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1/18 special issue

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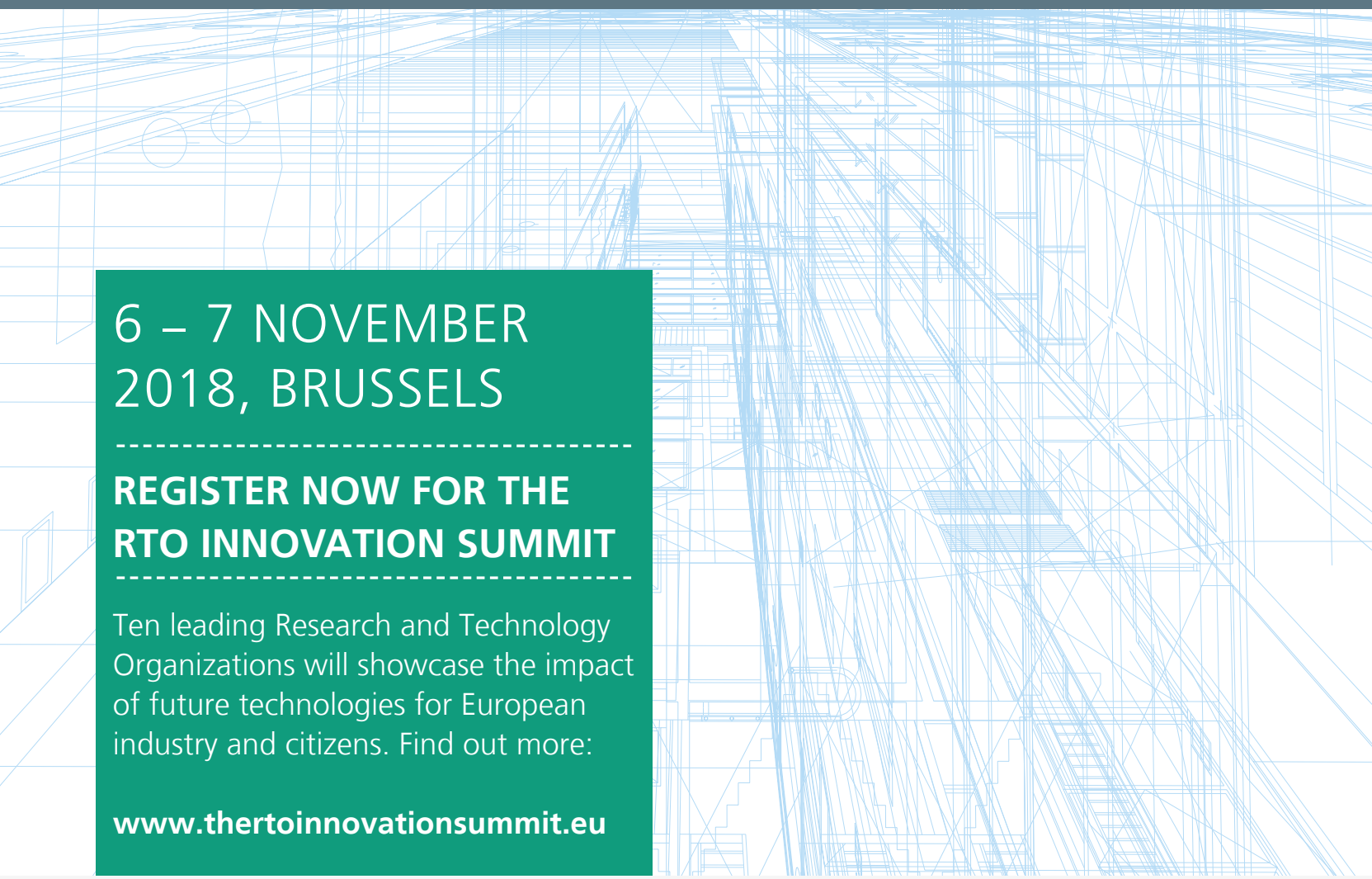

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Breaking new ground

Prof. Reimund Neugebauer
© Fraunhofer/Bernhard Huber

In Germany, healthcare expenditure is rising faster than the OECD average, and healthcare costs continue to grow faster than GDP. Although this causes a cost burden, it also opens up a market for cost-effective solutions. According to Germany's Federal Statistical Office, the threshold of one billion euros per day in healthcare expenditure was exceeded for the first time in 2016. The figures are based on a comparison of countries conducted by the OECD in 2017. This is where Fraunhofer researchers come in. Collaborating in interdisciplinary teams, they develop efficient solutions and work to translate research results into medical applications and therapies as quickly and efficiently as possible. Up until now, it has often taken decades to turn the results of basic research into new medicines and pharmaceutical production methods. The bottleneck in this process is the step from lab research to clinical testing, in other words the gap between the discovery of new active ingredients and the development of corresponding drugs by the pharmaceutical industry.

As a specialist at the interface between research and industry, Fraunhofer has a broad array of technologies at its disposal. Out of a total of 72 Fraunhofer Institutes, 45 are active in healthcare research, addressing the four major areas of biomedical science – drugs, diagnostics, devices and data, or the 4 Ds. You can find out more about this in the lead article (starting on page 8).

In the competitive international research marketplace, Fraunhofer is a highly sought-after partner. The guiding principle of our partnerships is to create scientific value for Fraunhofer and generate positive effects for Germany, Europe and the partner country in question. This has given rise to a complex network of direct commissions, consortium projects, strategic partnerships and Fraunhofer subsidiaries. Ultimately, the international dimension of our research is a crucial factor in qualifying Fraunhofer employees for demanding tasks in both the global economy and the globalized world of science. Fraunhofer's high level of international revenue underscores its success on the international stage. Last year, the organization's revenue from projects with international customers and partners amounted to 311 million euros.

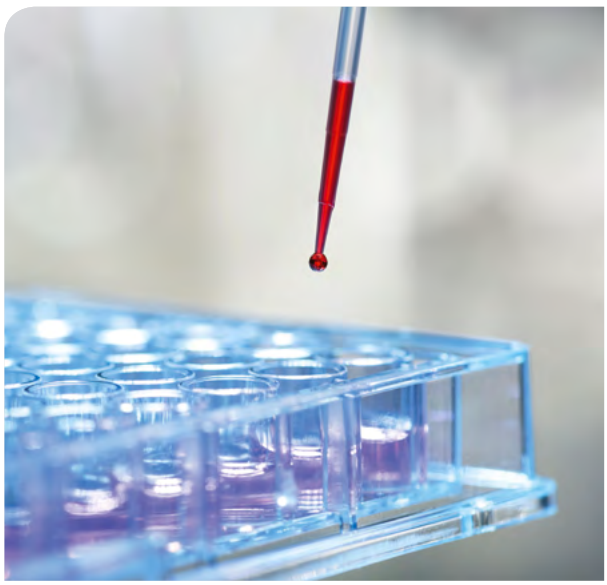
The use of biotechnology in the medical field, in manufacturing and in agriculture offers considerable potential for value creation and sustainability. One of the articles in this issue of our magazine showcases the EU-sponsored SteamBio project, in which wood, a renewable raw material, replaces fossil fuels as feedstock for the production of valuable chemicals (see page 22).

Nature provides the blueprint for many of our innovations. Fraunhofer is driving the Biological Transformation by making increasing use of natural resources and principles in technical systems. Information technology enables us to model complex biological processes and structures at the molecular level. The result is nanostructured materials, for example, or therapeutics that are tailored to each patient. This approach to research encourages a new way of thinking, one that aims for a holistic, balanced interplay of processes and material streams. Today, many processes are organized with the goal of obtaining maximum output from minimum input. That can have negative consequences: in intensive agriculture, for instance, which depletes the soil of nutrients and makes it unusable for future crops. Nature, on the other hand, teaches us that it is better to optimize a system so as to establish a stable equilibrium, rather than trying to maximize the output of individual processes. We believe the Biological Transformation will have as profound an effect on the economy and on society as the digital transformation.

I hope you enjoy reading this issue of our magazine.

Sincerely,

Reimund Neugebauer
President of the Fraunhofer-Gesellschaft



Content

Smart glass for stopping break-ins

Jewelry shops, art galleries and banks have windows that are fitted with special safety glass and connected to alarms for protection. The disadvantage of this setup is that the glass pane, or at least part of it, has to shatter to trigger the alarm. A new alarm system developed by researchers at the Fraunhofer Institute for Technological Trend Analysis INT and the Fraunhofer Institute for Photonic Microsystems IPMS, however, can detect any attempted manipulation of the window before the glass breaks.

The system registers changes in temperature as well as shocks to the glass in real time – leaving burglars without a chance. All it takes to set off the alarm is a light tap on the safety glass or manipulation with a flame. Any attempted assault on the glass changes its mechanical properties which the new system immediately registers, activating the alarm. A demonstrator of the new break-in protection system has now been completed.

Conventional safety glass has to shatter to trigger the alarm. © *iStock*

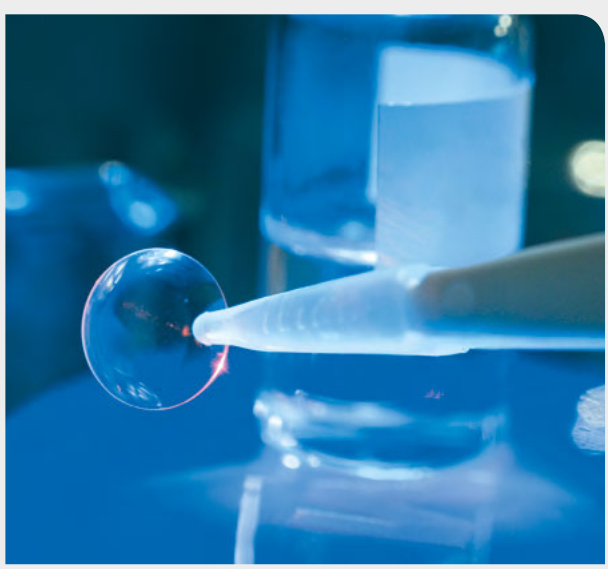
Curative contact lenses

Infections of the cornea are one of the main causes of reduced visual acuity all over the world. In fact, the World Health Organization (WHO) attributes a quarter of all cases of blindness to corneal clouding. This condition is often caused by microbial keratitis – inflammation of the cornea triggered by bacterial or fungal pathogens or acanthamoeba.

Ophthalmologists' biggest cause for concern is acanthamoeba keratitis because in this form the disease rarely responds to the drugs available on the market today. Current forms of treatment can have severe side effects and may damage the cornea.

Researchers at the Fraunhofer Institute for Applied Polymer Research IAP are now taking a new approach to the issue: contact lenses with antibacterial properties. Initial laboratory tests of this potential alternative have shown promising results.

Antibacterial contact lenses could be the key to fighting acanthamoebic infection in the eye. © *Fraunhofer IAP*



Printing high-tech car parts in 3D

At the begining of the year, Gemany's former Laser Zentrum Nord became part of the Fraunhofer-Gesellschaft as the Fraunhofer Institute for Additive Manufacturing Technologies IAPT. One of its showcase projects, developed in partnership with Bugatti Engineering GmbH, is a 3D-printed titanium brake caliper.

Due to the very high strength of titanium, it was previously difficult or even impossible to mill and machine such a component from a single block. Fraunhofer IAPT was able to solve this problem with its powerful 3D printer.

The titanium caliper is 41 cm long, 21 cm wide, 13.6 cm high and weighs only 2.9 kg – over 40 % less than the currently used aluminum caliper while at the same time offering an even greater load-bearing capacity. In-vehicle tests to verify the potential of the part for large-scale production are set to begin this year.

This 3D-printed brake caliper will be tested for use in the Bugatti Chiron. © *Bugatti Automobiles S.A.S.*

A box on wheels for industry-oriented social networking

In addition to working side by side in the future, humans and machines are set to share information and communicate with each other via social networks. Now, experts at the Fraunhofer Institute for Material Flow and Logistics IML have developed the first truly interactive driverless transportation solution for industry-oriented social networking of this nature.

At first glance, Emili – the ergonomic, mobile and interactive transporter for intralogistics applications – looks like a small box on wheels. This autonomous transportation device, however, has some unusual features. Thanks to wearable technology, it can be controlled, summoned and dismissed by human gestures. Logistics personnel wear smart armbands containing tiny computer systems that wirelessly transmit the gesture-controlled information to Emili. Alternatively, smartphones, tablets or smart glasses can be used to give her instructions. Emili is even able to communicate. A smiley on her energy-saving display indicates that everything in the warehouse is how it should be.

If required, this interactive driverless transportation device can double up as a container. Emili's outer dimensions are exactly the same as a small load carrier, meaning she can be easily stacked and integrated into any conventional small parts warehouse system.

Smart load carrier Emili follows the instructions given by her inventor, Jana Jost. © *Fraunhofer IML*

Health Research in 4D

Testing new drugs in clinics, searching for specific biomarkers, developing sentient prostheses, brainstorming concepts for secure data management – health-related research certainly comes in many guises. The research efforts of 45 of 72 Fraunhofer Institutes address four major areas of medical science – drugs, diagnostics, devices and data, or the 4 Ds for short. The authors visited four research teams on the cutting edge of translational medicine, where fundamental research is ushered out of the lab and into the world.

Text: Christine Broll and Frank Grotelüschen (data)

No less than 45 of the 72 Fraunhofer Institutes work in fields of interest to the four key areas of medical science – drugs, diagnostics, devices and data, or the 4 Ds for short.
© iStock, Vierthaler & Braun

Dr. Nadine Schneider (right) and her team in the Fraunhofer Translational Medicine branch of IME are working on an innovative vaccine for rheumatoid arthritis. *All pictures on this page © Bernd Müller*

Bottom: Drugs formulated in clinical trials are manufactured individually and described with painstaking precision.

Top: Dr. Jochen Graff regularly draws blood from subjects during clinical trials to gauge how the body responds to the new drug.

Left: Immune cells from the blood of patients with rheumatoid arthritis get the once-over under a microscope.

Drugs

Sabine Schuster* is slightly nervous as she steps into the clinical study ward run by Fraunhofer IME's division of Translational Medicine and Pharmacology TPM on the campus of Frankfurt am Main's University Hospital. She has never taken part in a drug trial before. As Dr. Jochen Graff, head of the ward, shows Sabine to her room, he explains the strict rules applied by the drug regulatory agencies to ensure trials are standardized.

"You'll be spending the next two days in our ward with meals and beverages served at set times. You're not allowed to eat anything else. No cigarettes or alcohol either. That would falsify the results," says Jochen Graff.

This trial intends to test a new drug for hereditary angioedema (HAE), a rare disease that has plagued Sabine Schuster since childhood. Her skin and internal organs are beset by recurrent swelling. A swollen larynx can be life-threatening; in fact, it is often fatal. Medication is available to manage acute seizures, but this new prophylactic drug aims to prevent these attacks from occurring in the first place. The Fraunhofer institute branch works closely with Frankfurt University Hospital's HAE outpatient unit to conduct clinical trials.

Strict protocol for taking blood samples

The trial starts the next morning. Research assistant Gudrun Schneckenburger inserts a needle into the vein of Sabine Schuster's left hand and connects it to the ECG and blood pressure monitor. Clinical investigator Dr. Graff then administers a pill; this medication in the form of a tablet containing the new drug.

The research assistant takes blood samples every 15 minutes during the first hour after the tablet is ingested; then every half hour and later every hour. "In the blood samples, we measure what the body does with the drug; how it is absorbed, distributed, broken down and excreted. We call this process pharmacokinetics," says Jochen Graff by way of explanation. These readings give scientists insight into the fate of new drug. They also serve to determine doses and dosing intervals for subsequent clinical trials, where the drug has to substantiate its ability to reduce the frequency of seizures in patients with HAE. The researchers assess many different parameters and biomarkers in the blood to identify side effects. Every step of the study is spelled out in a trial protocol that is subject to the approval of the regulatory authorities and an ethics committee.

Innovative study designs

All phases of early clinical drug development take place on the Fraunhofer group's ward. This includes phase 1, where the new drug is first administered to humans, and phase 2 with selected patients. All phase 1 studies apart from anticancer drug trials have to be conducted with healthy subjects. There is more to these early phases than merely investigating pharmacokinetics and calculating dosages; they also serve to test the active ingredient's safety.

Dr. Frank Behrens, who heads up the group's clinical research, points out the limitations of this approach: "What can a 22-year-old healthy student's tolerance and metabolism tell me about a drug that I later want to administer to a 65-year-old woman who has already had several prior diseases?" This is why Frank Behrens and his team of scientists from diverse disciplines are developing innovative study designs to test new active ingredients on real patients rather than on healthy subjects. He works closely with medical specialists on the Frankfurt University Hospital campus to select drugs and conduct special tests to prove their effectiveness. The Frankfurt group, which is a branch of the Fraunhofer Institute for Molecular Biology and Applied Ecology IME, has been busy helping set up the LOEWE Research Center for Translational Medicine and Pharmacology funded by the state of Hessen. Its partners are the University of Frankfurt and the Max Planck Institute for Heart and Lung Research in Bad Nauheim. This organization's mission is to expedite the transition of medical research findings from the test bench to the bedside. Physicians who divide their time between the clinic and the project group play an important role in this respect. "Researching physicians bring problems from the patient's bedside straight to our lab," emphasizes Prof. Gerd Geisslinger, head of the Fraunhofer IME branch and the LOEWE Center.

From the lab to the clinic

The aidCURE project shows how R&D contributes throughout the value chain in Frankfurt. Determined to develop an active ingredient to treat rheumatoid arthritis in a joint effort with Prof. Rikard Holmdahl of Stockholm's Karolinska Institute, Prof. Harald Burkhardt spent years conducting fundamental research at the university. The agent being developed is a type of vaccine that targets and switches off the mechanism that triggers pathogenic autoimmune reactions.

Fraunhofer IME-TMP is translating this basic research into applied science under the auspices of Dr. Nadine Schneider. "We are now looking for a way to economically produce the complex protein molecule on an industrial scale," reports Burkhardt. Clinical testing in humans can commence once the team reaches this milestone and wraps up the preclinical safety studies required by law. Dr. Frank Behrens, head of the study, is already drafting the trial protocols.

* Name changed by the editors

Fraunhofer IZI's pipetting robots isolate RNA from tissue samples in search of new biomarkers to diagnose prostate cancer.
© *Fraunhofer IZI*

A therapy's success hinges on the diagnosis – the more accurate the disease's characterization, the more targeted the treatment. Another research team is investigating new diagnostic parameters in a project called RIBULUTION.

Diagnostics

The pipetting robot's tips slowly descend over tiny test tubes containing tissue samples, dripping a solution that dissolves the tissue. The pipettes' tips rise silently as the test tubes shuttle down the line to the next station. A downstream device mixes in reagents, centrifuging and purifying the sample step by step until pure RNA comes to the fore.

RNA is the object of investigation in the RIBULUTION project, which has been underway at Leipzig's Fraunhofer Institute for Cell Therapy and Immunology IZI since 2011. It is funded by the Fraunhofer Future Foundation. RNA's structure is similar to that of DNA. While DNA resides in the cell nucleus and carries genetic information, RNA serves various purposes within the cell. Scientists know a great deal about messenger RNAs that hold the code for protein synthesis. Non-coding RNAs, or ncRNAs, for short, are a more recent discovery. They regulate diverse processes in the cells, which makes them prime candidates for research. The idea is that ncRNAs' profile will indicate if a disease has thrown the regulation of cellular activities out of balance.

