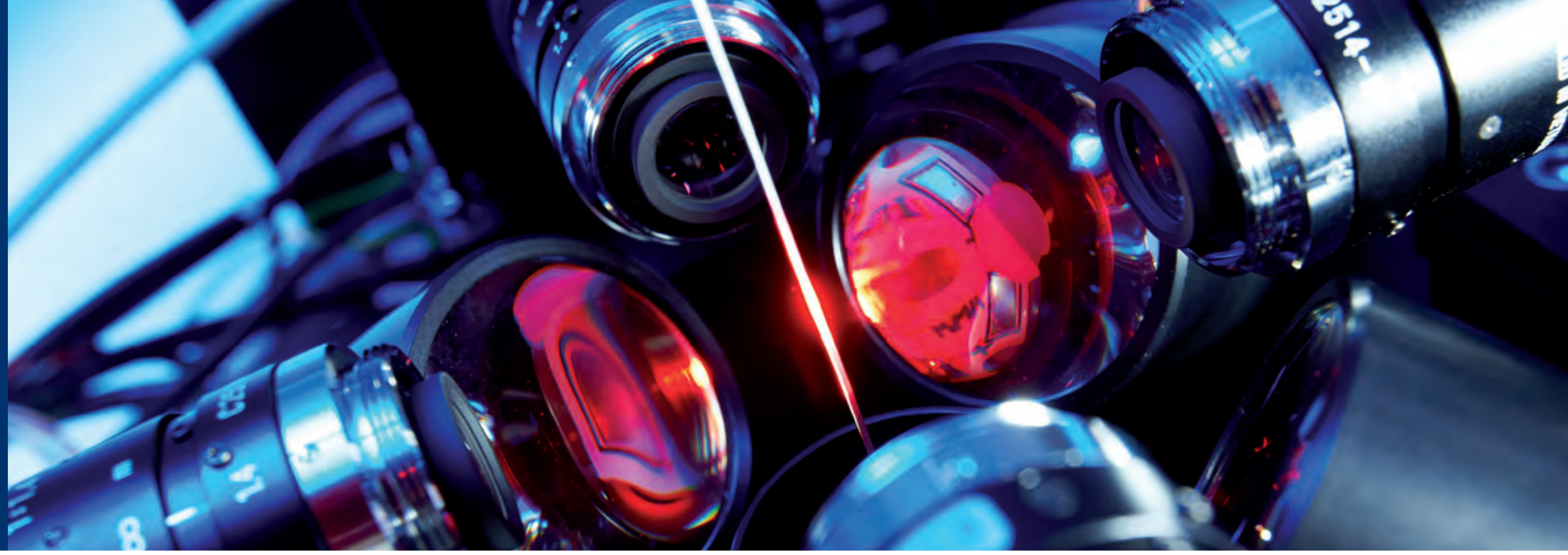


PRODUCTION CONTROL

»We measure as fast as you produce«

Dr. Heinrich Höfler

Fraunhofer IPM develops optical systems and imaging techniques that enable surfaces and 3D structures to be analyzed in production and processes to be controlled. The systems measure fast and accurately so that small defects or impurities can be detected even at high production speeds. This makes 100 percent inspection possible in production. A wide variety of methods are employed, which include digital holography, infrared reflection and fluorescence techniques combined with very fast hardware-related image and data processing. The systems are used in applications such as forming technology and the automotive sector.

Inline Measurement Techniques

Work in the group concentrates on measuring systems that provide evaluated data in real time – e.g. for regulating sensitive manufacturing processes. This is achieved by combining optical measurement techniques with extremely fast evaluation procedures.

Optical Surface Analysis

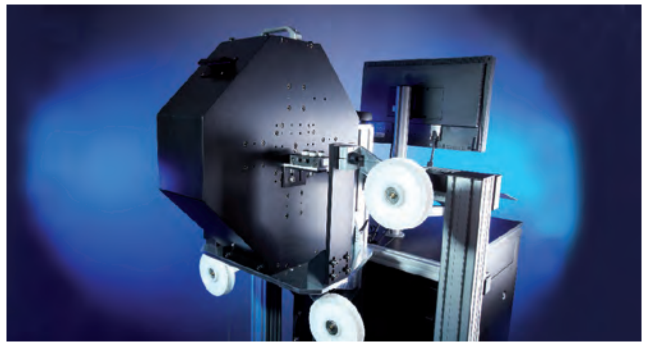
Work in the group focuses on the development of turnkey devices for surface analysis. The methods employed are amongst others fluorescence measuring technology as well as infrared spectroscopy. The group's extensive experience in systems engineering encompasses know-how in optical units, image recording and processing.

INLINE MEASUREMENT TECHNIQUES

WIRES WITHOUT FLAWS: DOCUMENTED QUALITY IN REAL TIME

Wire is used in a wide range of areas – in the automotive industry, in mechanical engineering and in telecommunications. Often it has to meet precise specifications in these applications. This is because even the tiniest error on a small piece of the metal is able to cause major damage in vehicles or machines. The WIRE-AOI imaging surface inspection system makes it possible to detect such defects or damage during the actual production process and thus avoid scrap and additional costs.

Defects on the surface of the wire are by no means scarce: during the industrial production of wire, a rolled metal rod is drawn through tapered openings of draw plates at speeds of many meters per minute. During this process, they are subjected to extreme wear. As a result, damage to the surface of the wire such as ridges, grooves or chatter marks may occur. The structural size of these defects varies within the range of some millimeters down to 100 micrometers. Yet even the tiniest surface defects can sometimes cause major problems in downstream production stages – or possibly lead to the failure of complex assemblies.



Whether made of steel or copper, whether conical or cylindrical: WIRE-AOI ensures 100 percent wire quality by detecting even the smallest surface defects during the actual production.

With WIRE-AOI, Fraunhofer IPM is supplying an inspection system suitable for production which inspects wire surfaces at drawing speeds of up to 600 m/min and is even able to detect minute flaws in real time. Previous image processing systems fail in performing complete detection of these microdefects on the fast-moving wire surface. In contrast, WIRE-AOI detects flaws reliably thanks to the pixel-parallel image processing inside the camera and extremely powerful pulsed LED lighting. The centerpiece of the system, the cellular neural network (CNN) camera, enables real time processing of up to 10,000 frames per second. The exposure time, and hence the limit for focused images, is approximately 5 µs. This is equivalent to more than one million lines per second.

One special challenge involves adapting such a sophisticated measuring technique to the specific production environment. Whether the wires are made of steel, aluminum or copper, coated or bare, cylindrical or conical – WIRE-AOI detects even the smallest surface defects in all types of wire, classifies them and documents them in a database. The customers themselves are then able to determine which defect should trigger actions such as a production stop. Using WIRE-AOI thus solves a wide range of inspection assignments on strip products such as wires, pipes and profiles.

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OPTICAL SURFACE ANALYSIS

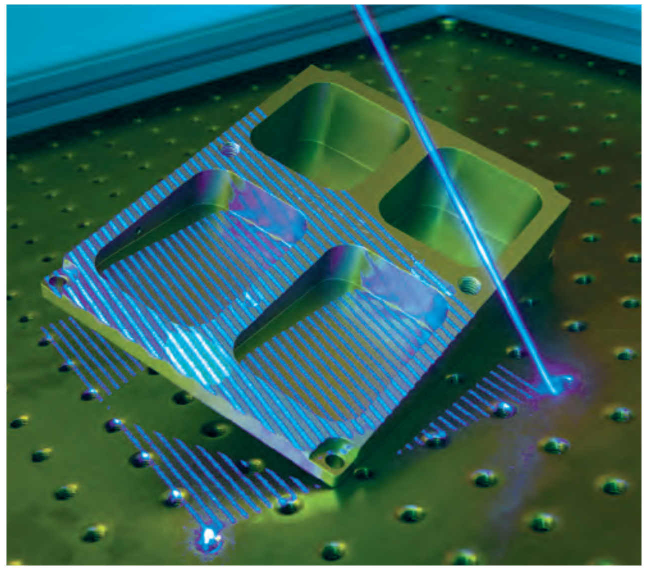
CLEAN COMPONENTS: PURITY TESTING WITH LASER SCANNERS

There is one thing that young children soon discover during their first attempts at handicrafts: if they try to glue together two parts that are dusty or dirty, they will fall apart instantly. The production of components in engineering, the automotive industry or medical technology also calls for »clean« working: components that undergo cementing at a later stage, in particular, can often not be properly connected when there is contamination on the surface – this is because only clean surfaces can be permanently coated, electrically bonded or joined.

Fraunhofer IPM has developed an imaging fluorescence detection system for industrial surface inspection. With a high level of sensitivity, the system detects organic contaminants such as oils, greases and silicones by exciting their autofluorescence with suitable UV wavelengths. Residues of cleaning agents can also be readily detected with this system. Within an extremely short time, the fluorescence measuring system determines the shape, position and quantity of the contaminant. During the process, the imaging enables precise recognition of the »problem areas« directly on the workpiece. The detection limits depend on the substance to be detected. In the case of strongly fluorescent media such as machine oils, even slight traces of impurities can be detected on the surface.

Using a laser scanner makes it possible to localize interfering contaminants on surfaces within the square-meter range. Imaging fluorescence detection was previously only able to capture small areas. The size restriction of the maximum inspectable surface was a result of the illumination with LEDs and the parallel detection of the entire surface area with the aid of a CCD camera. Now, in order to inspect larger areas, a scanning system has been constructed for the first time: the beam of a UV laser is deflected with the aid of mirrors across a scanning range of +/- 20°. At a distance of 60 cm from the surface under inspection, it is thus possible to examine components on an area of 50 cm x 50 cm. The fluorescence induced on the surface is then detected. A software package compiles the data thus gathered from the individual measuring points to form an image of the surface. This image then undergoes further processing so that, for example, areas of high intensity – i.e. with greater contamination – are automatically recognized and evaluated.

Thanks to the use of this novel scanning technique, it is not only possible to examine flat components (sheets) but also those with complex geometries such as gear wheels or body shell parts.



Autofluorescence reveals contaminants imperceptible to the human eye. A laser scanner renders them visible – now on large areas, too.

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BUSINESS UNIT
MATERIALS CHARACTERIZATION AND TESTING

TOPICS

- Non-destructive materials testing
- Measurement of layer thickness
- Chemical analysis (pharmaceuticals, hazardous substances)
- Safety applications

EXPERTISE

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

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MATERIALS CHARACTERIZATION AND TESTING

»Using terahertz technology, we can identify explosives in letters«

Prof. Dr. Georg von Freymann

Fraunhofer IPM develops measuring systems that work with terahertz and microwaves suitable for practical application in the characterization and testing of materials. In doing so, our scientists make use of their skills in the technology of optical systems and measurement, spectroscopy and the development of crystal and semiconductor components. Terahertz or microwave measurement techniques are an interesting alternative to ultrasound measurements when no mechanical contact is possible or allowed, but also to X-ray measurements when ionizing radiation raises problems. Using the measurement systems developed by Fraunhofer IPM it is possible to characterize materials through packaging and thus find concealed drugs or explosives. In materials testing, it is possible to detect defects in ceramics, plastics or also glass-fiber reinforced composites by non-destructive means. There is particular interest in measuring the thickness of layers, e.g. in coating processes or also in the production of pharmaceutical tablets. Through our terahertz know-how, we are in a position to characterize the behavior of materials in rapidly changing fields, which, for example, is of relevance for electro-optical modulators.

Industrial Terahertz Measurement Techniques

Work in the group concentrates on the development of industrial terahertz systems according to customer requirements for the non-contact or non-destructive testing of objects or the spectroscopic identification of chemical substances.

Terahertz Opto-Electronics

The group develops measuring technology for ultra-fast electronics extending into the terahertz frequency range, e.g. for characterizing electronic super-high frequency circuits. Extremely fast electro-optical converters are combined with ultra-fast optical systems.

INDUSTRIAL TERAHERTZ MEASUREMENT TECHNIQUES

LAYER BY LAYER: NON-DESTRUCTIVE MULTI-LAYER ANALYSIS

The legend of the Silver Arrow: according to the tale, the eponymous Mercedes racing car was once found to be too heavy ahead of a competition. Without further ado, the mechanics scraped off the white paint in a cloak-and-dagger operation in order to achieve the prescribed weight. All that could be seen at the end was the bare aluminum sheeting: thus was the Silver Arrow born. And eighty years later the subject of weight reduction still plays a major role in automobile construction and aviation. If too much paint is applied when the vehicles are being coated, the excess paint layers may have an adverse effect by adding unwanted weight. Early inspection is therefore extremely important if production is to be efficient and conserve resources.

Terahertz waves are able to measure the thickness of each individual paint layer during the actual paint process, without making contact, non-destructively and independent of substrate. Faults are detected during the process and the painting plant can be regulated so that no superfluous paint is applied.

It had hitherto not been possible to measure individual, thin layers of paint or lacquer on non-metallic substrates such as carbon-fiber reinforced plastics reliably and thus avoid faults at an early stage. Conventional devices for measuring paint thickness, which work for example with an eddy-current technique, are only able to measure the overall thickness of all paint layers on a component and can only do so on metals. With terahertz measuring technology, Fraunhofer IPM is for the first time using a method that permits reliable measurement of layer thickness even in multicoat paint finishes – and does so not only on metals but also on plastics and composites, such as those which are increasingly being used in automobile construction.

Terahertz waves, which lie between infrared light and microwaves in the spectrum, are partially reflected at boundary surfaces, where there is a step in the refractive index. Measuring the differences in time delay of the reflected partial waves allows the respective layer thickness to be determined. In contrast to X-rays, terahertz waves are not ionizing and hence give no rise to health concerns. Special radiation protection is not required.

Terahertz waves enable layer thicknesses to be measured without making contact, non-destructively and independently of substrate.

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TERAHERTZ OPTO-ELECTRONICS

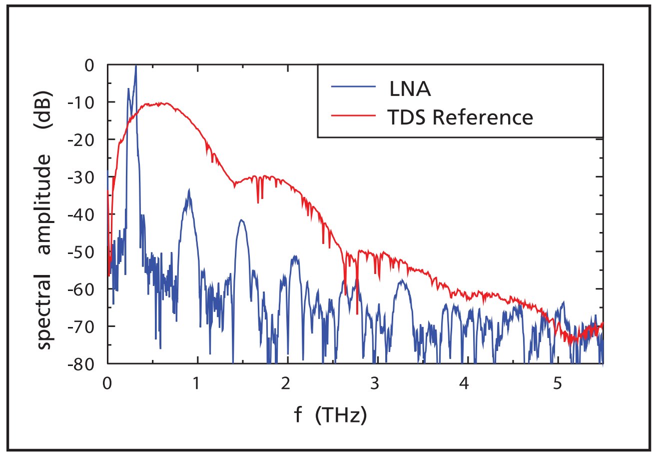
MEASURING DEVICE WITH POTENTIAL: NETWORK ANALYSIS WITH TERAHERTZ WAVES

For decades engineers and scientists involved in the development of high-frequency electronics have repeatedly been pushing against the boundaries of what is feasible. Their aim here is always the same: better and more efficient systems for communications technology. With the terahertz network analyzer »Tera-VNA«, Fraunhofer IPM now aims to give electronics engineers space for new developments.