Biomarkers for prostate cancer

With this hypothesis in mind, Prof. Friedemann Horn and his team at Fraunhofer IZI began their search for biomarkers to diagnose prostate cancer. The current PSA test is flawed – too many false alarms – so a reliable test is urgently

The electrodes on this arm connect to a control unit that transmits signals to the virtual hand prosthesis visible in the background.
© *Bernd Müller*

As Dmitry Amelin concentrates on the movement of his hand, electrodes measure the muscle impulses that could serve to control a prosthetic hand.
© *Bernd Müller*

needed. "An elevated PSA level usually prompts a biopsy. Over 200,000 prostate biopsies are performed every year in Germany, but the suspected carcinoma is only confirmed in around 67,000 patients," says Horn. So, many of these biopsies are unnecessary.

First the RIBULUTION team isolated all the RNA from tumor samples, benign growths and healthy tissue. A single tissue sample may contain several hundred thousand different molecules. The researchers sequenced and compared molecules, and then tallied the ncRNAs to identify the most frequently occurring types in the given samples.

Other Fraunhofer Institutes and industrial enterprises helped automate the workflow from end to end with pipetting robots to process large quantities of samples, thereby creating the platform technology for RNA analysis.

Automated platform technology

"We have identified around ten ncRNA molecules that are suitable biomarkers. They provide the basis for a test to diagnose prostate cancer in urine," says Friedemann Horn. He expects the drug to be launched in 2020, by which time an ncRNA test should also be available. It will help predict if the prostate carcinoma is aggressive and requires immediate surgery or if it grows so slowly that surgery may be unnecessary.

This automated method can help find new biomarkers for a wide range of diseases relatively quickly. The platform technology is sure to interest pharmaceutical companies that are developing tests to monitor the efficacy of new drugs in clinical trials. Research in diagnostics and therapy is converging. Nowhere do the two mesh as tightly as in theranostic implants that combine therapy and diagnosis in a single

system. The Fraunhofer Institute for Biomedical Engineering IBMT at St. Ingbert is developing this type of implant.

Devices

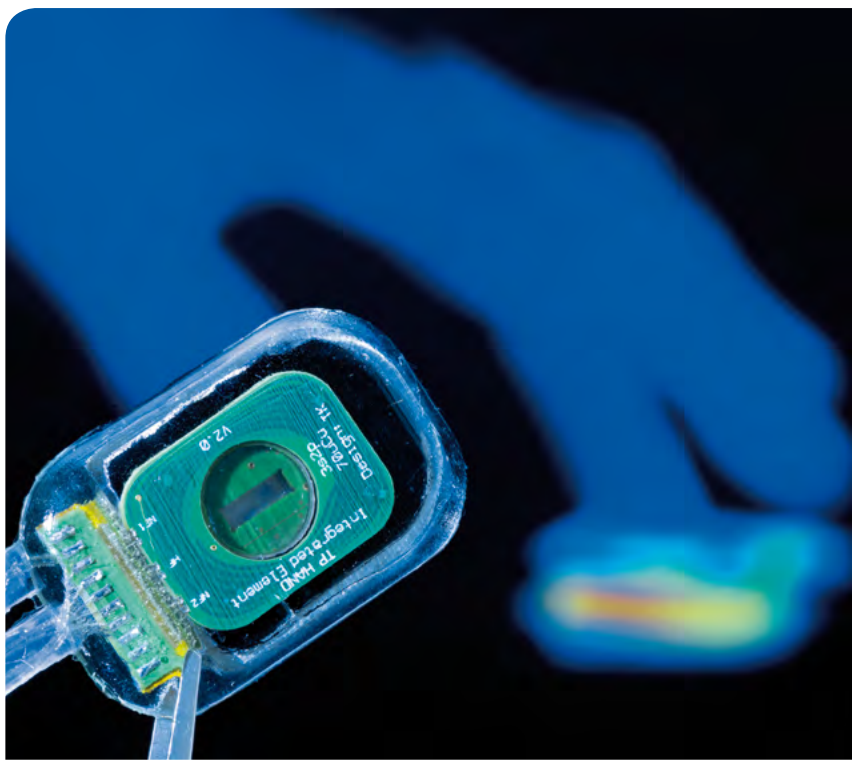
Complex and invasive, theranostatic implants present one of the greatest medical engineering challenges. They must be tested thoroughly at an early turn during the inceptive development phase in the lab. This is a job for Dmitry Amelin, a biomedical engineer at Fraunhofer IBMT. He attaches eight electrodes to his left forearm in preparation for the tests. The electrodes connect to a small box on his desk. Amelin pinches his thumb and index finger together like a pair of tweezers and watches the monitor for the signals that the electrodes are picking up from his muscles. "We are working on the control system for a hand prosthesis. The small box containing all the control circuitry will later be implanted in the patient's forearm stump," explains Amelin.

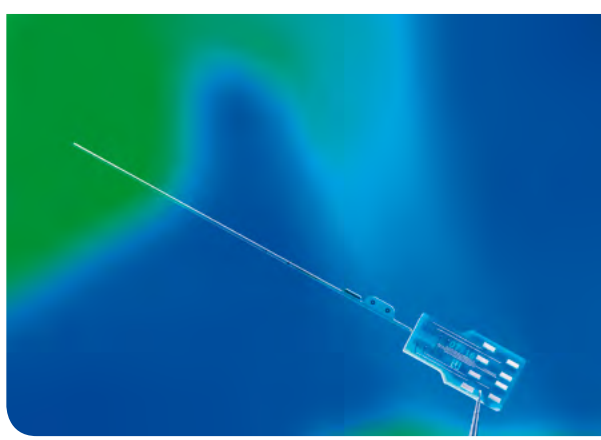
This little box contains a lot more than that – the experience Fraunhofer IBMT gained over decades devoted to building intelligent implants. This know-how encompasses wireless signal and power transmission, mounting and interconnecting technology, and biocompatible encapsulation. As it turns out, developing and producing the electrodes for implants to communicate with the human nervous system is something of an art.

Control through muscle movement

In the lab, the electrodes serving to control the hand prosthesis cleave to the skin's surface over the muscles. They will later be implanted subcutaneously, directly under the amputee's fascia. The software counterpart to the implant's electronic hardware detects the movement pattern and sends the appropriate control signals to the prosthesis, which then also pinches the thumb and index finger together.

This is one direction of communication between human and prosthesis. "What's groundbreaking about our design is that the prosthesis also gives the wearer sensory feedback," explains Prof. Klaus-Peter Hoffmann, head of the Biomedical Technology Department at Fraunhofer IBMT. To this end, the scientists installed sensors in the prosthesis that are then connected to the human nervous system. "We developed double-sided filament electrodes that are as fine as hair and attach directly to the nerve," adds Hoffmann. This should enable the patient to feel the amount of pressure the prosthesis is exerting; that is, the firmness of its grip. And it should be able to do this in real time. It will surely be another ten to fifteen years before this technology makes it out of the lab. But the first preclinical trials are already underway.

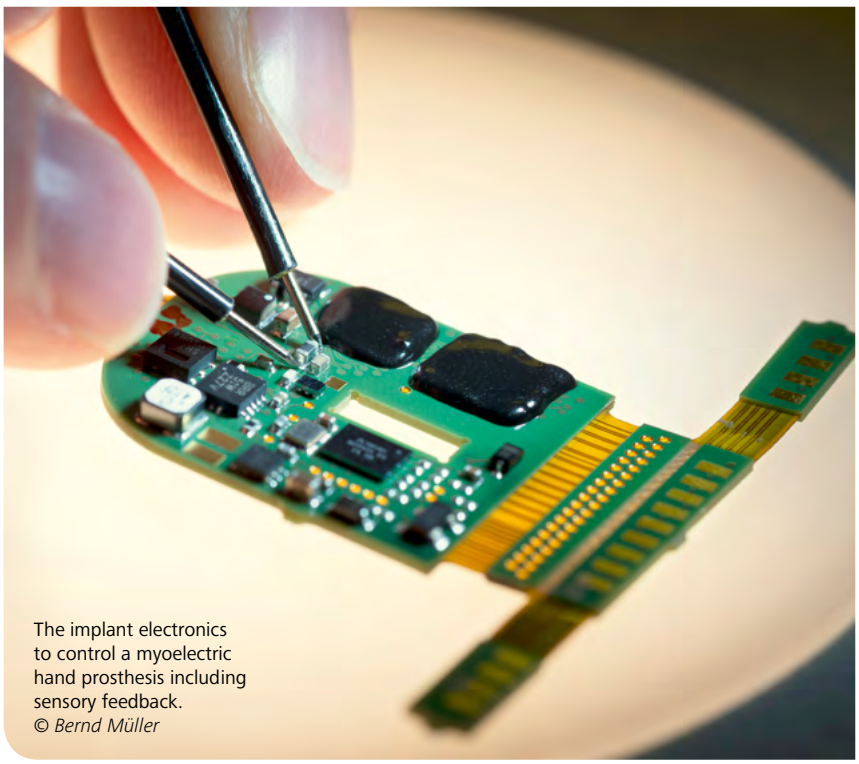




The control unit for the hand prosthesis (pictured at the top) is implanted in the forearm. The prosthesis delivers sensory feedback to the patient via a gossamer filament electrode that attaches to a nerve. *Both pictures © Bernd Müller*

Theranostic Implants, a lighthouse project

Hoffmann's team has been looking into the art of controlling hand prostheses in a host of projects that go all the way back to 2002. Fraunhofer IBMT and twelve other Fraunhofer Institutes have joined forces in a lighthouse project called Theranostic Implants, which has been making remarkable progress. One research group within this lighthouse project succeeded in developing an intelligent hip prosthesis. Its onboard sensors and actuators enable the doctor to monitor the prosthesis's fit and readjust it when necessary. A third



The implant electronics to control a myoelectric hand prosthesis including sensory feedback.
© *Bernd Müller*

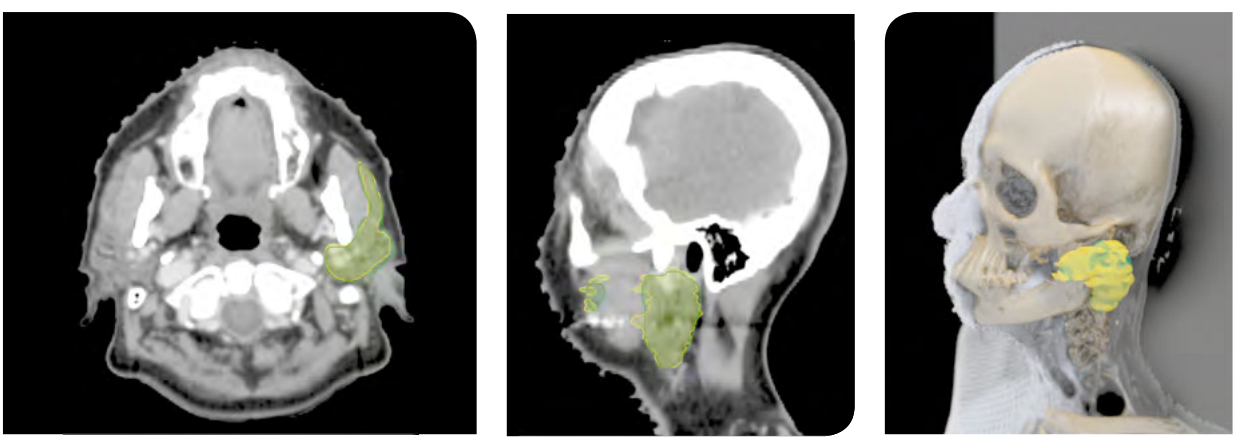
The Medical Data Space – a safe haven for medical data

The medical community collects enormous volumes of data in research labs, in clinics and at health insurance companies. The Fraunhofer-Gesellschaft is developing the Medical Data Space to tap the potential of this precious data pool. It is a place where sensitive medical data can be securely connected.

The Medical Data Space builds on the Industrial Data Space developed by Fraunhofer in a joint effort with industry and government. This space enables industrial enterprises to securely exchange data, while ensuring they retain control over their data.

Patients' privacy is the top priority for the Medical Data Space's designers. As in the Industrial Data Space, data remains in the owners' possession rather than being stored centrally in a cloud. This provides added security.

www.fit.fraunhofer.de/med-data-space

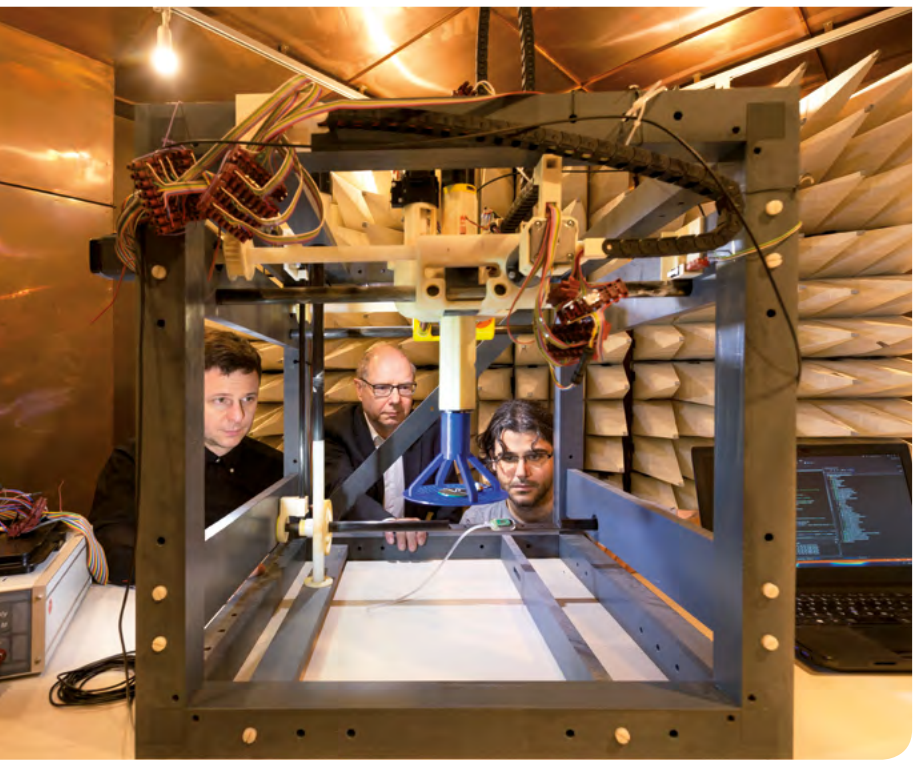


Two lines surround the parotid gland on the CT scan. A doctor drew the yellow line; a learning algorithm computed the green one.
© *Fraunhofer MEVIS*

subproject produced a sensor implant to continuously monitor blood pressure.

The electrodes on the implant that Dmitry Amelin is testing are still connected by way of wires. The next challenge is to develop micro-implants that merge the electrode and implant into one device, thereby eliminating cables and connectors. Of course, synchronized activities require wireless communication between the micro-implants. However, Hoffmann is unwilling to use the usual radio signals to this end for one terrifying reason: "Pacemakers have already been hacked in the USA. Instructions for hacking cochlear implants for the hearing impaired are also circulating on the Internet." This prompted Fraunhofer IBMT to start investigating ultrasound communication for intelligent implants in the newly launched "I-call" project.

Secure transmission and storage of sensitive data is becoming increasingly important. This is why Fraunhofer has joined forces with partners in the healthcare sector to develop the Medical Data Space. An IT platform that dovetails diverse medical data would be a boon to diagnosis and therapy.



Prof. Klaus-Peter Hoffmann (center) and his team are testing wireless signal and power transmission for theranostic implants in a specially isolated room. © *Bernd Müller*

Data

We are in an office at the Fraunhofer Institute for Medical Image Computing MEVIS in Bremen. Dr. Jan Klein bends over the computer and clicks the mouse to call a picture to the screen – a CT image of a human head. "The cerebellum is in the back; the teeth are visible up front. The colored area is the parotid gland," says the computer scientist. These markings help doctors in clinics map out the radiotherapy for head and neck tumors. Physicians want to spare the glands any unnecessary radiation to minimize side effects such as a dry mouth.

The small organ on Jan Klein's screen is bordered by two lines. A doctor drew the yellow line. The green line was calculated by a learning algorithm based on a neural network. Initially trained with 450 reference data sets, it is now learning how to recognize certain structures in images autonomously – and very successfully at that. "As you can see, the two lines are close together. Our program often outperforms doctors because the daily workload in clinics usually leaves physicians pressed for time when they draw these lines," says Klein.

Connecting medical data

This automatic segmentation – that is, the ability to recognize and mark a specific organ in an image – is just a small part of a larger project called QuantMed. Fraunhofer researchers are pursuing this initiative to build the technological foundation for an IT platform that will provide valuable services to medicine. Commenting on its goal, Institute Director Prof. Horst Hahn says: "We are working on digital infrastructure that links diverse medical data. Specifically, we are connecting image data from MR scanners and X-ray machines with other clinical information such as blood counts, genetic data and digitized tissue samples."

Deep-learning algorithms can then comb through these complex, entwined data sets in search of telltale patterns. The results of these analyses support doctors in a number of ways, for example, to help identify cerebral hemorrhages, devise more patient-friendly radiotherapy strategies for tumors, and answer the question of which drug is the most promising option for chemotherapy. A term has been coined for using computers to combine images and clinical data to more accurately predict a therapy's chances of success: experts call it radiomics.

Automatically detecting cerebral hemorrhages

The new technology builds on individual 'knowledge nodes' that can extract valuable information from data sets. "This type of node may be located in a clinic, for example. Our learning algorithms work completely autonomously so that no sensitive patient data is leaked," says Klein.

Nodes can nonetheless exchange information via a computing hub that validates, consolidates and enhances the knowledge sourced from learning algorithms at multiple clinics. "For example, this could help optimize the way cerebral hemorrhages are automatically detected and classified on CT images. It would lighten the workload; rather than performing this time-consuming task manually, the doctor merely has to check the computer's results," explains Klein.

QuantMed kicked off in October 2016. Hospitals, hospital associations, a professional association and businesses are on board. "The first version of the system is ready midway through the project, and now we're going to ramp up test operations. The end result should be a viable infrastructure that enables hospitals and research institutions to routinely extract new knowledge from vast quantities of data," says Hahn.

We visited four teams. Each works on an entirely different project. But they do have one thing in common: they collaborate with experts in other disciplines under the umbrella of the Fraunhofer-Gesellschaft. Doctors, scientists, engineers and computer scientists work together across the boundaries of their chosen fields to make that 4D connection in the Fraunhofer Network. ■

“We can traverse the interfaces in medical research”

Prof. Gerd Geisslinger is the Fraunhofer-Gesellschaft’s Medical Research Officer. In an interview with “Fraunhofer magazine”, he explains why Fraunhofer is in a unique position to tackle challenges in medical research and to pull together the four key areas of biomedicine – drugs, diagnostics, data and devices.

Interview: Christine Broll

Why is the Fraunhofer-Gesellschaft placing such emphasis on medical research?

The continually rising cost of providing healthcare is one of the biggest challenges facing the national economy in the decades to come. In 2016, healthcare expenditure in Germany exceeded one billion euros per day for the first time ever. The German Federal Statistical Office expects these costs to increase by a further five percent or so in 2017. This means that health expenditure is rising much faster than gross domestic product, which will lead to considerable problems for the healthcare system.

How can German society deal with these problems?