In order to dimension and calculate electronic systems to the optimum, electronics engineers need data that are reliable and as exact as possible on what are called scattering parameters (S-parameters). These S-parameters describe the behavior of linear electric parts, components and networks by means of wave dimensions. Hitherto, these values had been measured with network analyzers in the frequency domain. However, electronic components now work with such high frequencies that conventional network analyzers are running up against their limits. With the development of the »Tera-VNA«, Fraunhofer IPM is doubling the achievable frequency range.

The »Tera-VNA« no longer measures the desired S-parameters in the frequency domain but in the time domain. The researchers rely on terahertz time-domain spectroscopy (THz-TDS) for this measuring assignment. This has three benefits: compared with commercial network analyzers costs decrease by a factor of about five. Furthermore, in the case of the »Tera-VNA«, only the waveguide modules or scanning heads have to be exchanged for different frequency bands, whereas in the case of electronic network analyzers several devices are often necessary for different frequency bands. Finally, the terahertz network analyzer »Tera-VNA« is also able to measure at much higher frequencies than are possible with today's commercial network analyzers. This opens up new opportunities.

Now, for the first time, researchers and developers in industry and science are able to analyze the S-parameters of high-frequency systems from 100 GHz to more than 2 THz. Here the number of required S-parameters depends on the number of gates in the network and results from the square of the number of gates. A high-frequency amplifier with one input and output can, for example, be described completely with the aid of four S-parameters: The values measured are the input and output reflection factors together with forward and backward transmission factors. The »Tera-VNA« will be used for the first time even in the extremely high-frequency components currently being developed to capture all four S-parameter with measurement technology.



Thanks to terahertz time-domain spectroscopy, the »Tera-VNA« opens up a wide spectral range – from 0.1 to well in excess of 2 THz – for measurement technology, illustrated here by an H-band LNA (low-noise amplifier).

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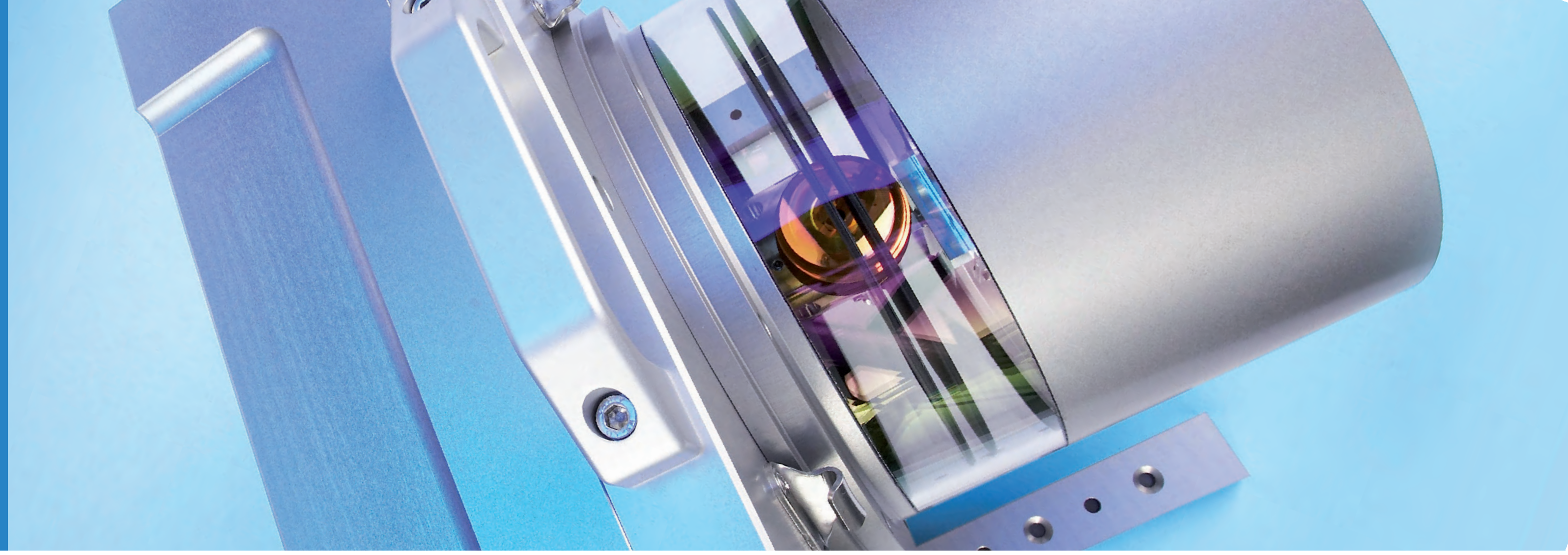
BUSINESS UNIT
OBJECT AND SHAPE DETECTION



TOPICS

- Transport and logistics
- 3D measurement of trains and railway tracks
- Examination of road surfaces
- Safety applications

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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OBJECT AND SHAPE DETECTION

»We specialize in mobile laser scanning – even at high speed«

Dr. Heinrich Höfler

Laser scanners together with customized lighting and camera systems that capture the geometry and position of objects three-dimensionally in their surroundings are the focus in the Business Unit for Object and Shape Detection. The systems measure at high speed and with high precision, particularly from moving platforms. Particular attention is attached to the robustness and long service life of the systems as well as to efficient data evaluation. Objects and shapes are detected over a broad size range: extending from tenths of a millimeter to dimensions of 10 meters. The measurement systems are in use around the world – in rail traffic and in the surveying of road surfaces. Supplementing them are special applications in the fields of safety as well as transport and logistics.

Laser Scanning

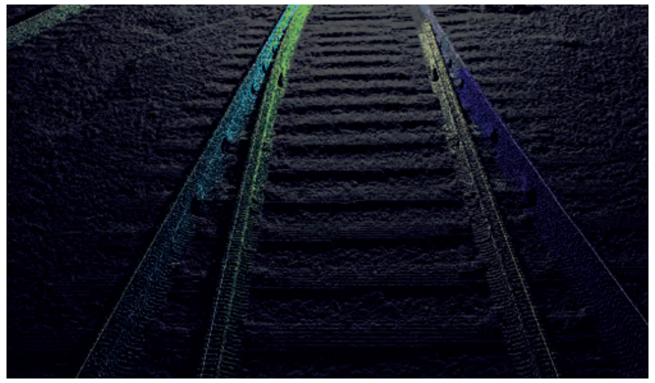
The group focuses on developing optical measurement systems based on time-delay measurements of light, which enable the distance and geometry of objects to be measured at high speed and with great precision. The systems developed are employed worldwide and in a variety of applications.

LASER SCANNING

WHAT IS IN THE POINT CLOUD? NEW ALGORITHMS DETECT MORE

Maintaining the transport infrastructure within Germany costs several billion euros every year. Yet this sector is chronically underfinanced. The result is road damage, decaying railway bridges and speed restrictions within the rail network. Automation techniques are increasingly being used for maintenance on railway routes. They enable costs to be reduced without jeopardizing traffic safety in any way. »Intelligent vehicles« equipped with 3D laser scanners record the surroundings at high resolution and describe it in a form known as 3D point clouds. Algorithms with the highest possible degree of automation enable damage to the track infrastructure to be detected automatically from these 3D images.

Fraunhofer IPM has developed a novel software system for the field of rail infrastructure to recognize railroad switches and tracks that uses high-resolution point clouds. The aim is to detect components of railroad switches from 3D laser scanning data and to determine the approach and diverging directions at railroad switches. Various detectors have been developed for the system: in addition to the rail detector, devices are also being employed for the detection of both track and frogs. The most important of these – the rail detector – uses a large number of attributes in order to describe and recognize rails. In addition to geometry and topology of the rails, examples of these attributes also include occluding edges. In order to recognize these edges in point clouds with greatly varying distances, a separate edge detector with adaptive thresholds has been developed.



Laser scanners deliver measurement data with increasing accuracy: new algorithms enable more information to be gleaned from them – e.g. on railroad switches or tracks.

Previous approaches generally used only primitive attributes to describe rails, e.g. the typical difference in height between the upper and lower edges of the rail. These approaches usually exhibit a high error rate. In contrast, the rail detectors developed by Fraunhofer IPM use a significantly higher number of descriptive attributes, which is one reason for the lower error rate. They are even able to recognize adjacent tracks.

In addition to the large number of detectable parameters, the selected approach opens up opportunities for optimizing capacity utilization in rail traffic: one conceivable option, for example, would be to determine the current position of moving trains with the aid of the 3D data. To this end, regular trains could be equipped with simple scanners; correlation of the point cloud generated with the previously recorded highly accurate 3D data for the rail network would enable the train to be localized precisely. Positioning by means of GPS is only possible to a limited extent in rail traffic due to the large number of tunnels. Furthermore, GPS requires sophisticated post-processing, a step that can be elegantly avoided in this way.

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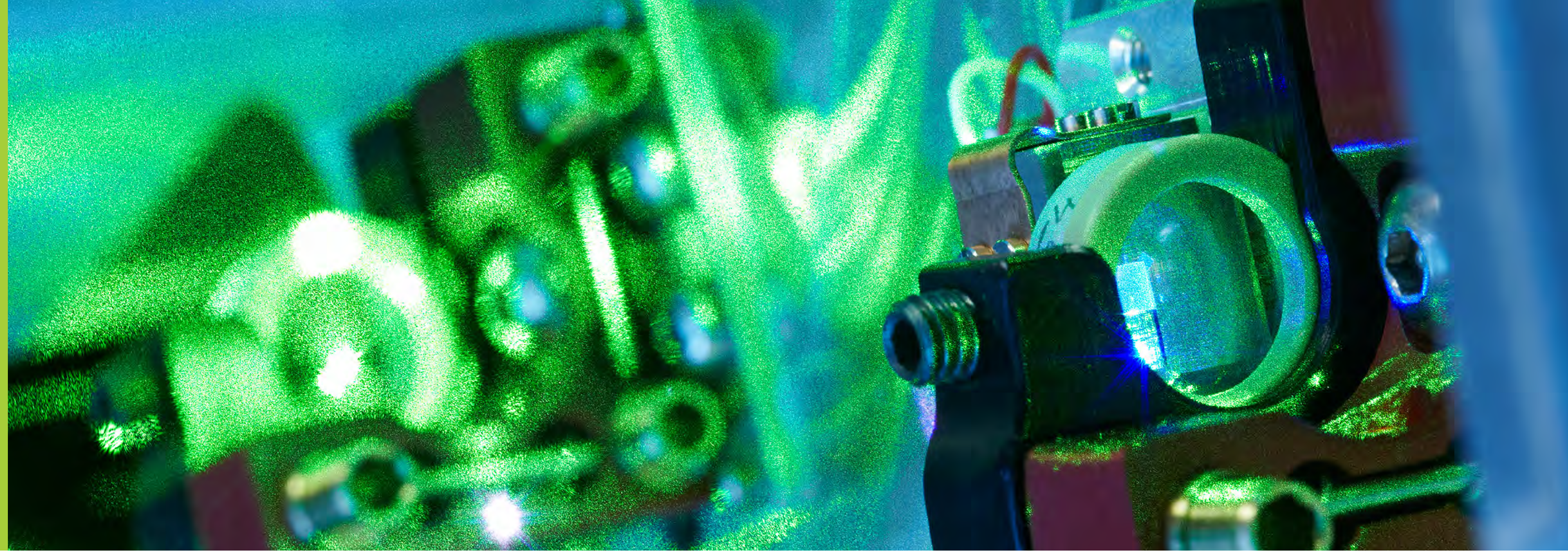
BUSINESS UNIT
GAS AND PROCESS TECHNOLOGY



TOPICS

- Gas analysis
- Particle measurement techniques
- »Food chain management«

EXPERTISE

- Spectroscopy from EUV to MIR
- Gas sensor technology
- Robust integrated systems
- Light source development

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GAS AND PROCESS TECHNOLOGY

»We measure outside what others can only measure in the laboratory«

Dr. Armin Lambrecht

In the Gas and Process Technology business unit, Fraunhofer IPM produces measurement and control systems to customer specific requirements. Short measuring times, high precision and reliability are the distinguishing characteristics of these systems – even under extreme conditions. The expertise includes laser spectroscopic procedures for gas analysis, energy-efficient gas sensors, particle measuring techniques for the analysis of fine dust, process measuring techniques and the characterization of laser materials. The bandwidth of applications broad and among those already implemented are instruments for exhaust gas analysis, sensor networks for monitoring the food transport chain, EUV spectrometers for measurements in the ionosphere, systems for the in-situ measurement of wear on tools and optical parametric oscillators as a tunable laser light source.

Integrated Sensor Systems

The focus of the group is on the development, conceptual design, characterization and manufacture of functional surfaces, miniaturized gas sensors and compact gas measurement systems. Gas sensor technology and electronics have been combined in compact and economical microsystems for this purpose.

Technology of Optical Materials

The focus of the group is on investigating the optical properties of solids and liquids by means of innovative spectroscopic procedures, examples include photothermal and photoacoustic methods. Years of experience in handling non-linear optical materials make it possible to construct efficient optical systems.

Spectroscopy and Process Analytics

Activities in the group center on the development of spectroscopic systems for the detection and analysis of gases, liquids and solids. In this field, the group makes use of its long-established experience in exhaust gas and particle measurement technology.

INTEGRATED SENSOR SYSTEMS

GAS SENSORS ON A ROLL: RAPID DETECTION OF FIRE GASES

Every year in Germany, more than 200,000 fires are reported. Conventional fire warning devices generally only detect smoke particles and have drawbacks as a result: they often trigger false alarms such as when someone is cooking and harmless steam is generated. In other cases – which are far more hazardous – they do not react to toxic gases.

However, early recognition of these generally odorless gases by reliable fire gas alarms is extremely important for effective fire protection. The detection of carbon monoxide and nitrogen dioxide, in particular, is crucial in this connection. Both gases are very toxic and inhalation can lead to death in humans within a few minutes.

Small, colorimetric and cost-effective: gas sensors, produced in a roll-to-roll process, measure toxic fire gases such as carbon dioxide and nitrogen dioxide.