Innovations at the intersecting frontiers of scientific disciplines, in particular, are the key to developing groundbreaking and, at the same time, cost-effective healthcare practices. The only way forward is to create new forms of collaboration, which will enable novel ideas to be translated cost-efficiently into concrete applications. And this is the emerging trend that we are currently witnessing in biomedical research: the gradual convergence of what we refer to as the 4 Ds, namely drugs, diagnostics, data and devices. At present, only application-oriented research organizations with a highly interdisciplinary operating structure, such as the Fraunhofer-Gesellschaft, possess the capacity and broad range of technological expertise needed to generate innovative, cost-efficient solutions.

How can Fraunhofer bring together the 4 Ds?

The way I see it, the 4 Ds also effectively correspond to four professional groups: physicians, natural scientists, computer scientists and engineers. Fraunhofer is unique among research organizations in that experts representing each of these groups work together under one roof. This places the Fraunhofer-Gesellschaft in an exceptional position to conduct cutting-edge biomedical research at the interface between the 4 Ds.

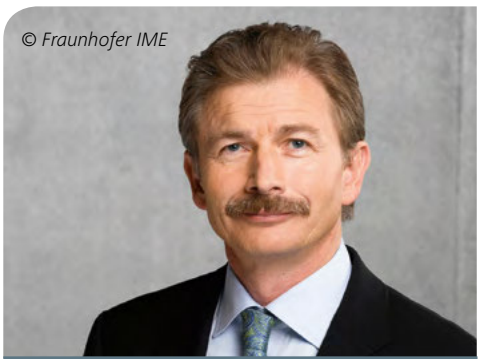
To what extent is the Fraunhofer-Gesellschaft already involved in medical research?

Fraunhofer’s visibility as a major player in medical research is not as strong as it deserves to be. We have contributed significant advances in the field of translational medicine, and our research has led to many innovative solutions. After all, 45 of the 72 Fraunhofer Institutes are involved in medical research in one way or another, and Fraunhofer spends some 15 percent of its research and development budget on projects linked to healthcare. These span the full range of topics from prevention and diagnostics to therapy and patient care.

How do you plan to pool the available expertise?

The President of the Fraunhofer-Gesellschaft, Prof. Reimund Neugebauer, is keen to raise the profile of our medical research. We intend to do this by promoting a new spirit of collaboration at multiple levels along the interfaces between the 4 Ds. Initiatives include setting up foundation-funded projects and the establishment of high-performance centers, in which we work closely with university medical faculties. One example is the High-Performance Center Translational Biomedical Engineering in Hannover.

In January, Fraunhofer founded a cluster of excellence dedicated to immune-mediated diseases – a virtual institute that encompasses all the 4 Ds. In addition, a call for proposals is currently underway for a lighthouse project on low-cost intelligent solutions in medicine. By systematically connecting up the 4 Ds, our application-oriented research can generate significant added value. ■



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Prof. Gerd Geisslinger

directs the Department of Clinical Pharmacology at the Goethe University Hospital in Frankfurt. He is also coordinator of the LOEWE Research Center Translational Medicine and Pharmacology and head of Fraunhofer IME’s Translational Medicine division.

Since 2017, Geisslinger has been Executive Director of the Fraunhofer Institute for Molecular Biology and Applied Ecology IME. In the same year, he was appointed as the Fraunhofer-Gesellschaft’s Medical Research Officer.

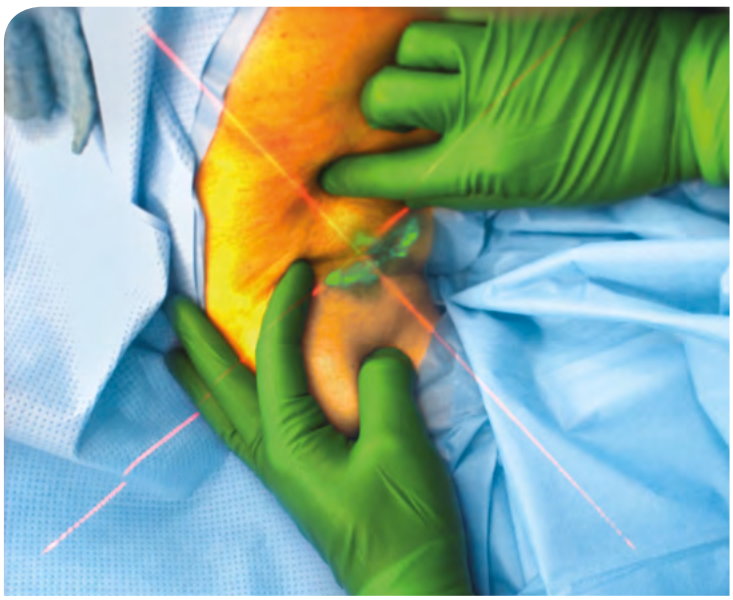
www.fraunhofer.de/en/research/fields-of-research/health-environment.html

Augmented reality in the operating theater

The rapid imaging of the new AR system 3D-ARILE is a decisive advantage. After the infrared dye indocyanine green is injected, the relevant lymph nodes immediately become visible. *©Trivisio / Lux Prototyping*

Malignant tumors frequently form metastases, which spread throughout the body via the lymphatic system. Determining the exact position of lymph nodes and removing them completely requires a great deal of skill on the part of surgeons. Physicians can now rely on a new tool to aid navigation.

Text: Britta Widmann



During the operation, the position of the lymph node is displayed virtually using a pair of AR glasses.
© *Fraunhofer IGD*

According to Germany's Federal Statistical Office, cases of skin cancer requiring hospital treatment have substantially increased in recent years. Malignant melanoma, also known as black skin cancer, is particularly feared. Cancer cells shed by the tumor can be transported via the lymph fluid into the lymph nodes. There, they grow into secondary tumors – metastases. The first nodes affected are the sentinel lymph nodes. These are the first lymph nodes draining the lymph from a malignant tumor. If the cancerous cells have spread to these nodes, there is a high likelihood that more metastases have formed. Sentinel lymph nodes, therefore, play a crucial role in diagnosing and treating certain forms of cancer, such as skin, breast and prostate cancer. Physicians take biopsies of the lymph nodes after excising a tumor to investigate whether the cancer has spread.

Data glasses help to localize nodes

Even with state-of-the-art medical knowledge, surgeons can't always determine the exact location of sentinel lymph nodes during operations, nor tell if the lymph nodes have really been entirely removed. 3D-ARILE, a novel navigation aid developed by the Fraunhofer Institute for Computer Graphics Research IGD in Darmstadt, aids surgeons in removing nodes.

The augmented reality system, in the form of a pair of data glasses, supports physicians, aided by markings, to localize lymph nodes. The unique feature of this system is that the AR glasses function in combination with high-performance software for medical navigation, and with a stereo system made up of near-infrared (NIR) cameras and indocyanine green (ICG) fluorescent dye. "To make the affected lymph nodes visible, a fluorescent dye is injected into the immediate area of the patient's tumor. The dye disperses via the lymph vessels and concentrates in the sentinel lymph node," explains Dr. Stefan Wesarg, department head at Fraunhofer IGD. Infrared light from LEDs excites the dye causing it to fluoresce. The NIR cameras pick up the fluorescence and reconstruct the affected lymph nodes in 3D. The data glasses display their exact location to the surgeon in real time. The necessary software was developed by the Darmstadt research team. "We chose to display diseased tissue in green. The surgeon can determine with the aid of the dye whether all the cancerous tissue has been removed," says Wesarg.

Reducing side effects for patients

Up to now, physicians have employed the radioactive nanocolloid technetium 99m as a medical tracer. By replacing this radioactive marker with ICG dye, side effects of the treatment can be significantly reduced. Time is also a crucial factor: the radioactive marker only causes the lymph nodes to emit radiation weakly. This has meant images have had to be made with scintillation cameras, which took approximately 30 minutes to precisely record the position of the lymph nodes. The use of data glasses enables the position of the affected nodes to be identified immediately – greatly facilitating the job of the surgeon, who doesn't need to look at an additional monitor and compare what it displays with the camera image. "The surgeon can focus exclusively on the patient, reducing the stress of the operation," says Wesarg.

Another advantage of the technology is that the AR glasses are very light and comfortable to wear, as dermatologists at Essen University Hospital have confirmed after numerous tests. All the project partners worked together closely when developing the system to optimally adapt the navigation aid to the needs of the surgeon.

The augmented reality system is a combination of hardware and software. The hardware was developed by Trivisio Prototyping GmbH. The researchers from Fraunhofer IGD were responsible for the development of the software. ARSPECTRA sarl is introducing the patent-pending system onto the market. ■

Take a hearty bite out of an apple, snack on a handful of peanuts, eat soy schnitzels – things that not everyone can do, at least not without regrets! About five percent of Germans suffer from a food allergy. Their only option up to now was to avoid eating anything likely to trigger an allergic reaction. Fraunhofer scientists participating in the FoodAllergen project are looking to improve life for allergy sufferers. An interview with project managers Dr. Peter Eisner (Fraunhofer IVV, Freising) and Dr. Michael Szardenings (Fraunhofer IZI, Leipzig).

Project manager Dr. Peter Eisner (left) from Fraunhofer IVV, Freising. © *Eisner Fraunhofer IVV*

Subproject manager Dr. Michael Szardenings (right) from Fraunhofer IZI, Leipzig. © *Fraunhofer IZI*

The allergy detectives

Interview: Andrea Schwendemann

Dr. Eisner and Dr. Szardenings, what can you tell us about your work on food allergies as part of the FoodAllergen project? Just what is an allergy?

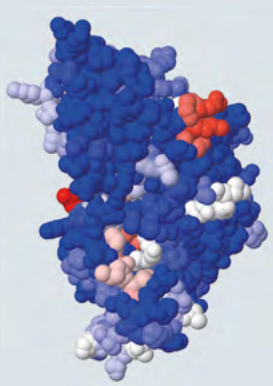
Michael Szardenings: The human body can produce antibodies against all foreign substances, even against a harmless slice of bread and butter. However, such "normal" antibodies, in particular IgG antibodies, don't cause allergic reactions. On the other hand, if a parasite bores into your skin, a special type, known as IgE antibodies, comes into play.

Peter Eisner: Exactly. Parasites are recognized by IgE antibodies on mast cells in the lower layer of the skin known as the hypodermis. This causes mast cells to release inflammatory substances like histamine, which trigger the familiar allergic reactions: itching, swelling, rashes and even reactions that need clinical treatment. When a person develops a food allergy, it's this defensive reaction to parasites that kicks in – quite clearly an inappropriate reaction.

You've been working very intensively on soybeans. Why soy, and what have you found out about the allergenicity of soy proteins?

Michael Szardenings: We started with soy because soybean extracts are found as ingredients in many foods and in other products such as skin care creams. Not only that, allergy to soy is widespread, with approximately one million sufferers in Germany. Using a specialized statistical big data analysis method, we have identified over 300 epitopes in soybeans. Epitopes are regions of proteins that trigger allergies. Other proteins we've already analyzed include hazelnut, celery, peanut, almond and even lupine and pea.

You have identified the parts of the proteins that trigger allergies. And now you're attempting to modify foodstuffs to make them better tolerated by allergy sufferers. How do you do that?



3D model of a soy protein: The red regions are those frequently targeted by antibodies in patients diagnosed with soy allergy, and most likely to trigger allergic reactions. White indicates the regions of the protein structure model that are targeted less frequently, while blue indicates regions that are not implicated in allergic reactions. © *Fraunhofer IVV*

Peter Eisner: One of our jobs at Fraunhofer IVV is to modify food proteins using various techniques. A natural soy protein looks like a ball of wool. We modify this ball of wool, or more precisely the epitopes – the sections of the ball of wool that trigger allergies. To achieve this, we employ many different food technology processes: we deform the protein, cut it, we heat and boil it, treat it with enzymes or microorganisms and let it ferment. Our aim is to modify the proteins in such a way that the body no longer recognizes them as allergens.

Will you ever be able to produce food that triggers no allergies? For instance, a hypoallergenic sausage?

Peter Eisner: We've already tested a number of techniques to modify proteins in foodstuffs, for example using enzymes or lactic acid bacteria. We demonstrated that, after modification, the food proteins contained fewer allergenic regions. So, we'll be able to reduce the allergenicity of foods or food ingredients in the future, in other words, decrease the number of epitopes per gram. But we won't be able to guarantee that food proteins contain absolutely no allergenic epitopes. The dream of an allergen-free sausage is still a long way off.

The FoodAllergen project runs until 2020. What do you hope to achieve by then?

Michael Szardenings: Improved patient diagnosis. Dr. Jörg Lehmann's department at Fraunhofer IZI is creating a biobank with 500 sera from allergy sufferers. With the help of the biobank, we're hoping that by the end of the project we can tell sufferers exactly what they react to allergically – with an allergy test requiring a single drop of blood and that can be simply carried out in the physician's office. The test should show precisely which epitopes are responsible for the allergic reaction. That the patient is allergic to soy but not to birch pollen, for example. The current prick tests can't differentiate cross-reactions.

Peter Eisner: Our goal at Fraunhofer IVV is to modify the allergenic proteins in foods such as soy and lupine, making them better tolerated by humans. Maybe one day we'll be able to process shrimps, so I can enjoy eating them again. Unfortunately, I found out I was allergic to such seafood last summer.

Michael Szardenings: There's still no conclusive method of precisely determining which allergenic food ingredients a product contains and in what quantity. Another important goal of the project is, therefore, to develop a kind of food allergy safety inspection procedure. ■

Many foods trigger allergies. © *iStock*

The FoodAllergen project

The project runs until 2020 and is funded by the Fraunhofer Future Foundation. A business developer is working in tandem with the researchers, taking care of contacts with industry.

What are the aims of the project?

- Develop novel ways of analyzing food allergies
- Reliably identify the allergens present in foods
- Reduce the allergenic potential of foods
- Develop detection methods that can precisely determine allergenic potential

Participating Fraunhofer Institutes:

- Fraunhofer Institute for Cell Therapy and Immunology IZI
- Fraunhofer Institute for Process Engineering and Packaging IVV
- Fraunhofer Institute for Molecular Biology and Applied Ecology IME
- Fraunhofer Institute for Toxicology and Experimental Medicine ITEM

Making efficient use of biomass

Wood is rarely used as a feedstock for the chemical industry due to the typically long distances between forestry exploitation sites and industrial processing centers. A new steam drying process, known as torrefaction, can significantly cut transportation costs. The technique yields, as a by-product, valuable base materials for the chemical industry.

Text: Janine von Ackeren

The use of wood as an industrial feedstock holds great promise as a replacement for finite resources such as crude oil and natural gas – both as a fuel source and as a raw material for basic chemicals. The challenge is coming up with innovative ways to convert the biomass into sustainable products and develop suitable processes to do so.

At present, much of the low-quality wood harvested during forest maintenance is ground into wood chips, which are nevertheless an important feedstock for the wood processing industry. They are then processed into pressboard, wood fiber insulation board, paper and cardboard. They are also used as fuel in thermal power plants and pellet stoves.

However, the high moisture content of fresh wood chips presents two problems: it is a lot of weight to transport and it is difficult to store the damp cargo. If not protected from rain and moisture, the material quickly rots.

Threefold advantage

Researchers from the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB have come up with a new technique to prepare wood chips for transportation. The technique was developed as part of the EU-funded Steam-Bio project together with ten other project partners from four European countries. "Instead of transporting the biomass simply as wood chips," explains Siegfried Egner, department head at Fraunhofer IGB and coordinator of the SteamBio project, "we torrefy it: we heat the biomass in a steam atmosphere free of oxygen. The biomass has three main components – cellulose, lignin and hemicellulose – and this process eliminates the hemicellulose." This significantly reduces the weight of the material, improves its specific calorific value and allows us to easily grind the material into a highly reactive powder.

The torrefied biomass is water-repellent and has significantly improved combustion properties since it is composed purely of hydrogen and carbon. This has considerable advantages for transportation and storage. It can be transported in open bulk containers, since rain beads off the surface without penetrating the interior. What is more, the torrefied biomass is considerably lighter than the untreated material, which significantly reduces transportation costs.

Untreated wood chips are tough and strong, but torrefaction renders them so brittle and fragile you can easily crumble them between two fingers. They can either be compressed into pellets or ground into powder. This brings with it a further advantage. Since it has a greater surface area, the biomass powder possesses great-

The pilot plant consists of a container with a storage bin and energy center, as well as a frame that houses the drying and torrefaction reactors, the attachment for extracting solids and the condensers.
© *Fraunhofer IGB*

Project partners in Spain are investigating torrefaction of various lignocellulosic substrates, including vine pruning (left untreated, right torrefied).
© *Fraunhofer IGB*

er reactivity in material uses than larger chunks. In energy applications, it can also be mixed with coal dust and fed into the firing system of coal-fired power plants. It is even possible to replace the coal entirely with biomass while keeping the same combustion system.

The volatile substances liberated in the torrefaction process are particularly valuable. They can be processed to obtain chemicals that serve as feedstock for a wide range of industrial products. Until now, these platform chemicals have been obtained from crude oil or natural gas; now, torrefaction offers a sustainable way to produce them. "In the case of many biomass materials, the platform chemicals generate so much profit that they can finance the entire torrefaction process," says Egner. In general, the more lignified the biomass is, the more profitable the platform chemicals prove. Partners from Glasgow University have developed a business model for the process.

Steam drying at over 200 degrees

So what is the process? What exactly happens during the heat treatment process? "Torrefaction in itself is not a new technique," explains Bruno Scherer, project engineer at Fraunhofer IGB. "In the SteamBio project we used steam drying technology developed at the IGB, adapted for this specific process. In this case, we're working with temperatures of between 200 and 250 degrees Celsius." The special thing about the technique is that the moisture contained in the biomass and the vaporous products yielded by torrefaction are specifically retained in the process chamber and themselves become the process medium. "In other words, we're working with superheated steam," says Scherer.

The high temperatures dry out the biomass and result in organic compounds with low boiling points that quickly become volatile. While cellulose and lignin remain in a solid state, the volatile substances pass into the gas phase. Researchers use special condensers to capture these gaseous substances and selectively cool them, thus recovering them as liquids.