Fraunhofer IPM has developed two colorimetric, low-power gas sensors for fire prevention, which are based on the principle of color change. A dye combined with a polymer reacts in contact with the target gas and changes color in the process. This color change correlates with the gas concentration. The sensor used to recognize the carbon monoxide is based on a binuclear rhodium complex, while chinonime color dye tetramethyle phenylene diamine is used for NO_2 detection. Deployment of a waveguide enables the gas reaction to be read out optically. As soon as a color change can be measured, an acoustic fire alarm is triggered.

The simple structure of the newly developed gas sensors means that they can be manufactured with a specially developed roll-to-roll technique. The molded interconnected devices (MIDs) are clipped into carrier plates and connected to form a roll of 15 m in length. All components can be produced by means of continuous injection molding. On the roll, the sensors pass through all the process steps consecutively, such as laser structuring, galvanization and SMD mounting of the electronic components.

The waveguide is clipped onto the carrier in a backend process. Thanks to this cost-effective production technique, the sensors are able to compete on price terms with conventional scattered light alarms – but simultaneously measure hazardous gases as well as smoke particles.

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SPECTROSCOPY AND PROCESS ANALYTICS

ULTRASOUND IN MUD: UNDERGROUND WEAR MEASUREMENT

Water, sludge, rock: machines used in mining or tunneling work under extreme conditions. The level of wear in such a harsh environment is high, and the materials have to be correspondingly robust. Here it is very important to recognize any damage incurred or malfunctions on important components in good time so as not to jeopardize either process or safety.

Fraunhofer IPM has developed a system of distance measuring technology in difficult environments based on robust ultrasonic sensors. They can be used to record the level of wear down to the nearest millimeter on parts such as drive shafts or cutting surfaces of tunnel-boring machines even in suspensions of sludge or bentonite. Data recording and evaluation – electronics and software – have been specially developed for the monitoring of critical components in liquid media. The current measuring ranges already lie between 70 and 350 millimeters, with a resolution of approximately 0.2 mm.

Ultrasonic measuring technology is especially suitable for use in difficult environments because it functions without making contact. This makes it attractive for measurements in liquid media such as drilling muds and suspensions. Consequently, ultrasonic measuring technology is already used successfully in pipeline engineering or in measuring the verticality of boreholes. Fraunhofer IPM has been able to demonstrate convincingly that it is also capable of measuring reliably under extreme conditions.

High demands are placed on the respective ultrasonic sensors in harsh environments: they have to remain functional even in sludge solutions containing rock. Tunneling applications, in particular, require a very robust structure for the sensor: it therefore has to withstand temperatures of up to 60 degrees and a high working pressure of up to 15 bar. Added to this are abrasive conditions, strong vibrations and pressure fluctuations. Using the ultrasonic measuring system developed by Fraunhofer IPM it is possible to identify defects in the millimeter range on important components reliable and without making contact. And all of this can be performed under adverse conditions. It thus enables processes to be designed with greater safety and efficiency, which is especially important in major construction sites for tunneling and mining.

Measuring precisely even under difficult conditions – that is the strength of the systems developed by Fraunhofer IPM for the contact-free inspection of important components in mining and tunneling.

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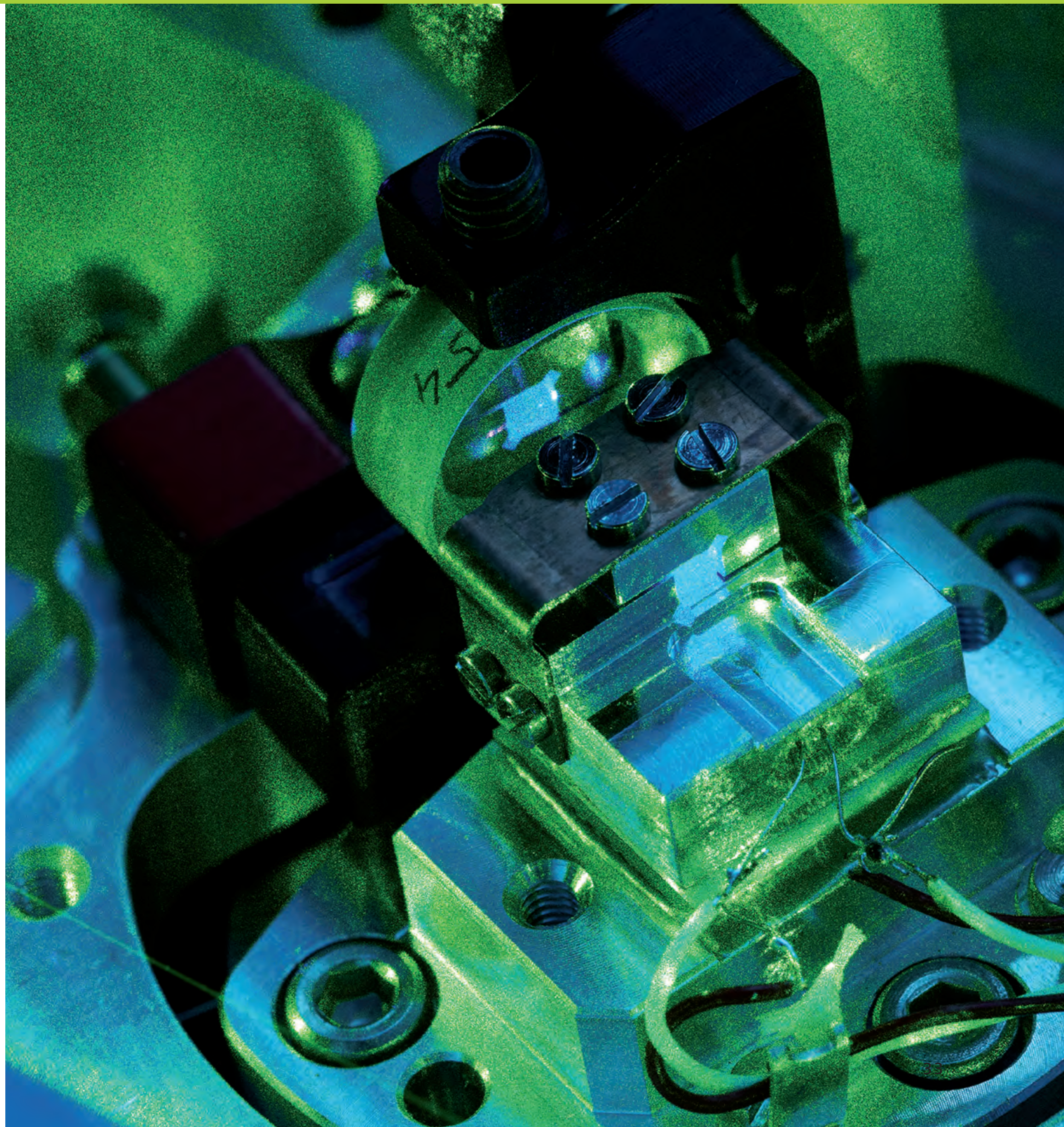
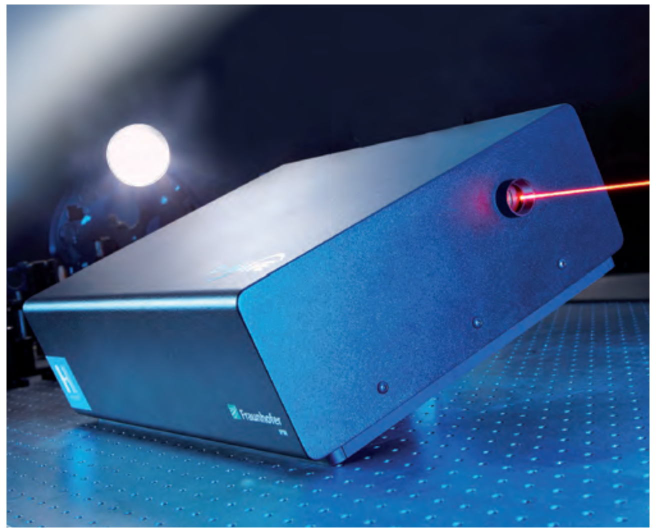
In an optically non-linear crystal, the light from a pump laser is converted into two new light waves. In this optical parametric process it is possible to generate light of any wavelength.



TECHNOLOGY OF OPTICAL MATERIALS

LASER LIGHT FROM BLUE TO RED: WAVELENGTHS AT THE TOUCH OF A BUTTON

»Light at the touch of a button« – something taken for granted by the average consumer turns out to be unduly complicated for science. Laser light as the key tool in photonics has to fulfill certain requirements according to the application. In spectroscopy, for example, the emission wavelength should change in a controlled manner, hence be capable of being tuned. As is desired of every tool, the handling should be as straightforward as possible. Scientists from Fraunhofer IPM and the Laboratory for Optical Systems at the University of Freiburg have now come a great deal closer to meeting this aim: on behalf of the Kassel-based company HÜBNER GmbH & Co. KG, they have developed the optical parametric oscillator »C-Wave« – a light source that for the first time emits continuous-wave laser light over the entire visible range of the spectrum, and does so at the touch of a button.



»C-Wave« is the first laser light source that generates continuous light over the entire visible spectral range, without the inconvenience of changing dyes.

Optical parametric oscillators (OPOs) are broadly tunable light sources with many different applications. In an optically non-linear crystal, the light from a pump laser is converted into two new light waves. In this optical parametric process it is in principle possible to generate light over very broad wavelength ranges, starting from a single laser wavelength. Until now, only pulsed OPOs have been available for the visible spectral range. However, some applications in precision spectroscopy, atomic physics or quantum optics demand continuous-wave laser light that has a very narrow spectral linewidth. Corresponding continuous wave light sources have hitherto only been available for limited wavelength ranges; one example here is the titanium-sapphire laser, which primarily covers the near-infrared spectrum. As a one-box light source generating continuous wave light across the entire visible spectral range, »C-Wave« now closes this gap.

This has practical benefits in applications: in spectroscopy, atoms and molecules exhibit characteristic absorption lines in different frequency ranges. Previously, only dye lasers were able to cover a substantial part of the entire visible spectral range in continuous wave operation. The individual dyes produce wavelengths in frequency ranges of typically 20 to 50 nm, which makes a frequent change of dye necessary. »C-Wave« does away with this tiresome »pit stop« – and hence also eliminates the risks associated with the inconvenience of handling the often toxic chemicals.

By the way: the flexibility of the »C-Wave« concept in terms of wavelength, performance and tuning modes was also able to convince the jury of the Photonics Prism Award. »C-Wave« received the prestigious award at Photonics West 2014 in California.

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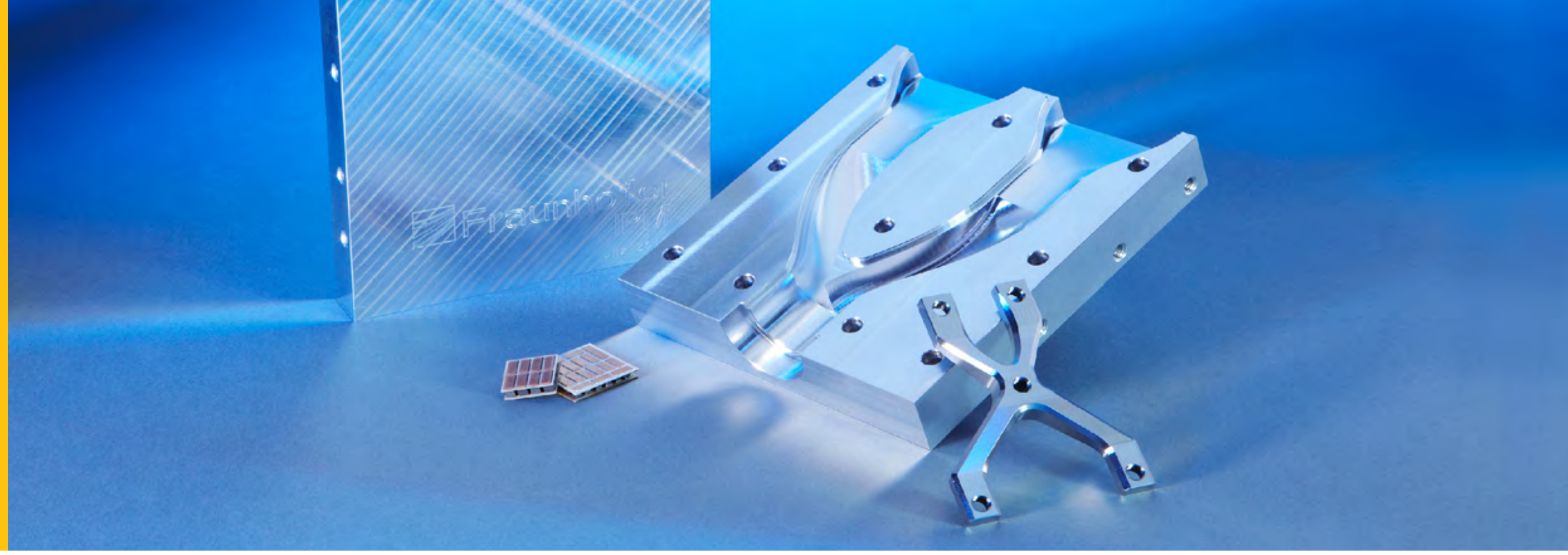
BUSINESS UNIT
ENERGY SYSTEMS



TOPICS

- Converting heat into electrical current
- Metrological systems
- Energy-autarkic sensor technology and wireless sensor networks
- Magneto caloric cooling

EXPERTISE

- Material synthesis and optimization
- Thin-film technology
- Development of thermoelectric modules and converters
- System design, integration and optimization

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ENERGY SYSTEMS

»Higher energy efficiency is only possible with smart use of surplus heat«

Dr. Kilian Bartholomé

Converting lost heat energy into electricity – this is what Fraunhofer IPM achieves with the aid of thermoelectrics: in future thermoelectric »energy harvesting« will play a key role in making more efficient use of energy. Here, the future range of applications for thermoelectric energy converters extends from the microwatt range for operating energy-autarkic sensor systems to the kilowatt range for exploiting waste heat in motor vehicles, combined heat and power stations and large-scale industrial plants.

Fraunhofer IPM has been conducting research for more than 15 years in order to integrate the technology of thermoelectrics into energy systems fit for the future. Today the research activities encompass materials research, the development of thermoelectric modules, their simulation and thermoelectric measurement techniques. The aim is to raise conversion efficiency as well as to develop materials and modules with long-term stability and environmentally friendly production processes. For applications, we design and implement systems in which thermoelectric generators can be integrated with optimum effect into complex plants.