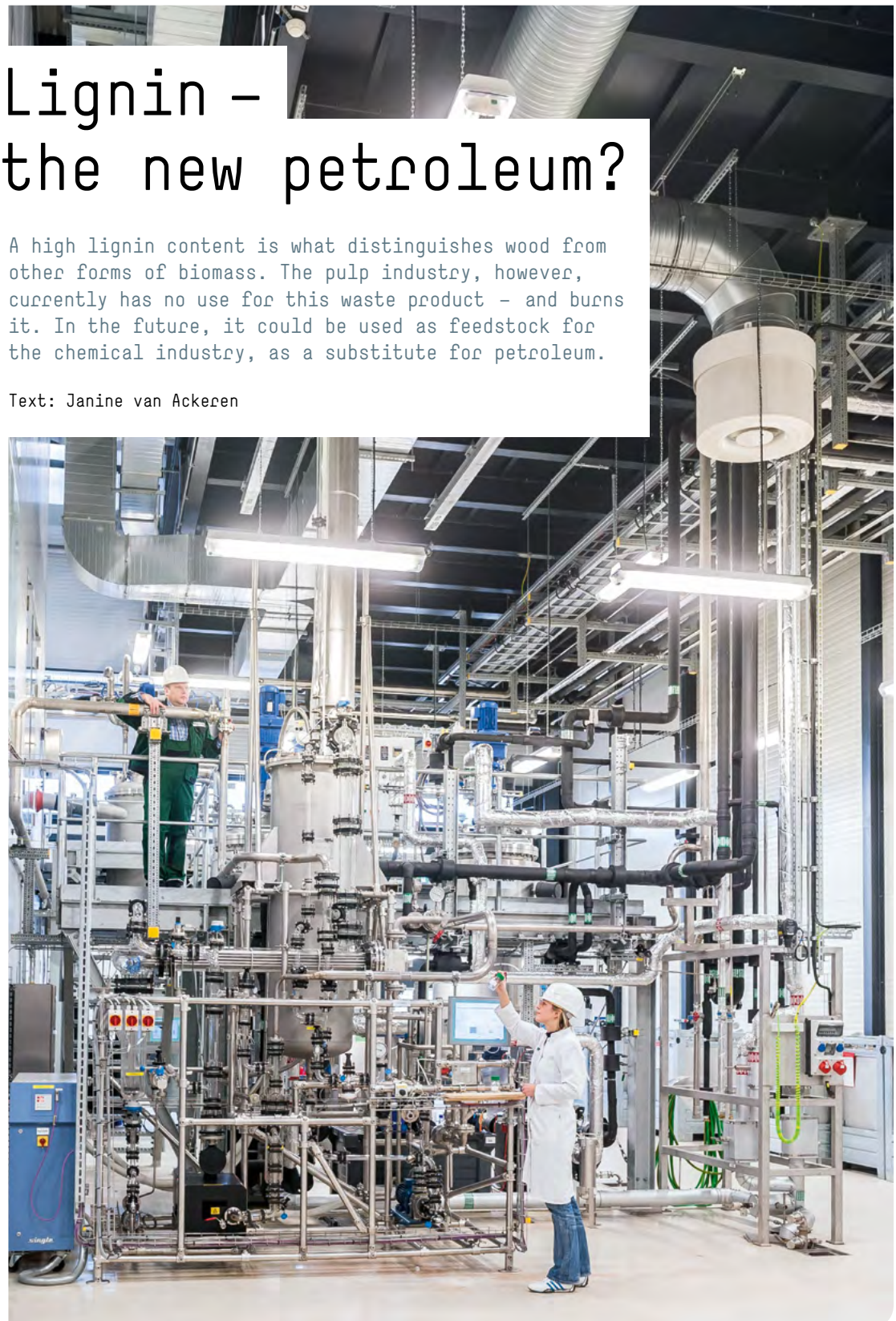
A pilot facility has been built and installed and was previously operated by project partner Heckmann Metall- und Maschinenbau GmbH, where it ran 24 hours a day, 7 days a week. Beechwood was used as the biomass.

The facility was then moved to Spain in January 2018 to continue the operation. Here, project partners torrefy pine, oak and beech wood, as well as vineyard pruning and waste from olive oil production. "The pilot project aims to characterize the yields of the solids and the volatile reaction products," says Egner. This research forms the basis for further commercialization of the technology. ■

Lignin – the new petroleum?

A high lignin content is what distinguishes wood from other forms of biomass. The pulp industry, however, currently has no use for this waste product – and burns it. In the future, it could be used as feedstock for the chemical industry, as a substitute for petroleum.

Text: Janine van Ackeren



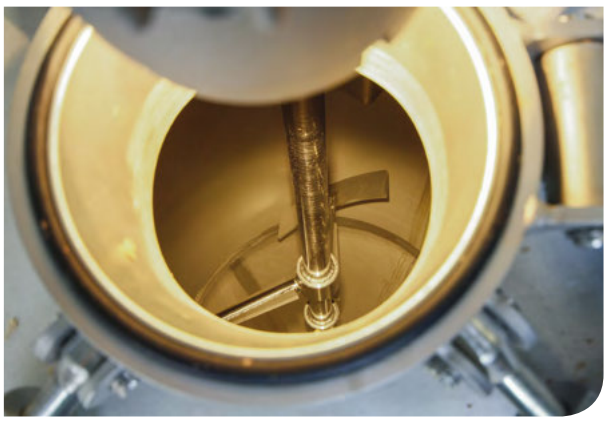
From left to right: Filtered lignin after precipitation from a digestion solution.

Filter press for separation of lignin.

Beech wood-chip waste from a sawmill as feed-stock for the organosolv process.

Tank for washing organosolv cellulose.
© *Fraunhofer CBP*

Subsystem for evaporating sugar solutions at the Fraunhofer CBP lignocellu-lose biorefinery plant.
© *Fraunhofer CBP*



Trees instead of petroleum? Many people think of wood primarily as heating fuel: evoking cozy images of winter evenings spent in front of a good old-fashioned wood-burning stove. In the future, however, wood could also be increasingly used as a raw material for basic chemicals in the chemical industry: because wood is a source of lignin, at 30 percent by mass one of the main constituents of woody biomass, and one of the most common organic compounds on Earth. It represents a correspondingly huge reservoir of raw materials. Worldwide, the pulp and paper industry annually generates approximately 50 million metric tons of lignin – as a waste product that ends up in the furnaces of power plants for internal energy production or to generate environmentally friendly electricity for the grid.

From wood right through to basic chemicals

Researchers at the Fraunhofer Center for Chemical-Biotechnological Processes CBP are now attempting to make use of this largely neglected treasure, making the lignin available as a raw material for the chemical industry, rather than burning it. "We're replicating the entire process chain on a pre-industrial scale: from the wood to the extraction of lignin, and all the way to the basic chemicals," says Dr. Daniela Pufky-Heinrich, group leader at Fraunhofer CBP. Lignin is usually removed from wood by treating it with sulfur compounds (lignin won this way is known as kraft lignin), leaving behind the desired cellulose fibers. The problem is that the sulfur contaminates the lignin, restricting its use as a raw material.

"Our alternative method involves optimizing the organosolv process for use in the pulp and paper industry," says Dr. Moritz Leschinsky, group leader at Fraunhofer CBP. Instead of sulfur compounds, the researchers use ethanol – common alcohol – to extract the lignin from wood, at temperatures of up to 200 degrees Celsius and pressures up to 28 bar. Whereas, here too, the cellulose is left behind as a solid fraction, the lignin dissolved in the ethanol can be precipitated out over a number of different filtration steps. The great advantage is that the lignin won in this way is free of sulfur residues. This means the pulp and paper industry could sell it for use as basic chemicals and thereby generate added value. The organosolv pilot plant constructed at Fraunhofer CPB is already capable of processing up to one metric ton of wood per week.

Up to now, lignin has been directly used to produce polyurethanes or phenolic resins. The question was what other basic chemicals could be generated from lignin. The researchers at Fraunhofer CBP now have an answer to that as well. Using alkali-catalyzed depolymerization, they cleave certain molecular bonds within the lignin, breaking down the large lignin molecule into several smaller base chemical molecules. In a nutshell, they add alkaline sodium hydroxide to the lignin, increase temperature and pressure – and end up with a mixture of basic chemicals which they can purify using physical processes such as filtration and distillation. "Above all, the challenge in development was, once more, to scale up the processes," explains Pufky-Heinrich. They have achieved their goal. The pilot plant constructed at Fraunhofer CBP can convert more than three hundred kilograms of lignin or more than three metric tons of lignin solution per week into various basic chemicals.

The lignin depolymerization process has met with great interest in both the pulp and paper and the chemical industries. Whereas the pulp and paper industry is chiefly interested in finding out which basic chemicals can be derived most easily from the lignin previously considered as a waste product, the chemical industry is examining the resulting basic chemicals more closely, subjecting them to various tests. For instance, project partners have used the basic chemicals to produce high-quality polyurethane rigid foams, which, among other things, can be used as insulation material in the construction industry. In short, there are many areas in which lignin could serve as a renewable alternative to fossil petroleum. ■

Fraunhofer subsidiary in Singapore

It is now 20 years since the Fraunhofer Institute for Computer Graphics Research IGD took the bold step of expanding to Singapore – at a time when internationalization was not yet high on the agenda of research institutions. Born of a small project group cooperating with Nanyang Technological University (NTU), the Fraunhofer Project Center for Interactive Digital Media was founded in 2010. Now it is the legally independent subsidiary Fraunhofer Singapore – the first of its kind in Asia.

Around 30 full-time staff conduct research focusing on Industrie 4.0, personal health, smart cities and visual computing. Since 2017, the team has been working closely together with scientists from the Fraunhofer Institutes for Secure Information Technology SIT and for Ceramic Technologies and Systems IKTS. These joint projects add cyber security and ceramic-based additive manufacturing to Fraunhofer Singapore's portfolio.

"It's a win-win situation. Partner institutes benefit from our network while extending our research in useful directions," explains Prof. Wolfgang Müller-Wittig, who has headed up the project center since 2001.

Non-stop production

Finding errors before production judders to a halt: that was the goal of the EU's "SelSus" project, for which the European Commission provided 5.4 million euros in funding. On board the project was the Fraunhofer Institute for Manufacturing Engineering and Automation IPA.

When machines break down during production runs, it is not only costly, but also impacts on-time delivery and thus harms a company's competitiveness. To make wear visible before it is too late, predict future defects and be able to carry out quick diagnostics into the cause of an emergency, Fraunhofer researchers worked with an international team from industry and the research sector to develop a decision-support system. This consists of sensor networks, databases in which the technical parameters of the machines are stored, and intelligent algorithms.

The new system is already being used on a press line by the Italian project partner Electrolux in Pordenone. It helps workers there to recognize and fix defects on time. In another use case involving the partners Harms & Wende from Hamburg and IEF Werner from Furtwangen, the SelSus system is able to send control signals to the components; in this way, they can continue to work in "safe mode" until their next maintenance for instance. The system's ability to monitor itself and keep production running inspired the project's name, SelSus.

New antibiotics

Antibiotic-resistant bacteria claim hundreds of thousands of lives worldwide every year. To be able to effectively treat infectious diseases, medicine needs new kinds of therapeutic agents. Developing them, however, takes a lot of time and money. The biggest obstacle is the long path between the discovery of new, potentially healing substances and clinical trials.

Researchers at the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM are seeking to close the gap in the drug development chain, together with scientists from the Hannover Medical School (MHH) and the Institute for Glycomics (IfG) at Griffith University in Queensland, Australia. In the Fraunhofer International Consortium for Anti-Infective Research (iCAIR) project, the partners will jointly identify and develop new therapeutics.

Each of them will contribute their own expert knowledge. Working together, the specialists want to devise new therapeutic approaches and, in selected lighthouse projects, identify active substances to combat the infectious agents Pseudomonas aeruginosa, Aspergillus fumigatus, Neisseria meningitidis and the influenza virus, and develop drugs up to the preclinical proof of concept.

Major project in Kuwait

Specialists from the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT have been asked to draw up a comprehensive waste management plan for Kuwait over the next four years. The emirate's Environment Public Authority is providing funding of 18 million euros for this purpose. For the Fraunhofer-Gesellschaft, this research project is its biggest to date in the Arab world.

A team of experts has already begun with the first step: a comprehensive evaluation to measure the incidence, composition and disposal channels of residential and industrial waste, industrial waste water and sewage sludge. At the same time, they will investigate the composition of landfills and their potential danger for people and the environment. All data and analyses will flow into a web-based geoinformation system (Environmental Monitoring and Information System for Kuwait "eMISK"). On the basis of the data generated, a national waste management plan will be drawn up for the next 20 years. Among other things, the plan will include targets for waste avoidance and recycling and will encompass technology recommendations and a remediation concept for the landfills. The contact partner at Fraunhofer UMSICHT is Dr. Peter Degener.

Lightweight design solutions

Together into the future: At the Fraunhofer Project Center for Composites Research, experts from the Fraunhofer Institute for Chemical Technology ICT develop fiber composite materials for lightweight design applications in the automobile industry in cooperation with materials scientists at the well-known South Korean Ulsan National Institute of Science and Technology (UNIST). The project center, which is located only 14 kilometers from the center of the industrial metropolis of Ulsan, was founded in 2016; Ulsan Metropolitan City invested 15.5 million euros in its establishment.

New technologies are needed to bring sustainable mobility to South Korea. The country is at the technological vanguard when it comes to reducing the emissions and the weight of vehicles and electrifying their powertrains. Ulsan is the most important industrial hub for this activity. Among other things, it is home to one of the world's largest automobile assembly plants.

German and South Korean researchers are now working together on processing methods for fiber composite materials, new material solutions and the translation of lightweight design solutions into large-scale production.

Through the project center, Fraunhofer gains access to an innovative growth hub for the automobile industry in Asia along with insights into market developments there. This acquisition of know-how can be employed for the direct benefit of German and European customers and facilitate their entry to the Korean market.

Open Innovation Platform

The United Nations Agenda 2030 entails a set of ambitious goals; from eradicating poverty and hunger to strengthening peace all around the globe and initiating an era of sustainable development. The Sustainable Development Agenda includes 17 goals (SDGs), among them renewable energy, improved infrastructure, quality education and access to clean drinking water.

The Fraunhofer-Gesellschaft wants to help achieve the SDGs through an Open Innovation Platform: "The platform facilitates swift matchmaking between expertise and know-how among Fraunhofer Institutes, the private sector, as well as start-ups in less developed regions that do not have access to research and development services," explains Dominik Reinertz, a team member of the International Business Development department at Fraunhofer.

By offering a combination of research findings and expertise on local realities, the platform aims at enabling efficient problem solving. The Open Innovation Platform not only strives to bring together suitable collaboration partners but also to help find the right funding opportunities.

The platform will go live at the end of November on the occasion of the General Assembly of WAITRO, the World Association of Industrial and Technological Research Organizations.

Wind power on the up

China is increasingly turning to wind power. More and more offshore wind farms are being built in coastal waters. In the province of Fujian, the China Three Gorges Corporation Fujian Branch CTG is planning the construction of two wind parks, which will have a combined output of 2.8 gigawatts. Now Fraunhofer technology is being deployed to precisely measure wind conditions and thus predict the electricity yield.

Two LiDAR buoys from the Fraunhofer Institute for Wind Energy Systems IWES have already been delivered to China. The floating LiDAR technology – the abbreviation stands for Light Detection and Ranging – makes it possible to measure wind speeds above the ocean up to a height of 200 meters. A laser beam sent out from the buoy and reflected from the particles in the atmosphere measures the speed of air particles (aerosols). The Chinese company Titan Technologies Corporation has been tasked with installing the buoys and collecting and evaluating the measurement data on behalf of CTG.

"We've been working with Fraunhofer for some years and appreciate their proven solutions, which are highly deployable even under complex operational conditions," explains John Feng, Chairman of the Titan Technologies Corporation and a member of the IWES advisory committee. The collaboration with the Chinese partner is promising for Fraunhofer in many respects: Titan Technologies Corporation can spread word of its experiences with the new technology in Asia; moreover, measurement campaigns increase industrial acceptance of the technology.

Security in cyberspace

How can we protect data and IT systems against unauthorized access and attacks? This question is becoming increasingly important for businesses and ordinary citizens. Consequently, cybersecurity solutions are very much in demand.

To improve the chances of start-ups being successful, the Fraunhofer Institute for Secure Information Technology SIT has teamed up with the Hebrew University of Jerusalem in Israel to found a new initiative: the Hessian-Israeli Partnership Accelerator HIPA enables young researchers from Germany and Israel to jointly develop solutions for practical security problems that arise in industry and society generally.

Israel is known for its many successful start-ups; moreover, the Hebrew University is one of the leading universities in the field of cybersecurity. Fraunhofer SIT is a member of the Center for Research in Security and Privacy (CRISP) in Darmstadt, the largest institution for applied cybersecurity research in Europe.

The young experts who take part in the three-month program not only receive methodical training and mentoring in the technical subject matter, but also learn how the different approaches in Germany and Israel can be combined. Students can apply for the second HIPA round up until November 30, 2018. Further information: www.cybertech.fraunhofer.de

Simple, fast and efficient – courtesy of blockchain

Shanghai's container port is one of the world's most advanced. © *iStock*

T-shirts made in Bangladesh, Colombian coffee, computers made in China – global trade has certainly snowballed over the last three decades. But business across national borders is still astonishingly complex with piles of paperwork to contend with. Blockchain technology could simplify and fast-track international trade.

Text: Dr. Sonja Endres

When a German company orders tablets in China, it is usually a letter of credit that secures the deal. Two banks, one serving as a proxy for the exporter and the other for the importer, monitor the transaction as impartial arbiters. They see to it that the exporter gets paid when the goods ship out as agreed. The importer, in turn, only has to settle the bill once the shipment leaves on time, in the quantity and quality specified in the contract. It is up to the exporter to furnish evidence that the transaction satisfies the terms of the contract. This stack of documents can include a waybill, a bill of lading, an export packing list and so on. Today these documents are still consigned to snail mail. Banks and trading partners shun email; it is just too vulnerable to manipulation.

"In some cases, the paperwork costs more than it does to deliver the goods," says Prof. Gilbert Fridgen from the Fraunhofer Institute for Applied Information Technology FIT. He holds workshops to familiarize the business and industry community with blockchain technology. Fridgen and his team at the Fraunhofer Blockchain Lab have joined forces with experts from Norddeutsche Landesbank to develop a prototype that enables paperless trading across the globe. With the benefit of blockchain, every step of an international deal from ordering to delivery can be documented securely and transparently.

A distributed database

Blockchain is a distributed database of sorts. Each blockchain user stores a complete data record as a set of cryptographically linked blocks. When one user adds data, the blockchain is updated for all users by way of a consensus mechanism. "This distributed consensus mechanism, paired with cryptographically linked blocks, ensures data in a blockchain cannot be manipulated," says Prof. Wolfgang Prinz, deputy director of Fraunhofer FIT, by way of explanation. All users would be instantly alerted should anyone attempt to change blockchain contents.

Blockchain can capture every step of a process, securely and irreversibly, with all the attendant data and documents. It is the perfect medium for international commerce and many other applications, for example, corporate documentation. "Auditing could be so much faster, easier and cheaper if all the relevant documents were

loaded to a blockchain," says Fridgen. It provides an accurate record of who did what, when and how. "Everyone who took part in our workshops was all ears when they heard that. The cost of audits often runs up into millions, particularly in highly regulated industries."

Blockchain is an intriguing prospect for any company with a business model based on positions of trust. "Blockchain is not yet a substitute for banks, notaries or auditors. But the technology does offer a lot of potential in these areas," says Prinz. Blockchain can make workflows easier, faster, safer and more efficient. It can be put to beneficial use in the import/export business and for other step-by-step transactions where the contracting parties still have to fill out and print forms, and then wait for collateral securities.

Another powerful feature of blockchain is that it enables a technology called smart contracts. These software programs automatically execute the terms of an agreement when the stipulated conditions are met. For example, the lack of a verified payment in a blockchain could prompt a smart contract to keep a leased car's doors locked. With this automated relationship between performance and obligations, it would be technically impossible to breach a contract and no need for litigation to enforce claims.

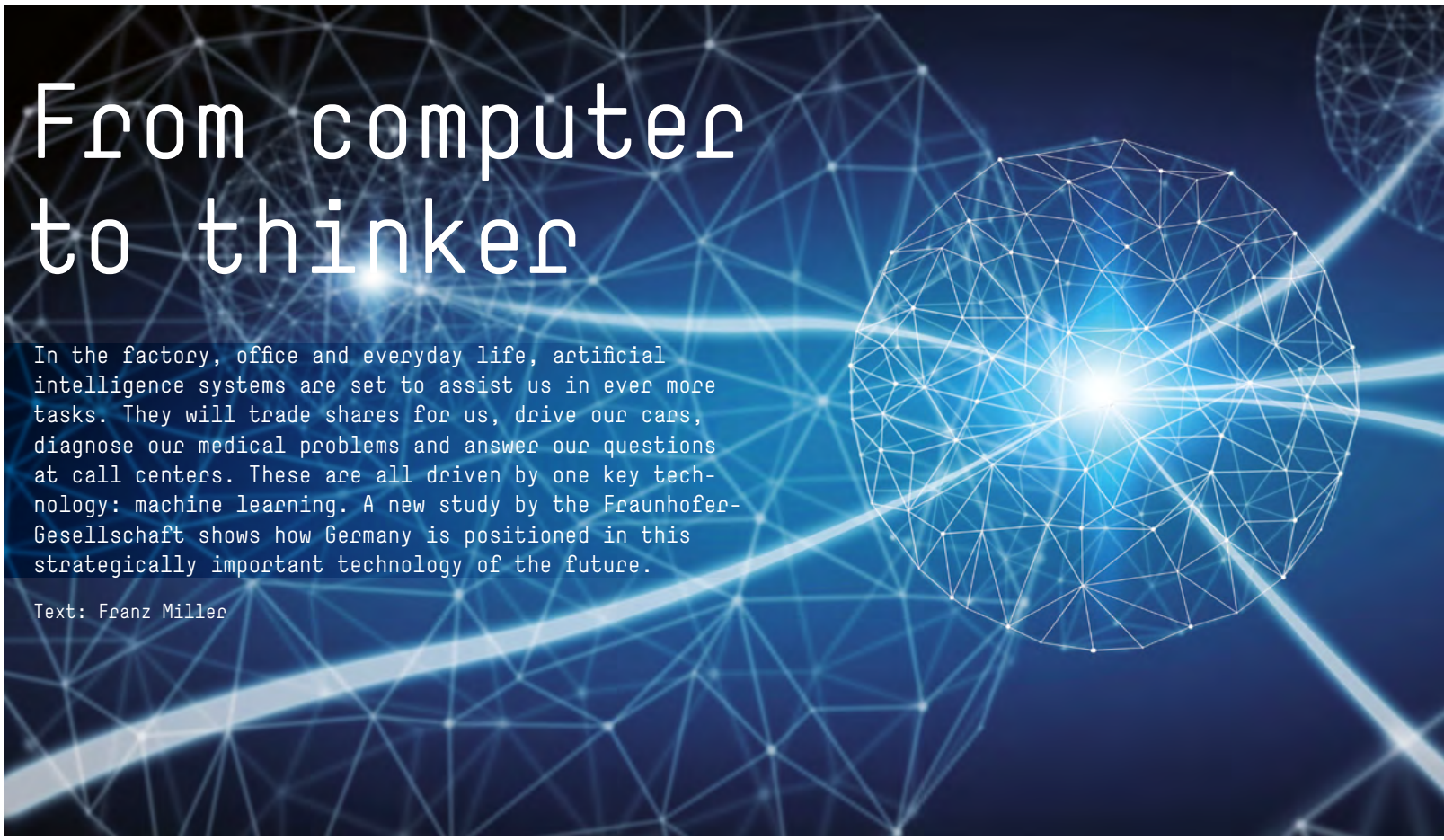
Blockchain also poses a challenge for providers of online trading platforms. The new technology could enable the buyer and seller to engage in secure transactions directly, without added protection from the platform's operator. "Blockchain technology could be used to create a new generation of the Internet. The Internet of Things that we're talking about these days would be joined by an Internet of Trust and Values," says Prinz with conviction.

Reliable proof of origin

For the logistics industry, blockchain is more promise than threat. It could document a delivery chain from end to end to guarantee the transported object's authenticity. "There is already a blockchain solution for diamond shipments," says Prinz. Similar blockchain solutions could serve to authenticate the origin of medicines and food products and verify the conditions under which they were shipped, for example, to prove that the cold chain was not interrupted.

Prinz and Fridgen are working on a wide range of applications with their colleagues Prof. Thomas Rose, Prof. Nils Urbach and their teams in the Fraunhofer Blockchain Lab. One is a blockchain-enabled jukebox with playlists compiled by group consensus. An entertaining gateway to the world of blockchain, it conveys the technology's basic functions to business-people who are interested in learning more about it. Another project features the BSCW groupware platform developed by FIT and OrbiTeam. The "Blockchain for Education" solution that has been realized together with the Fraunhofer Academy and the TÜV Rheinland Academy enables the registration and verfication of education certificates. This solution is currently being extended towards the certification of products.

"We have already identified many potential applications with the support of the people who have attended our workshops," says Fridgen. "As yet, we are still working with prototypes, but this development may go quickly. So, it is important to act now, adapting business models to this new technology and using it to optimize processes." ■



From computer to thinker

In the factory, office and everyday life, artificial intelligence systems are set to assist us in ever more tasks. They will trade shares for us, drive our cars, diagnose our medical problems and answer our questions at call centers. These are all driven by one key technology: machine learning. A new study by the Fraunhofer-Gesellschaft shows how Germany is positioned in this strategically important technology of the future.

Text: Franz Miller

The headlines in recent times have been startling: "Hello, this is AI speaking", "Google predicts when people will die" and "Who is liable when AI is responsible for mistakes?" A predictable media circus breaks out every time a computer defeats us in board games like chess or GO, in eGames like DOTA2 and most recently in debates. And the same old myths get retold about the battle of man against machine. People have radically different views on artificial intelligence (AI). Critics invoke the coming jobs crash and warn of a future in which machines will ultimately control us, while enthusiasts rhapsodize in big company adverts about the fantastic future we'll be enjoying thanks to artificial intelligence.

"The debate about artificial intelligence is often typified by half-knowledge, assumptions, fears and myths, but also by exaggerated expectations," stresses Prof. Stefan Wrobel, head of the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS. "Education is what is needed." He adds: "Public acceptance of machine learning techniques is crucially important to advancing their widespread use." This is something the new Fraunhofer study Machine Learning, commissioned by the German Federal Ministry of Education and Research, is keen to address. From the outset, the AI researchers clearly emphasize that they are not in the business of building artificial brains or artificial people, any more than aircraft manufacturers are interested in creating artificial birds. They are developing machines that are capable of learning and – similar to humans – solving elementary cognitive tasks.

The new technologies have long since arrived in our everyday lives. Virtual assistants like Siri, Alexa or Cortana have already become the indispensable housemates of many families. Cut them off from the network, however, and they become dumb in both senses of the word; when asked questions, all they can do is forward them on to gigantic data centers, where they are processed and the data collected. If you order a pizza over the Internet, you'll find yourself communicating with a chatbot simulation of a human. Soon we will scarcely know if it's a computer we're talking to on the phone. The number of situations in which we will encounter learning systems in the future is huge.

The breakneck advances in artificial intelligence were set off by the new machine learning (ML) methods known as Deep Learning, which are modeled on artificial neural networks. By training on vast amounts of data, these systems are developing astonishing capabilities. Ultimately, such techniques are responsible for the enormous strides made in speech, text, image and video processing.

The global digital race to get there first

The starting gun has been fired on a global race to harness these economically and strategically crucial technologies, primarily between the USA and China. Master these technologies faster and more effectively than anyone else and you'll be a winner in the age of Industrie 4.0, the Internet of Things and robotic cars.

"Machine learning – competencies, applications and research needs"

The study is based on a research project funded by the German Federal Ministry of Education and Research (BMBF) and was conducted by the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS, the Fraunhofer Center for International Management and Knowledge Economics IMW, and Fraunhofer headquarters. It presents a condensed introduction to the most important machine learning concepts and methods, gives an overview of current challenges and the issues that need to be researched and describes Germany's position in the application of machine learning.

www.bigdata.fraunhofer.de/ml-studie

In September 2016, five companies – Google, Facebook, Amazon, Microsoft and IBM – joined forces to form the "Open Artificial Intelligence" research alliance. China adopted a plan in July 2017 to become the world leader in all areas of AI by 2030. The strategic importance of AI has also been recognized by the German government. It is currently formulating its Artificial Intelligence Master Plan, which should be completed by the fall of this year.

Learning machines are regarded as a critical technology in the digital transformation of the economy and society. There is hardly a sector that the technology will not radically change: industrial production, medicine, law, finance, process control, logistics, customer management and transport. Learning machines analyze images, research documents, advise us how to invest, optimize processes in industry, detect defects before malfunctions occur, and as robots, work hand-in-hand with humans. "The potential of ML-based products is particularly promising from the viewpoint of Industrie 4.0, for example in industrial analytics and forward-looking optimization of production processes," notes Prof. Thorsten Posselt from the Fraunhofer Center for International Management and Knowledge Economy IMW.

In machine learning, "knowledge" is generated from "experience". Take cats as an example. The learning algorithm forms patterns in the neural net from thousands of images that have been labeled as portraying cats. Using these patterns, it can recognize cats, even if only partially seen in the image. A crucial factor to the quality of the knowledge learned by the system is how much sample data it has access to. And that is why machine learning is most effective when vast quantities of images, documents and speech recordings are made available to it. This leads to systems that learn to identify breast cancer, heart disease, osteoporosis and the first signs of skin cancer from medical images.

Strong in fundamentals, weak in implementation

In the study, the researchers analyze publication and patent statistics to provide evidence for how effectively Germany is taking advantage of machine learning. They show that Germany is well positioned in basic research but has deficits in converting this into products for the market. The comparatively low number of patent applications filed in Germany reflects this. The large technology companies in the USA, which have access to enormous volumes of data, boast unassailable advantages over German midsized companies, which have only a limited database at their disposal. Because access to data is crucial for competitiveness, their only recourse is to exchange their data with others. But this is only acceptable when use of the data is controlled and protected.

The other major challenge for Germany, the experts warn, is its lack of skilled employees. Insufficient numbers of data scientists and machine-learning specialists severely threaten Germany's ability to compete. An extremely important research objective is to explain just how learning systems take decisions. Experts call this "explainable AI". The intention is to identify how the systems make their decisions. Other areas that researchers are keen to explore are "machine learning with limited data" and "machine learning with additional knowledge from experts". Additional knowledge can compensate for missing data and increase traceability.

The numerous legal and ethical issues need to be clarified in tandem. Who is liable for potential damage and errors? Who is responsible for the content generated? Who holds the copyright? Why did the machine decide this way and not the other? Are particular people discriminated against? What can the system decide for itself? How are data and consumer protection guaranteed?

The central ethical challenge is to design systems in a way that is consistent with the principles determining our view of society, law and our values. "It would never be acceptable for an AI to behave less ethically, less morally, less correctly, less socially acceptably than a human being," emphasizes AI expert Stefan Wrobel. If this challenge is met, learning machines will be accepted as valuable assistants and not perceived as an assault on our human ignorance. ■

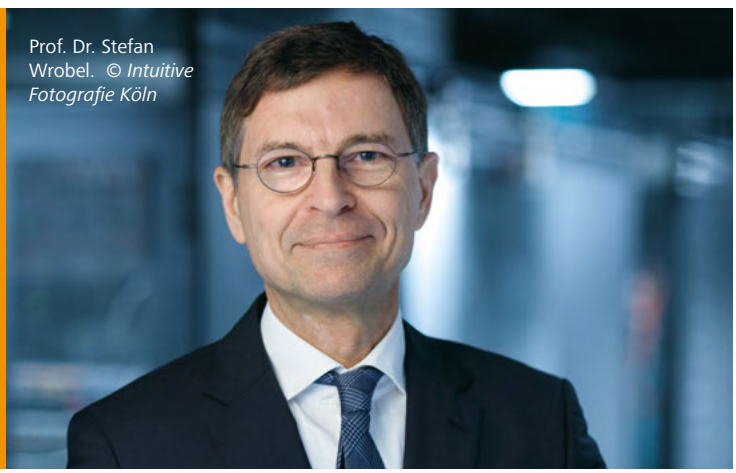
Machine learning at Fraunhofer

Fraunhofer is committed to anchoring machine learning in Germany and supporting companies in strategically implementing it. Both in Germany and in Europe, many Fraunhofer Institutes develop key AI technologies along with their applications. These include machine learning methods for industrial applications and the deployment of cognitive systems in cybersecurity, as well as further research into artificial neural networks. In addition, Fraunhofer supports companies in meeting current challenges, for example through its new Machine Learning Research Center. Researchers are working on transparent and robust approaches to strategically integrate AI into production, business and sales processes. The Fraunhofer Big Data Alliance is responding to the shortage of skilled workers with an extensive training and certification program for data scientists, which can be completed through modular course study accompanying full-time employment.

“We’re far from the end of this development”

An interview with Prof. Dr. Stefan Wrobel, director of the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS and professor of computer science at the University of Bonn, about opportunities, challenges and the acceptance of artificial intelligence.

Interview by Anne-Marie Tumescheit



Prof. Dr. Stefan Wrobel. © *Intuitive Fotografie Köln*

What exactly is artificial intelligence?

Intelligence is a key attribute of human beings – one we tend to credit humans with possessing exclusively. Now, if machines are able to do things that we would generally classify as intelligent, we call this artificial intelligence. The term currently encompasses machines that are able, for instance, to interpret images or respond appropriately to spoken statements; it even refers to seemingly simple things like the digital assistants on our mobile phones.

Where do you think the boundary lies between AI and machine learning?

Right at the dawn of artificial intelligence, AI pioneer Alan Turing knew that it would hardly be practical to program intelligent computers down to the very last detail. As early as 1950, he wrote that there must be a faster method – namely machine learning. With these methods, computers are able to learn from observations, existing data and examples, thereby improving their performance. This means reducing the range of human work. And that we can train intelligent systems.

Can these intelligent computer systems be compared with human intelligence?

You can always compare two things, even if they are different in nature. Just as an airplane doesn’t fly like a bird, a computer doesn’t think like a person. We have to observe the outcomes and then judge whether we would classify them as equally intelligent, less intelligent or more intelligent than what a human would accomplish. In this regard, computers have already achieved major breakthroughs, such as winning the game show Jeopardy or cracking the game GO – to say nothing of chess.

Would it be accurate to say that, for things like strategy and image recognition, AI is now just as good as people, or even better, but that humans still have the upper hand when it comes to creative endeavors?

I think it’s no longer quite so easy to make this generalization today. It depends on whether a computer can actually learn an activity from examples. Can the requisite knowledge be modeled in advance? Whether the implementation then involves a creative element or not – that’s a deeper philosophical question.

In online interactions, we must now ask: How long does it take me to identify AI in action? For customer service and support queries, the first thing we encounter nowadays is often a chat bot.

We cannot confirm artificial intelligence in a philosophical sense; all we can do is demonstrate the nondistinguishability of human-human interactions from human-machine ones. Of course this can be very useful for practical purposes. If you consider companies that would like to use AI for customer contact, for instance: machines can already provide simple functionalities and straightforward answers at the first level.

Neural network is another buzzword in the AI community. What does it mean?

Neural networks are a machine learning method originally inspired by biology. The term refers to a sequence of functions that calculate outputs over several layers from a certain set of inputs. Over the past few years, we have acquired the ability to train such networks even when they have a wide variety of parameters – into the hundreds of thousands, or even millions – across multiple levels.

Similarly to how the human brain works, this kind of network is able to determine, structure and represent intermediate results in a completely different way, allowing it to accomplish much higher performances. This is made possible by algorithmic progress and the massive amount of training data we have available today. The selection of this data is hugely important, especially when we decide not to model knowledge in advance, thus waiving the opportunity to incorporate certain guiding principles into the system. Another important factor is the strong growth in computing power.

We often read of "strong" and "weak" AI. What exactly is the difference?

This discussion has been around for many decades, and there is no universally recognized rule. The debate around "strong" and "weak" AI is about whether we classify AI merely as "exhibiting intelligent behavior," which would describe "weak" AI, or whether AI ultimately functions just like a human mind, which we would characterize as "strong" AI. This then gives rise to the related question as to whether we would even attribute consciousness or accord personal rights to an artificially intelligent system – be that in an emotional, philosophical or merely legal sense. Behind this lurk the fascinating questions: In a profound sense, what is intelligence and what is creativity? How do we want to accept and treat artificially intelligent systems? It's worth discussing these questions in depth.

Does this raise the question as to whether an AI system must behave ethically or morally?

It would never be acceptable if an AI system were to behave in a less ethical, less moral, less correct, less socially acceptable manner than a human. Of course we have to apply at least the same standards to AI systems as we do to people. In fact, we should apply higher standards, as AI systems do not get tired and are never emotional or lacking concentration.

What that means in specific cases will, of course, be highly contested. We're all familiar with the debate about self-driving cars. However, I think the discussion will become less controversial precisely because of the capabilities and reliability of machine systems. If AI systems prevent dangerous situations from arising in the first place, we have to view that as a plus. Essentially, I hope that society as whole engages in a thorough debate about what artificially intelligent systems should do and should be able to do and what they should not do.

How are companies already using AI today?

In the field of image processing, for example, intelligent solutions have long been used in industrial environments, and now they have become even smarter thanks to their ability to learn – for instance, machine vision systems are already in operation across the whole spectrum of manufacturing, industry and visual inspection. Applications that are more familiar to the general public include systems for autonomous vehicles, chat bots and user interfaces – for example, the much-improved ability of computers to process speech.

What is the current state of research in AI?

Over the past few years, we've seen impressive progress in the possibilities of very parameter-rich, deep neural networks that we can actually train. And we're far from the end of this development. In the next few years, it will become important to also reincorporate other, knowledge-based AI techniques. This is a research area that we have singled out as a priority at Fraunhofer, too.

Take medicine for example, where it's still very costly to procure the requisite data for large-scale analyses. Or take industry, where medium-sized enterprises simply do not have millions of posts of a video or picture agency at their disposal, rather just 500 or 1000 individual classifications that were compiled in-house. This will be a major and highly important development.