Energy Autarkic Systems and Thermoelectric Measurement

Work in the group centers on the development of metrological systems for characterizing thermoelectric raw materials, modules and entire systems. It also includes the design of Sensor systems that supply themselves with energy.

Thermoelectric Energy Converters

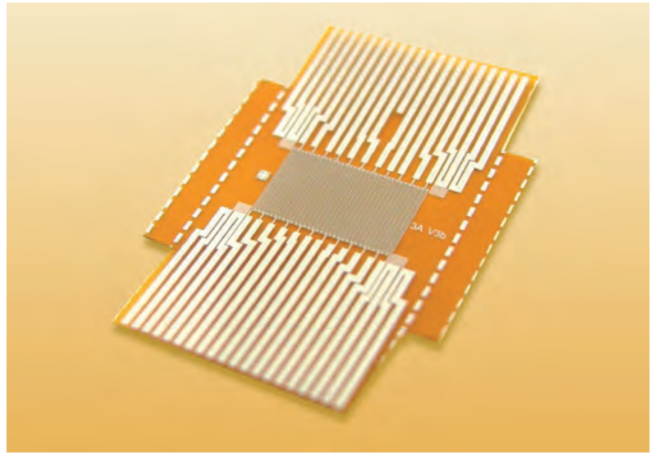
The focus of the group is on »energy harvesting«. In order to convert heat into electricity, the group is developing more efficient thermoelectric materials, modules and systems and optimizing production methods for converters.

ENERGY AUTARKIC SYSTEMS AND THERMOELECTRIC METROLOGY

MEASURING FLEXIBLY: SENSORS ON FLEXIBLE CARRIER MATERIALS

The new flexibility in sensor technology applies in two ways: sensors of the new generation should be adaptable, which concerns the measuring task, and capable of bending. Fraunhofer IPM works in different projects on the development of electronic sensors on flexible substrates such as Kapton or PET film. These »measuring tapes« are fundamentally capable of determining a large bandwidth of physical variables: from simple temperature measurements, via the measurement of electrical or thermal conductivity and heat capacity, to the determination of parameters such as the Seebeck coefficient or radiation intensity.

A mechanically flexible calorimeter chip has been created for biological and chemical applications to measure the heat capacity of liquids. It can be integrated into microfluidics systems. For this purpose an extremely sensitive temperature difference sensor made of bismuth telluride has been deposited and connected on a Kapton substrate. Due to its low thermal conductivity, the mini-calorimeter achieves a high degree of sensitivity. The chip with a size of not even 10 mm × 10 mm is produced using thin-film technology on a 4-inch substrate. The result is an economically priced sensor designed as a disposable product and intended above all to be used for screening measurements in lab-on-chip techniques. The measuring resolution of 15 mV/K can be increased drastically even with the same chip size. In combination with an absorber, the calorimeter can be used as a radiometer. At room temperature, for example, it is therefore possible to measure the increase in chip temperature brought on by the heat radiated from a hand.



Flexible sensors facilitate measurements on curved surfaces and are flexible in terms of the measuring tasks.

Another flexible sensor chip has been designed specially for the rapid measurement of thermoelectric materials. Without complex sample preparation, the chip determines the thermal and electrical conductivity as well as the Seebeck coefficients simultaneously; it is merely necessary for the surface of the sample to be sufficiently smooth. With this technique it is possible to determine the thermoelectric quality of the material – a crucial measure for the efficiency of thermoelectric modules – faster than has previously been the case in the screening procedures. In order to carry out the measurement, the flexible »sensor tape« is pressed onto the surface of the material with a plastic stamp and thus adapts to the contours of the sample. The latter should be flat but does not have to be level. The measuring structure of the chips is applied to a Kapton film in a wafer-based thin-layer procedure.

Fundamentally, the chip design can also be used for the characterization of liquids. By simply being immersed in a liquid, an »electronic tongue« of this kind is able to measure many parameters such as thermal conductivity, heat capacity, pH value and flow rate.

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THERMOELECTRIC ENERGY CONVERTERS

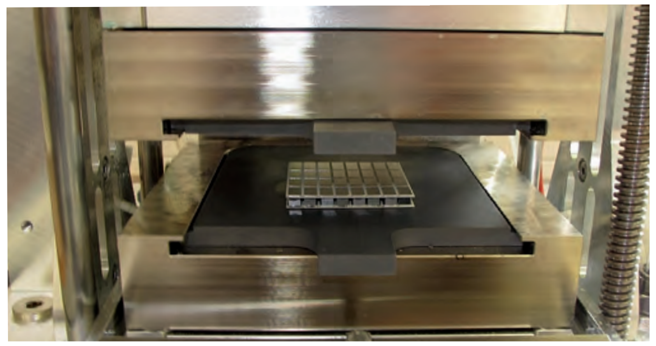
READY FOR CONTACT: HIGH-TECH AT THE SOLDERING STATION

Electrical and thermal contacts play a decisive role in the performance and long-term stability of electronic components. Fraunhofer IPM has acquired outstanding expertise in this field over the past decades. Examples can be seen in the bonding technologies developed at the Institute for a wide range of materials, such as silicides or special alloys such as chalcogenides or half-Heusler alloys based on Ni-Sn-Ti, which are used above all in the thermoelectric conversion of waste heat into electrical current.

Thermoelectrics places extreme demands on electrical and thermal contacts because – when these contacts are used in automobiles for example – they are subjected to very rapid temperature changes. Due to the complex design of thermoelectric generators, the contacts additionally require a particularly sturdy structure. The generators consist of various ceramic-metal semiconductor connections with a wide range of thermal expansion coefficients, which, with an overall height of a few millimeters in the application, are exposed to a large temperature gradient. Furthermore, the contact material must not »poison« the thermoelectric semiconductor material by diffusion and adversely affect the thermoelectric properties as a result.

Various bonding techniques and contact materials together with special analytical methods have been developed in order to meet all these requirements. Two bonding methods have proven to be especially successful: in the sheet or module soldering method, the heat is introduced over a large area from two sides for the soldering operation and subject to a regulated pressure for a precise time period. Melting of the solder is monitored and this permits selective control of the soldering operation. In the spot jointing technique, areas smaller than 10 mm × 10 mm can be heated up very quickly to create a bond. This method is not only suitable for soldered joints but also for diffusion welding, because here the heat can be applied with great spatial precision for a variable period ranging from milliseconds to minutes.

Success has thus been achieved in developing mechanically and thermally cyclically stable contacts with low electrical contact resistances between semiconductors and metals and to construct new kinds of thermoelectric generators.



In module soldering, the heat for the soldering operation is applied over a large area from two sides.