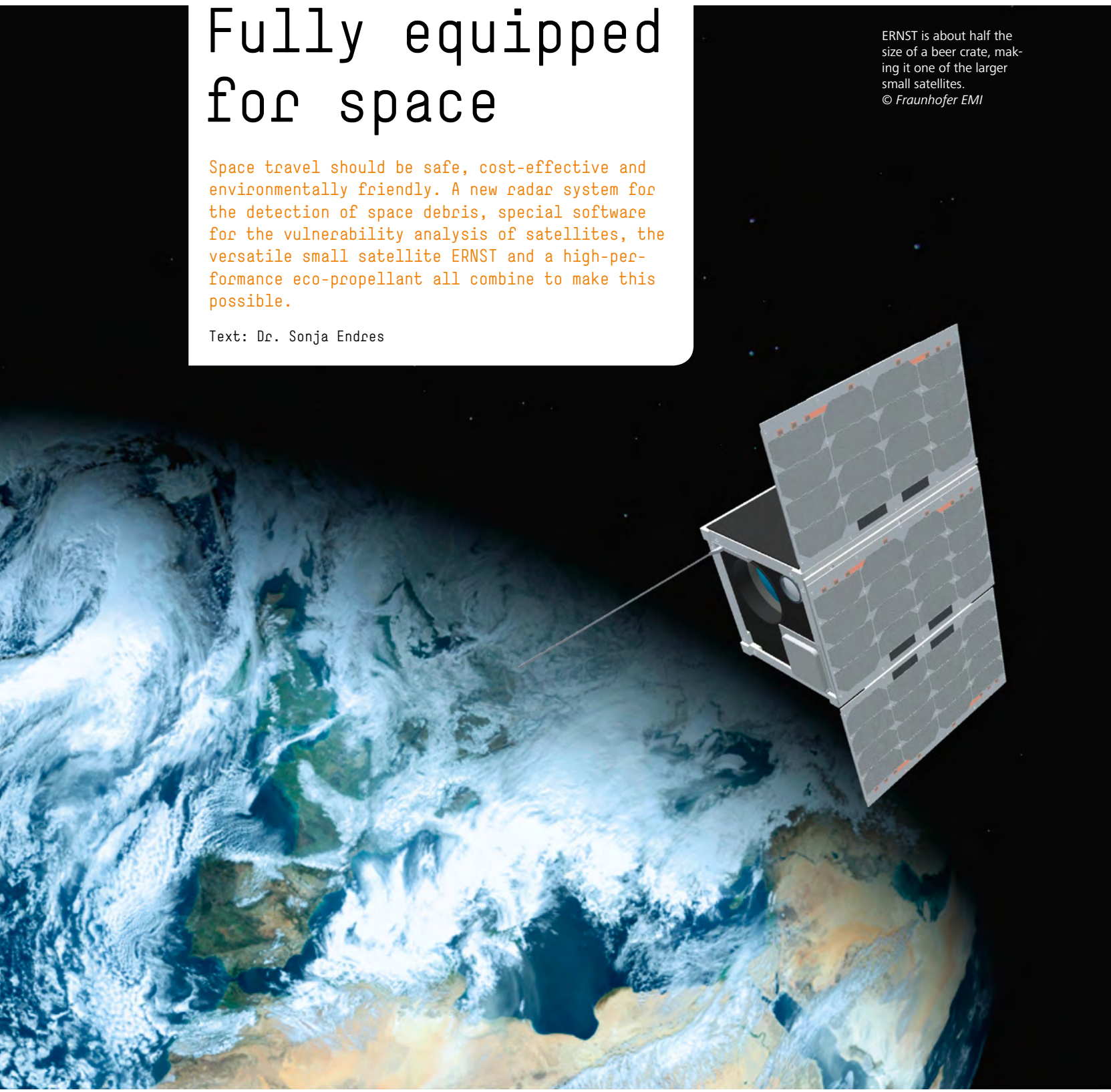
What do you think companies should do now as regards AI?

Companies should apprise themselves of the current possibilities of AI and look at examples – and then think about how they can use these opportunities. This must happen at the highest level, because it affects the fundamental design of the company's business model and the company's positioning. You can't become a business that uses artificial intelligence if you aren't also a data-oriented, data-driven, digitalized company. If data is the key resource you want to work with, then this data must be secure. If it is, in fact, an asset, a trump card that you want to use to operate in the market, then you have to consider the following: Who can you share this data with, with whom do you want to build up these business models? What data are you allowed to collect? What is the cyber security situation? Accordingly, my simple message is: Start now. Invest now, build up skills and know-how, look for the right partners. This is why Fraunhofer integrates AI support into our consulting for digitalization and for big data, as these questions are closely interrelated. ■

Fully equipped for space

Space travel should be safe, cost-effective and environmentally friendly. A new radar system for the detection of space debris, special software for the vulnerability analysis of satellites, the versatile small satellite ERNST and a high-performance eco-propellant all combine to make this possible.

Text: Dr. Sonja Endres

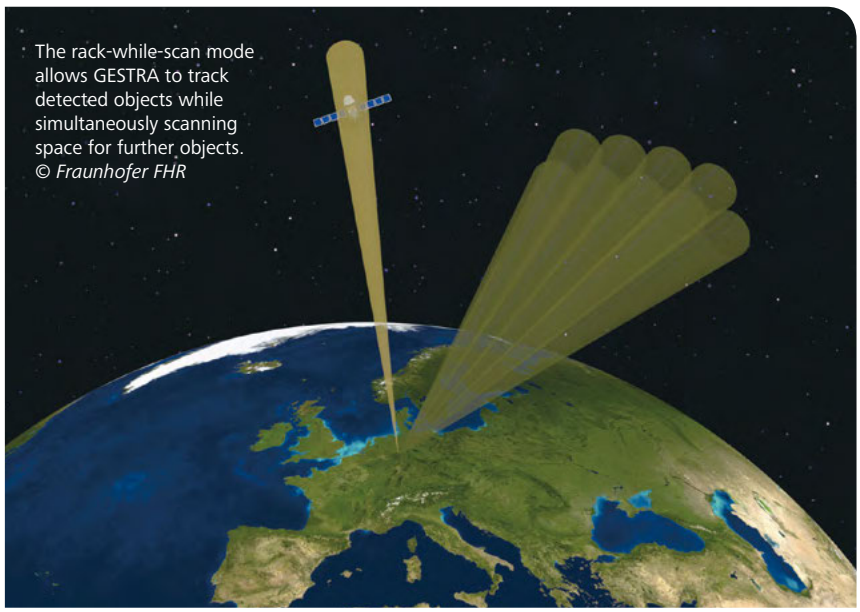


ERNST is about half the size of a beer crate, making it one of the larger small satellites.
© Fraunhofer EMI

In the blockbuster movie Gravity, the characters Dr. Ryan Stone and Matt Kowalski – played by Sandra Bullock and George Clooney – learned to their distress how devastating pieces of debris in orbit can be. And in real life, too, debris hurtling around in space damages satellites and space stations.

Back in 1978, American astronomer Donald Kessler warned about the common practice of leaving large objects such as burned-out rocket stages, payload fairings and disused satellites to orbit the Earth uncontrolled. He pointed out that every collision generated a large number of pieces of debris, which – in a chain reaction – would lead to countless more collisions in turn. Ultimately, this would render near-Earth orbits unusable, argued Kessler. Even launch vehicles would be unable to traverse this zone collision-free on their way to higher orbits – space travel would be at an end.

Although the amount of debris in space has increased considerably since the 1970s, happily this scenario has yet to transpire. Nevertheless, orbiting debris poses a serious threat to everything that moves in space. To avoid this debris, it is important to know where it is.



The rack-while-scan mode allows GESTRA to track detected objects while simultaneously scanning space for further objects.
© *Fraunhofer FHR*

Safe travels thanks to GESTRA and TIRA

"Using the GESTRA surveillance radar, which was developed at Fraunhofer FHR, objects and pieces of debris can be reliably detected in low Earth orbit up to an orbital altitude of 3000 kilometers," says Helmut Wilden, Team Leader for Multifunctional RF Sensor Technology at the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR in Wachtberg near Bonn.

While GESTRA is able to scan large regions of space around the clock, the TIRA radar system – also from Fraunhofer FHR – observes individual objects more closely (see page 38). "GESTRA can detect unknown objects, determine their number and calculate their orbits. More precise information about their size, shape or possible damage is supplied by TIRA." In this way, the two complementary radar systems supplement U.S. orbit catalogs, which have been the main sources of information to date. "NASA does not disclose all its data. Therefore, it is important to be able to access our own measurement data. We're proud that DLR Space Administration entrusted us with this official task on behalf of the German government," says Dr. Nadya Ben Bekhti, co-project manager for GESTRA at FHR.

GESTRA consists of a transmission system and a receiver system, each of which are enclosed by protective casing known as a shelter. "The antenna technology is based on the phased array principle, which involves the pooling of radiation energy from numerous individual antennas. Using the beams – or "lobes" as we call them – you can not only scan large areas very quickly and flexibly for objects but also set aside one lobe for object tracking, while the remainder continue searching independently of the tracking lobe. This track-while-scan mode is optimized for use in space surveillance," explains Ben Bekhti.

GESTRA is unique in being extremely powerful and yet mobile. It can be transported anywhere using a heavy goods vehicle. "In this way, we can respond to changed environmental conditions," says Ben Bekhti. As soon as integration of the individual components into the shelters has been completed and everything has been successfully tested, GESTRA will be brought to its installation site in the summer of 2019. "It is expected that GESTRA will be installed on the Schmidtenhöhe site in the German city of Koblenz. The radar system will be connected to the German Armed Forces' Space Situational Awareness Center in Uedem in the far west of Germany, from where it can be operated by remote control," says Wilden.

Vulnerability analyses and intelligent design

When collisions with pieces of debris are unavoidable, robust materials and clever designs help protect satellites against serious damage. The new PIRAT software developed by the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI in Freiburg calculates whether the satellite design or individual components are able to withstand impacts from space junk. To do this, PIRAT takes into account the flight

Conventional rocket propellant causes acid rain. © *ESA – David Ducros*

path of the planned mission and the particle collisions to be expected on that course. Combining this with the experimental simulation of collisions, the researchers at EMI create vulnerability analyses and protection concepts. Dr. Martin Schimmerohn, group manager for spacecraft technology at EMI, explains: "PIRAT allows us to determine the failure probability of individual components – also those inside the satellite – if a piece of space debris pierces the external wall upon collision and spreads out as a cloud of fragments. Through the clever placement of components and the adding of thin protective layers, you can find a safe design with minimum impact on the overall system."

ERNST: the quick and cost-effective way of traveling to space

So that yet more space debris is not created in the future, today's engineers ensure that new satellites are able to re-enter the Earth's atmosphere under their own power to burn up there when their mission is over. The small satellite ERNST will also be equipped with technology to allow re-entry. In developing ERNST, EMI scientists have created a small satellite that is lightweight, reliable and versatile – reducing the development time and costs. "Generally, several small satellites ride piggyback with large launch vehicles – this allows even small groups of researchers with limited financial resources to carry out tests in space. In research, this is an important step forward for us," says Thomas Loosen, Head of the Fraunhofer Space Alliance Administrative.

Fraunhofer Space Alliance
www.space.fraunhofer.de/en.html

Small satellites – sometimes called cube sats on account of their shape – have a standard size of one unit (roughly 10 x 10 x 10 cubic centimeters). Consequently, they fit perfectly into special containers which are stacked on top of each other in the launch vehicles. The disadvantage of cube sats is their limited performance. For example, they cannot be fitted with a large solar panel surface for generating power. In addition, the payload weight is also limited. As a result, there has been a trend toward building larger cube sats.

"ERNST consists of twelve units, making it about half of the size of a beer crate. The format is ideal, because it facilitates the carrying of more complex payloads and offers higher performance, while also ensuring compatibility with commercially available cube sat components," says Schimmerohn. Despite its larger size, ERNST still fits in the standard transport containers used in launch vehicles, filling their space to the maximum.

"The small satellite is designed as a modular platform, which is reproducible and can be individually adapted to meet the needs of particular missions," adds Schimmerohn. "We've procured flight-proven technology, such as the on-board computer, and combined it with our own technological developments, such as a filter wheel and a data processing unit."

Expanding possibilities in space

For its mission, which begins at the start of 2021, ERNST will be equipped with an infrared camera for Earth observation. Interestingly, the camera is mounted on a special bracket known as an optical bench, which was manufactured using metallic 3D printing technology. 3D printing methods afford new, almost unlimited design freedom as well as shorter production times. They have previously been used only to a very limited extent in the space sector on account of the stringent safety and quality standards.

"It's not the 3D components that are problematic, but conventional verification techniques. Many tests are based on optical methods, which do not work with the comparatively rough surfaces of additively manufactured parts," explains Schimmerohn. "The loads on the components are greatest during the launch of the rocket. In comprehensive tests, we established that the optical bench withstands these loads."

Schimmerohn and his team used the advantages that additive manufacturing techniques offer. Using intelligent algorithms, they developed a light, organically appealing structure that adapts optimally to the environmental conditions. "On the outside of the optical bench, we created a three-dimensional surface made up of many small pyramids. This gave us a larger radiating surface, via which the heat generated

during operation of the satellite can escape into space. In this way, we could combine various functions in a unique component."

Schimmerohn is convinced that additive manufacturing methods will be used increasingly in space technology in the future – not instead of, but as a useful complement to conventional techniques. "Equally, small satellites will not replace large ones, but will substantially expand our possibilities in space." Schimmerohn sees great potential especially in the collecting and connecting of heterogenous data. In addition, many small satellites can be connected to each other to form larger constellations, enabling them to provide services such as full coverage Earth observation in high quality.

Environmentally friendly launches

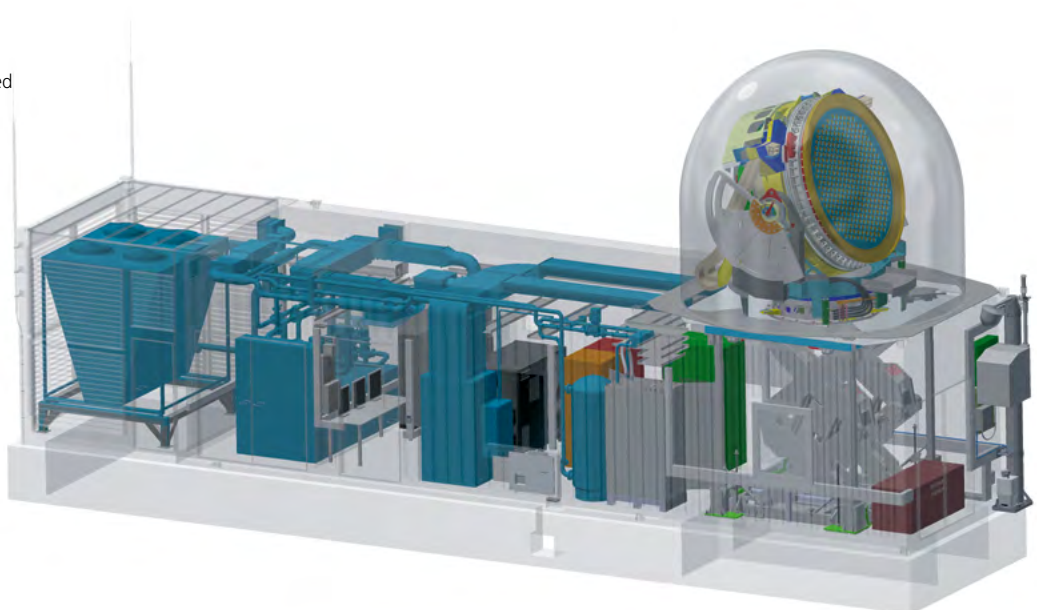
So that Earth does not suffer from the increasing activity in space, researchers at the Fraunhofer Institute for Chemical Technology ICT in Pfinztal near Karlsruhe have now developed a rocket propellant that does not use ammonium perchlorate (AP), which is harmful to the environment and to human health. AP is used in conventional propellants as an oxidizer, which ensures that enough oxygen is available for combustion. The problem is that it produces tons of hydrochloric acid as a waste product – during the launch of the European Ariane or Vega rockets, around 70 tons; during the launch of the American Space Shuttle rocket, more than 80 tons. This acid gets into the environment and causes acid rain in the area around the rocket launch pads.

AP itself is also dangerous: it disrupts the human hormonal balance and leads to various serious effects in organisms.

For this reason, the European Commission is considering whether to ban the production and use of AP. "With our propellant, which was developed in the joint European project GRAIL, we offer an AP-free alternative that is just as powerful," says project manager Dr. Volker Gettwert. He and his team replaced AP with ammonium dinitramide (ADN) – an oxidizer that was developed in Soviet laboratories in the 1970s. "ADN is commercially available in large quantities. That is a big advantage compared to products we develop ourselves, because there are often problems in upscaling the volumes, in other words the step up from small quantities in the laboratory to large quantities in the factory. That costs time and money."

However, it is not simply a matter of replacing AP either, because the new oxidizer also changes the characteristics of conventional propellant. "ADN burns off much faster than AP. We have to adjust the propellant mixture accordingly. After all, the rate of combustion determines the amount of gas that is produced – and more gas generates more thrust for the rocket. The new propellant must also withstand the compressive load generated during ignition. If it crumbles or cracks form, a huge surface is suddenly created. Then, much more is burned than intended, the pressure in the combustion chamber rises and the whole thing can explode."

The ICT team has managed to optimize the new propellant so that its characteristics match those of conventional propellant. "That's a big advantage, as it means that the rocket propulsion systems do not have to be technically adapted to be able to use the new propellant. The chances are good that the propellant will be used in space travel in the near future." ■



For transport, GESTRA's radar dome can be removed and the antenna retracted.
© *Fraunhofer FHR*

A lethal threat: Space debris in orbit

Defective satellites, metal wreckage, wayward tools – countless objects are orbiting the Earth, putting commercial satellites and space missions in harm's way. Fraunhofer researchers are working on a way to detect space-borne junk and pinpoint its exact position.

Text: Mehmet Toprak

No worries – it's just garbage. Collect it, dispose of it and be done with it. However, this flotsam is drifting in Earth orbit at altitudes of 1000 kilometers and higher. Metal scrap such as separated rocket stages, defective satellites and other debris – even screwdrivers lost by astronauts working in space – are circling the planet. There are at least 20,000 known objects, plus countless tiny bits of detritus floating in orbit. Then again, "float" may be a poor choice of word considering that this junk is hurtling through space at a speed approaching 30,000 kilometers an hour. At that velocity, a piece of metal measuring just one centimeter across poses a lethal threat. It would hit anything crossing its path with the force of a midsized car doing 50 kilometers an hour.

Small wonder, then, that removing this flying junk presents such a towering challenge. And before these pieces can be rendered harmless, they have to be found first.

High-performance radar at Wachtberg

That sounds like a job for TIRA (Tracking & Imaging Radar). There is nothing in Europe quite like this space observation radar at Wachtberg operated by the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR. Its centerpiece is an antenna with a diameter of 34 meters, shielded by a white dome-like shell called a radome.

The antenna rotates 360 degrees horizontally and 90 degrees vertically. Weighing a hefty 240 metric tons, it completes a full turn in 15 seconds. TIRA was not built to keep an eye on garbage, of course. It serves mainly to analyze objects in space and detect asteroids and meteorites. TIRA also supports missions conducted by space agencies from around the world.

However, the task of detecting scrap in orbit is moving up the priority list. This debris jeopardizes many satellites serving to broadcast TV signals, communicate, navigate and watch the weather. Modern society has come to depend on all these high-tech satellites; we would be lost without them.

Dr. Ludger Leushacke, head of the Radar for Space Observation department at Wachtberg, is proud of the antenna's remarkable performance: "The system detects objects just two centimeters in diameter at a distance of 1000 kilometers." Thousands of these tiny pieces of junk are orbiting the planet. And every impact creates new, even smaller fragments, for example, when out-of-service satellites collide.

The unique advantages of radar

Radar's physical properties are an asset when it comes to determining the precise location of even very small objects. It detects objects in any weather, day or night. Radar beams pierce the cloud cover, which optical telescopes cannot do because they need light to work.

Also, distance is not a factor in radar images' resolution. Radar can reach out across 1000 kilometers to capture rich detail. "A typical optical telescope would have to move within a 50-kilometer range of the object to achieve the same resolution," says Leushacke.

Simulation software to predict position and rotation

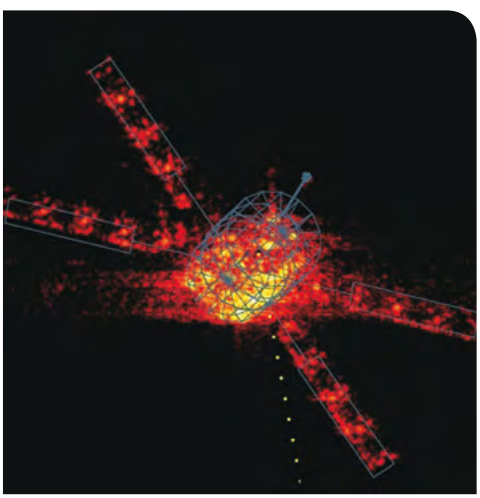
The system works with imaging and tracking radar. Imaging radar produces detailed images of the captured object; tracking radar determines the orbit. Heads up, experts: The narrow-band tracking radar operates at a transmission frequency in the L band (1.333 GHz); the imaging radar in the Ku band (16.7 GHz). Data received by the antenna are then evaluated. Leushacke and his team work with a company called Hyperschall-Technologie Göttingen (HTG) to this end. Its developers have programmed software that simulates the motion of objects in orbit. The program also simulates very complex tumbling patterns based on the FHR's radar data. "These forecasts are so reliable and accurate that we can predict how an object will behave in one or two years," says Leushacke by way of explanation. Every space mission requires some lead time and therefore has to be carefully planned, so this predictive capability is vital.

Space-borne fiber lasers

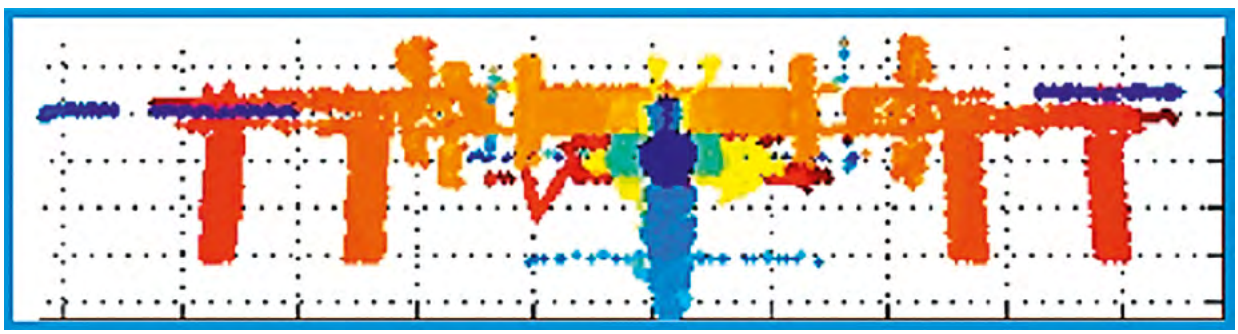
The FHR has its colossal radar system, but colleagues at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena have opted for something completely different. They developed a remarkably powerful fiber laser that detects oncoming objects in space rather than from Earth. The IOF's laser is able to fire ultra-short bursts of light lasting just a few

A collision with debris can wipe out a satellite.
© *Fraunhofer FHR*

The experts use existing wireframe models of objects such as a satellite for comparison with radar images.
© *Fraunhofer FHR*



The enormous space observation radar at Wachtberg finds objects measuring just two centimeters across.
© *Fraunhofer FHR*



This is how Jena-Optronik's RVS 3000 sensor "sees" the International Space Station ISS (simulated image). This sensor data helps the ATV transport module to dock. © *ESA*

What is a fiber laser?

Fiber lasers are solid-state lasers. A solid – in this case, glass fibers – is "doped" with rare earths such as erbium or neodymium to create the active medium needed to generate a laser beam. These elements amplify light. The medium is repeatedly bombarded with light, which is reflected back from a mirror at the end of the glass fiber to excite these elements. The light emitted by the first erbium atom triggers a cascade, prompting all other atoms to emit light. This creates an extremely bright and focused beam. Fiber lasers' peak power ranges up to several megawatts and the quality of their beams far outstrips that of CO_2 lasers.

The ATV-5 control center in Toulouse. The ATV transport module can be seen in the huge display in the background. © *ESA*

billionths of a second at a rate of 10,000 times per second. And it needs less than 10 watts of input power to do this.

Jena-Optronik GmbH integrated this fiber laser into its RVS 3000 sensor system. No larger than a shoe box, this system is built to travel in space shuttles and transport modules. When these vehicles approach an object, the laser determines its exact distance and rotation.

How does that work? Movable mirrors aim the transmitted light signal towards the object, for example, a defective satellite. Its surface reflects the light, which a sensor then detects. The light signal is a range-finder – the system calculates the distance based on the travel time to the object and back. But the RVS 3000 can do a lot more than that. Again, the laser emits more than 10,000 bursts of light per second. At the same time, the mirrors constantly change their angles. The light beams sample the object's surface much like a scanner, providing a set of data points called a point cloud. Imaging processes convert this cloud into a highly accurate 3D image of the object. Dietmar Ratzsch, managing director of the Jena-based high-tech manufacturer, says: "The system's sensors are extremely sensitive; they even register a billionth of the emitted light intensity."

The RVS 3000 serves not only to analyze space debris. The European Space Agency ESA, for example, uses the Jena-based company's technology to automatically dock the ATV transport module to the International Space Station ISS. It is not enough for this laser to be powerful and precise; it also has to be rugged enough to take a lot of punishment. "One challenge for us was to prepare the laser for the extreme stress of deployment in space. The G forces at launch, radiation in space and extreme temperature fluctuations put a lot of strain on the optoelectronic instrument," notes Dr. Thomas Schreiber from the Fiber Laser Group at Fraunhofer IOF.

Could this fiber laser blow away space flotsam with a heat ray? The laser cannons of sci-fi flicks are a very long way off yet. The best way to dispose of space debris today is to nudge the individual objects out of their orbits so that they slowly but safely sink into the atmosphere and incinerate on reentry. ■

The French Myriade satellite bus transports, controls and supplies MERLIN with energy. © *CNES / illustration David DUCROS, 2016*

A climate watchdog in space

Hailstorms, droughts, late frost – German winegrowers and farmers are not alone in feeling the fallout from climate change. Extreme weather is on the rise everywhere. A robust new laser system that takes readings with unprecedented accuracy is to be launched aboard the MERLIN climate satellite. The purpose of this Franco-German mission is to gather data on the greenhouse gas methane.

Text: Dr. Sonja Endres

Methane, primarily a byproduct of decomposition, is emitted from sewage, the stomachs of cows and landfills. Odorless and colorless, this gas is also trapped in coal deposits. When released, it combines with air to form an explosive mixture that has caused many accidents in mines. Vast quantities of this gas are imprisoned in the seabed at depths of more than 500 meters in an ice-like solid called methane hydrate. If the water warms, these hydrates break down, liberating methane with devastating consequences for the climate. Methane is 25 times more harmful to the climate than carbon dioxide, but it is – as yet – much rarer in Earth's atmosphere. Over the past ten years, its concentration has risen sharply – and unexpectedly. Researchers are puzzled as to why. To find answers, they have to measure where and in what quantity methane is released into Earth's atmosphere.

Previous satellite-based systems were unable to provide sufficiently reliable, high-resolution global measurements. They relied on sunlight to detect methane. Light absorption gives scientists an indication of the molecules present in the air, but these measurements can only be taken in cloudless skies on the sun-facing side of the Earth.

Measuring methane anytime, anywhere

"Our laser-based measuring system is independent of sunlight, so it can be used to measure anytime and anywhere," says Hans-Dieter Hoffmann who is co-developing the new laser technology at the Fraunhofer Institute for Laser Technology ILT in Aachen. "This mission aims to provide climate scientists with accurate global data on methane distributions so that they can better predict climate change for the prime contractor Airbus Defence and Space."

To this end, scientists at Fraunhofer ILT are developing a laser that can transmit very precise single-frequency light pulses to Earth. The measurements obtained this way enable the presence and concentration of methane to be determined far more accurately than in systems that rely on sunlight, but in both cases they are based on light absorption. The laser pulse can be set precisely to the absorption line of methane at a predetermined wavelength. "Every gas has its spectral fingerprint. It absorbs light particularly well or poorly at specific wavelengths. The important thing is to select wavelengths at which other gases have no absorption line to be sure of obtaining undistorted measurements," explains Hoffmann.

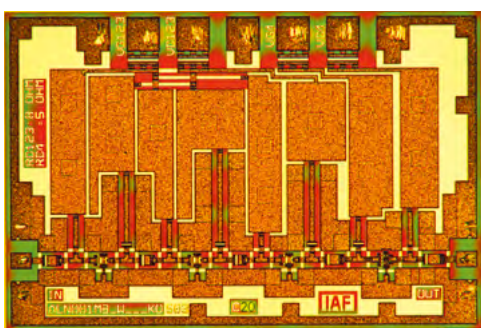
The laser has to shrug off temperature changes from minus 30 to plus 50 degrees Celsius and hold up to strong vibrations if it is to operate reliably and maintenance-free throughout a three-year space mission. "We developed optomechanical components for the laser such as mirror and lens mounts that meet these demands and retain their very precise settings."

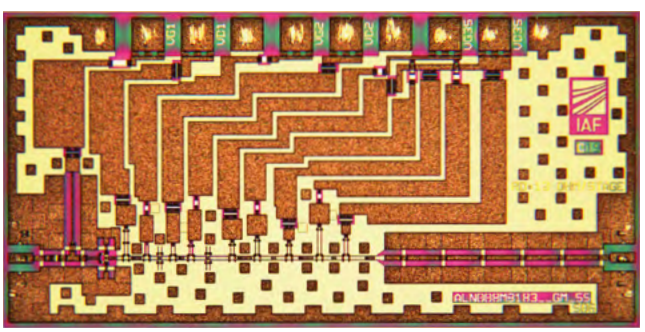
The air inside the laser must also be kept clean. "Adhesives contaminate the air. Tiny particles detach, deposit on the mirrors and destroy the optics," explains Hoffmann. "That's why we used nothing but solder and screws to assemble the laser – an unprecedented technique that makes this system even more robust and therefore also an interesting prospect for many industrial applications." The German part of the MERLIN project is funded by the German Federal Ministry for Economic Affairs and Energy under DLR contract 50 EP 1601. ■

Microwave amplifiers improve weather forecasts

In the years ahead, the European Space Agency (ESA) will send a number of new weather satellites into space that will be able to measure key meteorological variables, such as precipitation, water vapor and temperature, better than ever before. At the heart of these measurement devices are extremely sensitive microwave amplifiers that were developed at the Fraunhofer Institute for Applied Solid State Physics IAF. These amplifiers can also detect very weak atmospheric signals that are important in improving the precision of weather forecasts.

Text: Tim Schröder





The amplifiers are made of indium gallium arsenide, a semiconductor material. They are so sensitive that they detect even very weak microwave signals. © *Fraunhofer IAF*

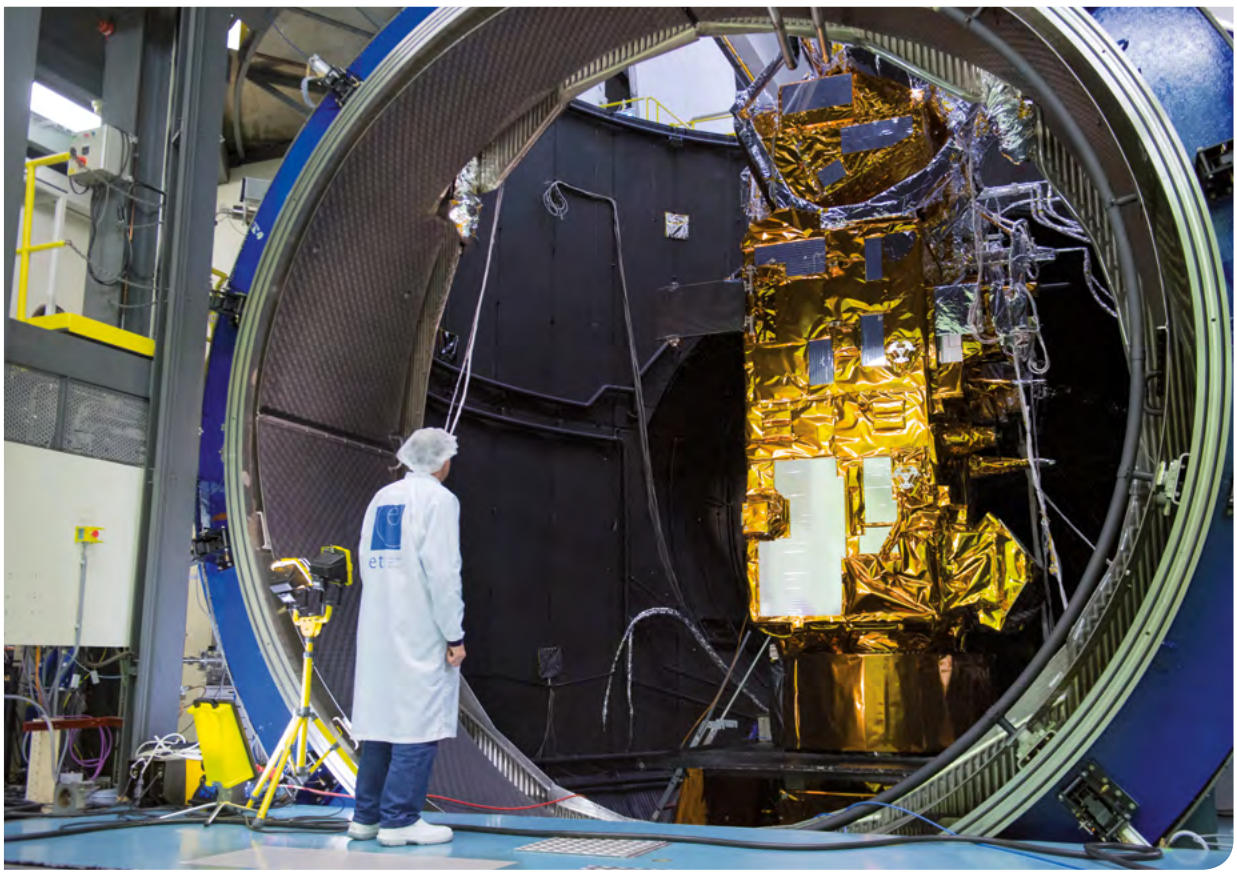
Unlike a few decades ago, weather reports today are remarkably reliable. Meteorologists can now predict the weather for the next two to three days quite accurately, thanks in no small part to the satellites that continuously survey the Earth's surface and atmosphere with their sensitive instruments and transmit thousands of current observation datasets back to Earth. Meteorologists feed this data into computer programs and use simulation calculations to determine how the weather is most likely to develop. But sensing the Earth from such high altitudes is a challenge. The instruments must be extremely sensitive in order to measure values correctly from a distance of several hundred kilometers. The better the sensors, the more accurate the measurements – and thus also the weather forecasts. This is why, in a few years, the European Space Agency (ESA) will launch the second generation of its MetOp (Meteorological Operational) satellites into space. There will be six of these satellites, all equipped with modern, improved measurement technology.

And onboard these satellites will be small but very special technological components developed by the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg: ultrasensitive microwave amplifiers. Every object and every surface emits microwaves, similar to the way our bodies radiate heat that can be seen on an infrared image. Water vapor, rain, fog and ice crystals, all of which are of particular interest for weather forecasts, also emit characteristic microwave radiation. This radiation can be used to determine the distribution of temperature and moisture in our atmosphere, from the Earth's surface up to the highest atmospheric layers. Cirrus clouds, which are composed of ice crystals and are found high up in the atmosphere, also have a major impact on climate and weather.

And only the ultrasensitive amplifiers from Freiburg are capable of measuring the microwaves they emit with a high degree of accuracy, as this type of radiation is in a class of its own.

For one thing, microwaves oscillate at frequencies in the upper gigahertz range. To amplify them, the components of the amplifier must be particularly small. For another, the microwave signals that radiate into space from the Earth and the atmosphere are very weak, measuring just a few nanowatts, and thus require particularly sensitive amplifiers. "Our amplifiers overcome both of these challenges," says Markus Rösch, a research fellow at Fraunhofer IAF. "At the core of these amplifiers are transistors made of indium gallium arsenide, a semiconductor material with unique properties and high sensitivity, and one that we can manufacture into ultrafast components." One property of indium gallium arsenide is that it barely restricts the flow of electrons through the material, thus reducing noise and enabling the amplifiers to detect even microwave signals with a strength of just a few nanowatts.

These transistors – or more precisely their gate electrodes – are the key component of the



According to the current launch schedule, the MetOp-SG satellites will be placed in orbit from 2021 onward – with the Fraunhofer IAF microwave amplifiers onboard.

amplifiers. A gate electrode is a kind of current valve that controls the flow of electrons through the transistor. The gate electrode in the IAF transistor is just 50 nanometers long. This is so small that the transistor can easily follow the ups and downs of the high-frequency microwaves and thus also amplify them.

The researchers at Fraunhofer IAF have been working with indium gallium arsenide for many years now and know how to deal with this challenging material. For, unlike classical semiconductors like silicon, it is much more difficult to work with. "Silicon readily lends itself to producing components in large quantities with absolutely identical characteristics," says Rösch. "Indium gallium arsenide is more obstinate, so special care must be taken during production to ensure that the components actually have the desired properties. And the smaller the components are, the more challenging this becomes." The IAF researchers have developed a precisely controlled manufacturing process in which the amplifier circuits are fabricated in 150 production steps, with an electron beam being used to form the smallest structures, the electrodes. There are only a few companies or institutes in the world that can do this with this level of precision.

On the MetOp satellites, the amplifiers are used in three different microwave receivers that measure various elements of the atmosphere, such as water vapor, ice crystals and oxygen. Each of these elements emits microwave radiation in a specific, characteristic frequency range. Oxygen, for instance, sends clear signals at around 54 gigahertz, while water vapor does so at around 183 gigahertz. IAF had to build amplifiers for a total of six frequency bands between 54 and 229 gigahertz. This entailed designing and producing a completely new amplifier for each frequency range, with circuit components precisely tailored to each frequency. "That was a major challenge. Merely designing an amplifier takes a good 14 days," says Rösch. "And we actually designed several amplifiers for each frequency band so we could compare them and choose the best one." The subsequent characterization – analyzing and testing the amplifiers – was just as laborious.

Microwave amplifiers robust enough to withstand a rocket launch

The amplifiers are currently in the qualification phase, in which the components are rigorously tested for utilization in space. As well as verifying conformance with strict quality specifications, the manufacturers of the MetOp instruments also test the transistors' resistance to the vibrations produced during a rocket launch. Markus Rösch is optimistic that the amplifiers will successfully pass the qualification tests: "The components are remarkably robust. And with our method, we can reliably produce structures measuring 50 nanometers." Still, it will be some time yet before all tests are completed and the MetOp satellites are ready to go into orbit. The first launch is scheduled for 2021. ■

A triple-bladed colossus

The world's largest wind turbine recently went up in Bremerhaven. This prototype, operated by the Fraunhofer Institute for Wind Energy and Energy System Technology IWES, will provide key performance data needed to build tomorrow's more economical and reliable offshore wind farms.

Text: Frank Grotelüschen

Rising to over 200 meters to the tip of the highest blade, this prototype wind turbine figures prominently on Bremerhaven's skyline. © *Adwen*

Three rotor blades make their steady rounds in the wind. At the top of a rotation, when a blade points vertically overhead, the wind turbine rises to its full height of 205 meters, eclipsing Cologne Cathedral by nearly 50 meters. "It is the largest rotating machine to ever be built by humankind. The gondola is the size of an apartment building, and you can walk 50 meters into the rotor blades without having to duck your head," says Prof. Andreas Reuter, director of Fraunhofer IWES.