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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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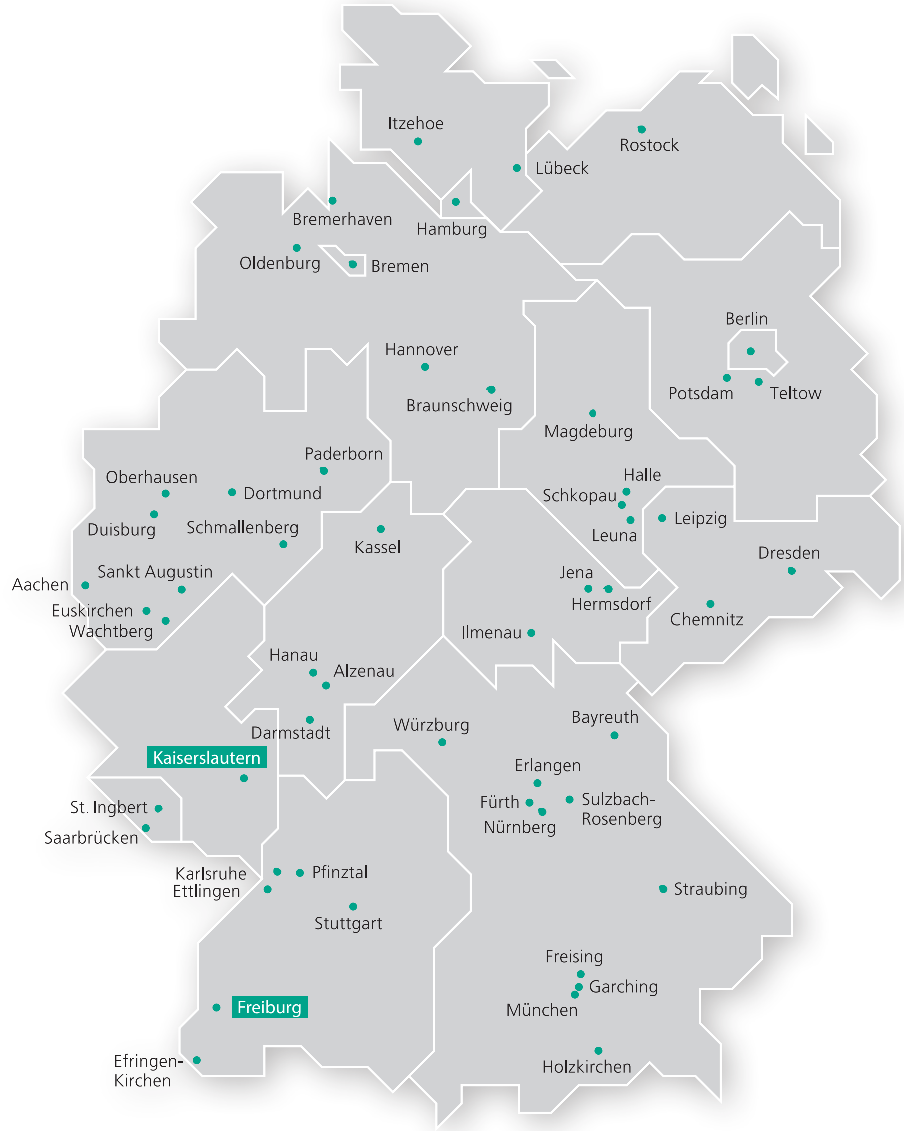

IEEE Microwave Theory and Techniques Society; Fraunhofer-Institut für Physikalische Messtechnik IPM, Freiburg/Brsg.
38th International Conference on Infrared, Millimeter and Terahertz Waves, IRMMW-THz 2013: Mainz, Germany, 1 - 6 September 2013

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Beer, Sebastian:
Development of a selective electrostatic sampling system for detection of trace explosives and illicit drugs.

Kießling, Jens:
Nichtlinear-optische Erzeugung von Dauerstrich-Terahertzwellen

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Beiträge zur Aufklärung des Einbaus von Titan in PbTe und (Pb,Ge)Te in Bezug auf einer Optimierung der thermoelektrischen Gütezahl ZT

Waasem, Niklas:
Photoakustische Absorptionsspektroskopie an hochtransparenten optischen Materialien

FRAUNHOFER IPM AT TRADE FAIRS...

- **Leading trade fair for energy – HANNOVER MESSE** Hannover
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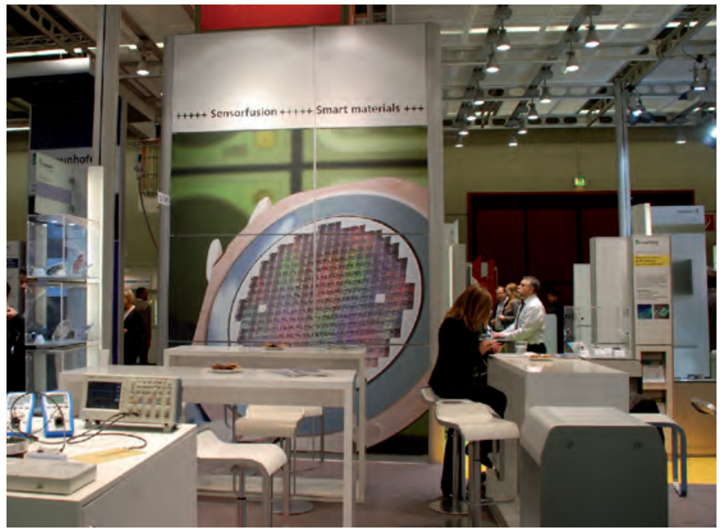

... AND AT CONFERENCES AND WORKSHOPS

- **Sensorik für erneuerbare Energien und Energieeffizienz (Sensor technology for renewable energies and energy efficiency)** Berlin
  Organizers: AMA Fachverband für Sensorik e.V. (Association for sensor and measurement) and the Renewable Energy Research Association (FVEE)
- **Schnelle Strahlablenkung für Laseranwendungen (Rapid beam deflection for laser application)** Nuremberg
  Organizer: bayern photonics e. V. and Bayerisches Laserzentrum GmbH
- **E-MRS Spring Meeting** Strasbourg, France
  Organizer: European Materials Research Society (E-MRS)
- **Fraunhofer Vision Technology Day** Munich
  Organizer: Fraunhofer Vision Alliance
- **Inspection and characterization of surfaces with image processing** Karlsruhe
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- **Freiburg Science Market of the University of Freiburg**
  Organizers: University of Freiburg / Freiburg Wirtschaft Touristik und Messe

ORGANIZED BY FRAUNHOFER IPM:

- Gas Sensor Workshop 2013 – Intelligent technologies for gas measuring technology
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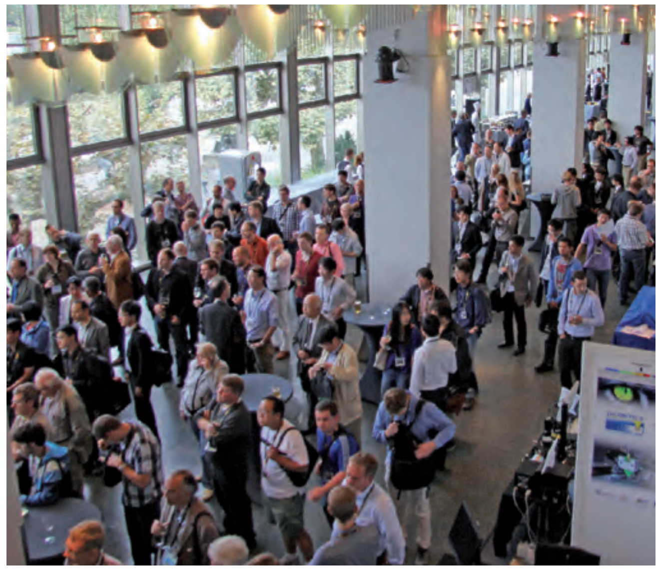

Top: Inquisitive visitors at the Freiburg Science Market. All five Fraunhofer institutes used this occasion to present hands on science.
Bottom: The »38th International Conference on Infrared, Millimeter and Terahertz Waves« organized by Fraunhofer IPM in Mainz was directed towards a specialist public.

EDITORIAL NOTES

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