This giant, which goes by the name of Adwen AD 8-180, is Fraunhofer IWES's most recent major project. Erected on a defunct Bremerhaven airfield, it has been generating electricity since July. Given good wind conditions, its output of eight megawatts of electricity can power around 15,000 households. Adwen is the name of the company that built the prototype; the Federal Ministry for Economic Affairs and Energy pitched in with 18.5 million euros to fund the field test. With a rotor diameter of 180 meters – roughly twice the wingspan of an Airbus 380 – this prototype is currently the world's tallest wind turbine, topping the previous record-holder's mark by 16 meters. Equipped with an array of sensors, this system will provide vital data to help answer the Fraunhofer researchers' questions: How do we maximize the operating efficiency of such gigantic machines and how do they interact with the power grid?

Wind turbines such as the AD 8-180 are designed for deployment in the high seas. "Offshore is where these giants are most economical. Big turbines hardly cost more to transport, assemble and connect to the grid than small ones, and they generate more income for operators because their energy yield is higher," says Reuter. Power output is also on the rise: In the early 2000s, the first offshore turbines delivered two megawatts; today's models achieve five to six. Manufacturers are now boldly going where none has gone before – to the next generation of eight-megawatt systems.

The AD 8-180 is a key prototype for this new generation. The industry usually builds wind farms far out at sea; this system went up on shore to enable easy access. It stands on terra firma, just a few hundred meters from another Bremerhaven IWES facility, the DyNaLab gondola test station. This is where engineers put the AD 8-180's powertrain through its paces. Enormous electric motors and hydraulic rams battered and turned the 777-ton structure for a full year, simulating extreme situations such as the fierce impact of gale-force squalls.

Firmly anchored in a 1700 m^3 concrete foundation in the fishing harbor, the system may now be tested under real-life conditions, from gentle sea breezes to hurricane-force winds. "We want to compare the results of this field test in detail with the results obtained in the laboratory. That way, we can check and improve the quality of DyNaLab tests," explains Reuter. The more realistic the results from the laboratory test bed, the better they can supplement or even supplant long and costly field tests. The benefit for manufacturers is that they can plan and conduct the tests required for certification that much faster. And the ability to fast-track new turbines' time to market is a big competitive advantage in the wind power industry, a global hot-cooker where the pressure to innovate runs high.

How does this goliath stand up to strong winds?

Bristling with sensors from top to bottom, the AD 8-180 prototype is well-equipped to capture all kinds of data. An IWES team of experts for internationally accredited field measurements draws on this wellspring of data to gage mechanical stresses and strains in the tower, generator and rotor blades, as well as temperatures, vibrations, electrical voltages and currents. A monitoring mast equipped with laser-based and various other wind measuring instruments is being installed in front of the plant. These devices can accurately record the turbine's wind exposure at any given moment. The prototype's sensors simultaneously measure how it responds to anything from sudden gusts of wind to constantly high wind speeds.

Another research focus of this project is that of investigating the system's grid compatibility. "Large wind turbines can have a huge impact on the power grid. And the more wind power they feed into it, the better we need to understand how this affects the grid," says Andreas Reuter. A power line runs from this outsized windmill to the DyNaLab to afford

To simplify access, the research facility for testing offshore wind turbines is located inshore. © *Adwen*

An outsized component, ready to be transported to the installation site. © *Adwen*

Tests conducted in the Fraunhofer Dynamic Nacelle Testing Laboratory simulate rotor stress and grid fluctuations. © *Adwen*

deeper insight into its grid compatibility. This line connects these facilities in a common virtual grid. In recent years, Fraunhofer experts have developed new and faster methods to investigate grid compatibility on a test bench. Experts now want to compare the results of these lab tests to the data from the AD 8-180 to underpin the findings gleaned from several months of field trials.

A research platform for new concepts

Wind turbines are also affected by fluctuations and malfunctions in the power grid. In the worst case, sudden spikes or drops in grid voltages may even damage the plant's components. To sound out these risks, the testers deliberately provoke such situations and observe the prototype's response. "Tests like this don't go over well in a public grid. But we can simulate faults in our virtual grid without the neighborhood's computers crashing," explains Reuter.

Further down the road, the AD 8-180 will also serve as a research platform for testing innovative operating concepts. Power companies are keen to engage in collaborative projects. They hope to find even more economical ways of operating offshore wind farms and to further improve their design.

Bremerhaven's mammoth mast is still the world's largest wind turbine. "I don't expect this record to last long," says Andreas Reuter. Even larger and more powerful turbines are very much en vogue these days. Makers of offshore wind turbines are already working on ten-to-twelve megawatt models with rotors spanning a diameter of more than 200 meters. The first prototypes are likely to be up and running in a year or two.

That may be as big as these behemoths get. Materials' load-bearing capabilities are finite, and the industry is already pushing at the limits of technology and physics with the next generation of giants. Reuter believes the doable is all but done: "Plants with 15 megawatts capacity should be on their way, but I find it hard to imagine that rotor blades much longer than 100 meters will be built in the near future." Anything that long would be likely to collapse under its own weight. ■

Making sustainable use of scarce water resources

Yurt community with no water infrastructure.
All photos © Fraunhofer IOSB-AST

Clean water is a rare commodity in Mongolia. Since 2006, Fraunhofer researchers have been working hard to establish a sustainable water management system in the Mongolian city of Darkhan and the surrounding area. The installation of new pipelines, pump systems and wastewater treatment plants in the second-largest industrial region in the country – covered by thousands of acres of steppe and desert – is now paying off.

Text: Britta Widmann

With a smile on his face, eleven-year-old Kenan inserts his prepaid top-up card into the machine at the water kiosk and presses the green button. Now he can fill his canister with fresh drinking water. Locals now have access to the water kiosk 24 hours a day, 7 days a week – even after the sun goes down. Until just recently, it closed at 4.00 pm. If the inhabitants of the yurt community wished to fetch clean water from one of the 35 kiosks on the outskirts of Darkhan, an operator had to be present to turn on the faucet and sell the water. Most "customers" are children who come along with canisters to fill with water.

"This setup was highly impractical, which is why we automated the kiosks. Now, the locals can come and fill up at any time at the simple push of a button. They pay for the water with prepaid top-up cards," explains Dr. Buren Scharaw, researcher at the Advanced System Technology Branch (AST) of the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB. Mongolian by birth, Scharaw manages the project known as MoMo, which stands for Integrated Water Resources Management for Central Asia: Model Region Mongolia. A team of natural and social scientists, engineers and partner companies have been working on the project since 2006 to put sustainable measures in place for the protection of scant water resources.

Dilapidated pipes, polluted rivers

Ensuring a supply of clean drinking water and the effective treatment of wastewater poses

Project manager Dr. Buren Scharaw explains to local experts how a small wastewater treatment system works.

Automatic payment at a water kiosk.

The catchment area of the river Kharaa.

a major challenge in Mongolia. On top of the outdated technical infrastructure, dilapidated pipelines and pump systems have caused living conditions in many regions of the country to deteriorate in recent years. Increasing industrialization and intensive mining and agricultural activities are polluting groundwater and rivers, and the extreme seasonal variations in temperature and the impact of the growing population make matters even worse. The Advanced System Technology Branch (AST) of Fraunhofer IOSB is coordinating the municipal water management component of the project – now in phase III. Germany's Federal Ministry of Education and Research (BMBF) is backing Fraunhofer's participation with funding to the tune of 2.9 million euros.

The model region selected for the researchers to study covers the catchment area of the river Kharaa and the city of Darkhan, where the team is monitoring environmental factors and installing innovative water management technologies. Darkhan is a typical Mongolian industrial city. It is home to some 100,000 inhabitants, approximately half of whom live in permanent housing while the other half live in yurts on the city's outskirts. The yurt settlements do not have their own supply of potable water. Instead, the inhabitants generally get their drinking water from water kiosks. The communities also lack proper sewage systems.

New drinking water systems and water treatment plants

Dr. Buren Scharaw has been traveling to Mongolia on a regular basis since 2006, where he has been helping to establish a sustainable supply of drinking water. In phase I of the project, Scharaw used monitoring systems to demonstrate that over 50 percent of drinking water in the Darkhan distribution network was being lost due to leaks. "Large volumes of drinking water were simply draining away into the ground. Given that temperatures drop significantly below freezing in the winter, the pipes are installed 4.5 to 5 meters deep underground. This makes it difficult to locate the leaks," says Scharaw.

Using Fraunhofer's HydroDyn water management software, the project team created a computer model of the distribution network and used it to simulate hydraulic flow behavior, flow velocities and water pressure. By visualizing the network in this way, they were able to gain an understanding of the process in areas for which they had no previous records. They employed a range of different methods, including data monitoring, volume and mass balancing as well as the comparison of physical and simulated values, to identify where the water was escaping. Using this information in conjunction with

A central water treatment plant in Darkhan shows its age.

MoMo project – German partners

- Bergmann Abwassertechnik AG
- The German Development Institute
- The Leibniz-Institute of Freshwater Ecology and Inland Fisheries
- p2m berlin GmbH
- terrestris GmbH & Co. KG
- Helmholtz Centre for Environmental Research – UFZ

Construction of a water treatment plant in Teshig Soum, Bulgan Province.

the sensors installed in the distribution network, the team was able to track down the locations of the leaks, reduce the volume of lost drinking water from 50 to 25 percent and minimize operating costs as a result. "In phase III, we're rehabilitating the pipework and now that we can monitor their energy consumption, we're working on optimizing the energy-intensive, decrepit pumps," says Scharaw. Given that groundwater is the only sustainable water supply in Mongolia, the researchers also analyzed and mapped the groundwater resources, including their volume and quality. "We have to monitor the groundwater continuously because contamination levels change all the time."

In another project milestone, the urgently needed reconstruction of Darkhan's dilapidated central water treatment plant has now begun, with partners from Germany among those involved in the task. Plans are also in place to build 25 decentralized water treatment plants in Mongolia.

The project sponsors have also had the opportunity to see the success of the project for themselves: "Three delegations from the BMBF already traveled to Mongolia to see the results of the work firsthand. I'm happy to say that they were extremely impressed," says Scharaw.

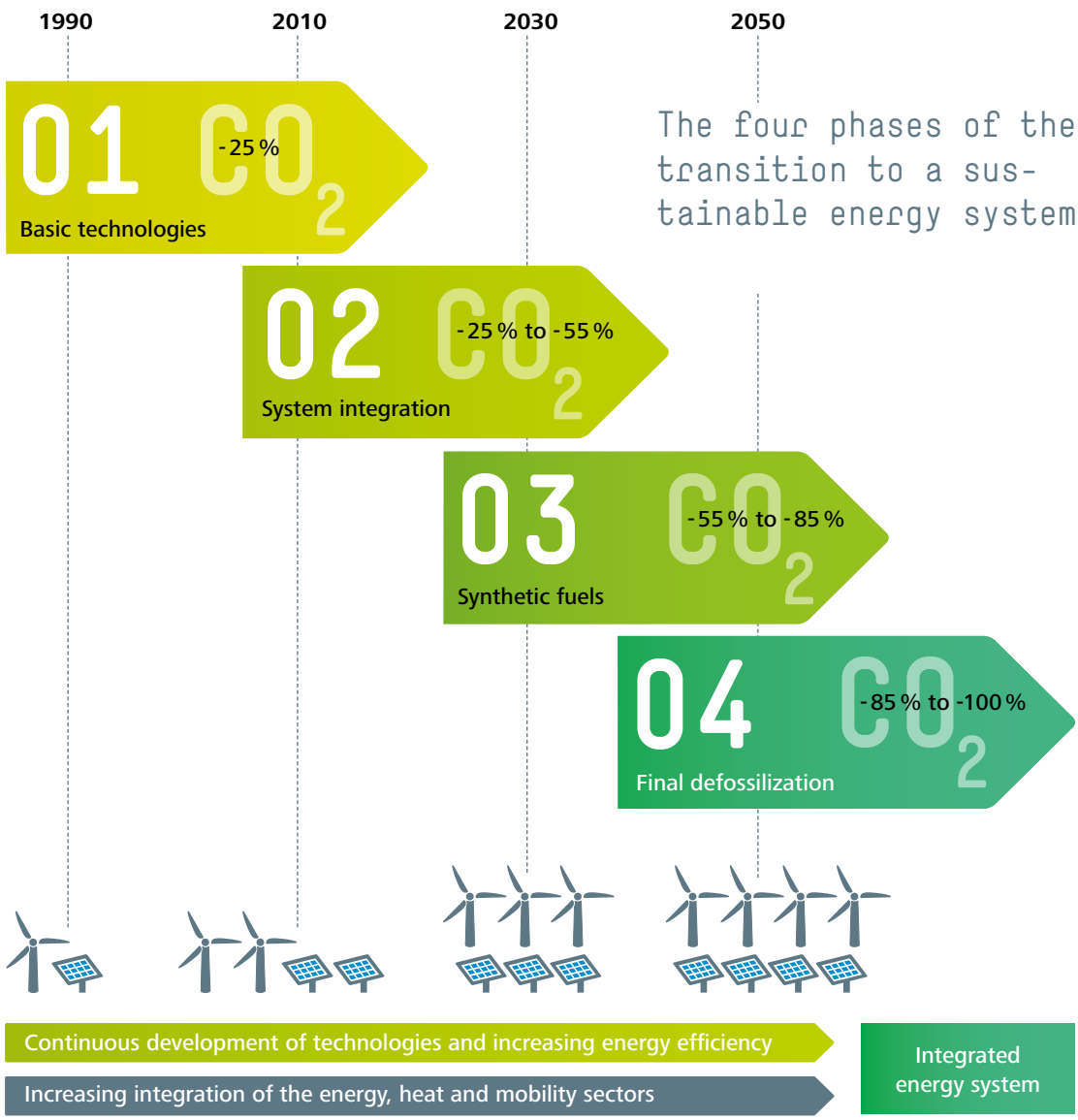
Research results set to be transferred to neighboring regions

The biggest challenge of all for Scharaw is yet to come: Phase III of the MoMo project is scheduled to end on December 31, 2018. This is when the project partners' involvement also comes to an end. After this date, all plants and equipment must be operated by local staff. "As things stand, they're not qualified to do so. The staff still need to be trained to make sure the region can continue to supply drinking water and wastewater services in the future, too. It's a mammoth task and responsibility lies with Fraunhofer to see it through," says Scharaw. Afterwards, he plans to transfer the research results to similar neighboring regions and consequently establish a foothold in the environmental and water sectors in the Central Asian market. ■

Transition to a new energy economy – Phase two

Only by implementing a clear change in policy will Germany succeed in reaching binding climate objectives. This is the conclusion of a joint position paper addressing the future of Germany's energy system published by the scientific academies acatech, Leopoldina and the Union of the German Academies of Sciences and Humanities. The conclusion is based on model calculations developed by Fraunhofer ISE. In the paper, the researchers call for greater integration of the energy, heat and mobility sectors in conjunction with a significant expansion of wind power and photovoltaics. In the long term, renewables are set to become the leading source of energy – including in the mobility and heating sectors.

Text: Franz Miller



The four phases of the transition to a sustainable energy system

Future Energy Systems

"A cross-sectoral approach – Options for the next phase of the transition to a sustainable energy economy" is the title of a position paper published as part of the Future Energy Systems ESYS academy project. The working group was chaired by Fraunhofer ISE director Prof. Hans-Martin Henning and acatech Executive Board member Prof. Eberhard Umbach. In the joint initiative by achtech (the German National Academy of Science and Engineering), Leopoldina (the German National Academy of Sciences) and the Union of the German Academies of Sciences and Humanities, around 100 energy experts from science and research are drawing up options for implementing a secure, affordable and sustainable energy supply.

The energy transition is well underway in Germany, but the climate targets defined under the Paris Agreement are becoming increasingly unattainable. After all, Germany has not succeeded in reducing its CO_2 emissions since 2009. To help turn this situation around, more than 100 experts from the scientific academies involved in the Future Energy Systems ESYS initiative have joined forces to identify solutions. In November, they presented their results in a report entitled "A cross-sectoral approach – Options for the next phase of the transition to a sustainable energy economy." In line with the climate targets, the aim is to have a flexible and future-proof energy system in place by 2050 that is compatible with new technologies.

"Germany is entering a new phase of the energy transition. In the last 25 to 30 years, wind power, photovoltaics and also biomass technologies have been developed, expanded and their costs reduced significantly. Now, the basic technologies are available for comprehensive system integration. From now on, the aim is to support and implement cross-sectoral technologies," explained Prof. Hans-Martin Henning from the Fraunhofer Institute for Solar Energy Systems ISE at the presentation of the study. Alongside acatech Executive Board member Prof. Eberhard Umbach, Prof. Henning chaired the working group that determined key aspects of the future energy supply on the basis of expert discussions, a comparison of relevant energy scenarios and his own model calculations. They then used this information to establish the options available to Germany to optimize its energy system. The calculations were made using Fraunhofer ISE's REMoD-D simulation and optimization model. This model determines – on the basis of binding CO_2 reduction targets – the cost-optimized path Germany must follow between now and 2050 to transform its energy system, taking all sectors and energy sources into account.

The energy transition is not just about electricity

According to Hans-Martin Henning, the extensive model calculations and analyses show that only a holistic, cross-sectoral approach will open up the avenues necessary to gradually convert the whole energy system to predominantly renewable energy, and thus achieve a drastic reduction in the use of fossil fuels. The transition must not focus solely on electricity generation but rather incorporate all three sectors, he says. Eberhard Umbach adds: "Although wind power and photovoltaics have grown considerably in recent years, 80 percent of Germany's energy is still generated from fossil energy sources. In the building and mobility sectors in particular, fossil fuels still dominate."

In the long term, the researchers expect electricity from renewable sources to become the leading source of energy. The new applications in the mobility and heating sectors, however, may cause electricity consumption to almost double by 2050. Wind power and photovoltaic systems would have to increase their capacity five- to sevenfold as a result – a highly ambitious task. Efficiency technologies and the targeted use of bioenergy, solar thermal power and geothermal energy could limit the need for additional wind parks and photovoltaic power and thus ensure society's acceptance of the energy transition.

Electricity generated from renewable sources is also the key to reducing CO_2 emissions in the mobility and building sectors. "Technologies that use electricity directly and efficiently, such as electric vehicles and heat pumps, are set to play an increasingly important role in the future. It's important that we start giving these technologies a stronger market presence today. We need to counterbalance the fluctuations in wind and solar energy generation with short- and long-term storage solutions and flexible energy usage models," says Hans-Martin Henning.

Batteries and pump storage units alone are not enough. For this reason, flexible electrolysis systems will be required to generate hydropower for use in industry, in mobility or as large-scale storage solutions.

"To ensure the supply remains sustainable, additional energy sources such as hydrogen and synfuels should also be available for sea and air transport, for instance, or to cover seasonal, weather-related bottlenecks," says Hans-Martin Henning, describing the tasks that researchers must address in the future. A great deal of research is still required to find solutions.

Synfuels set to become indispensable

Synthetic fuels are set to become a cornerstone of the energy system thanks to their suitability for storage and use in applications for which purely electric solutions can be used only with difficulty or not at all, i.e. air, sea and heavy-duty transport. According to the study, hydrogen will play a decisive role in third phase of the energy transition due its versatility. It can be used, for example, for heating buildings and as fuel for transport, or stored for energy generation at a later time. Converting hydrogen into methane or liquid fuel allows it to be easily stored and transported. The natural gas grid provides an ideal long-term storage solution. Whether in the form of natural gas, biogas or synthetic gas, gas will play an increasingly important role in general thanks to its low emissions and versatility.

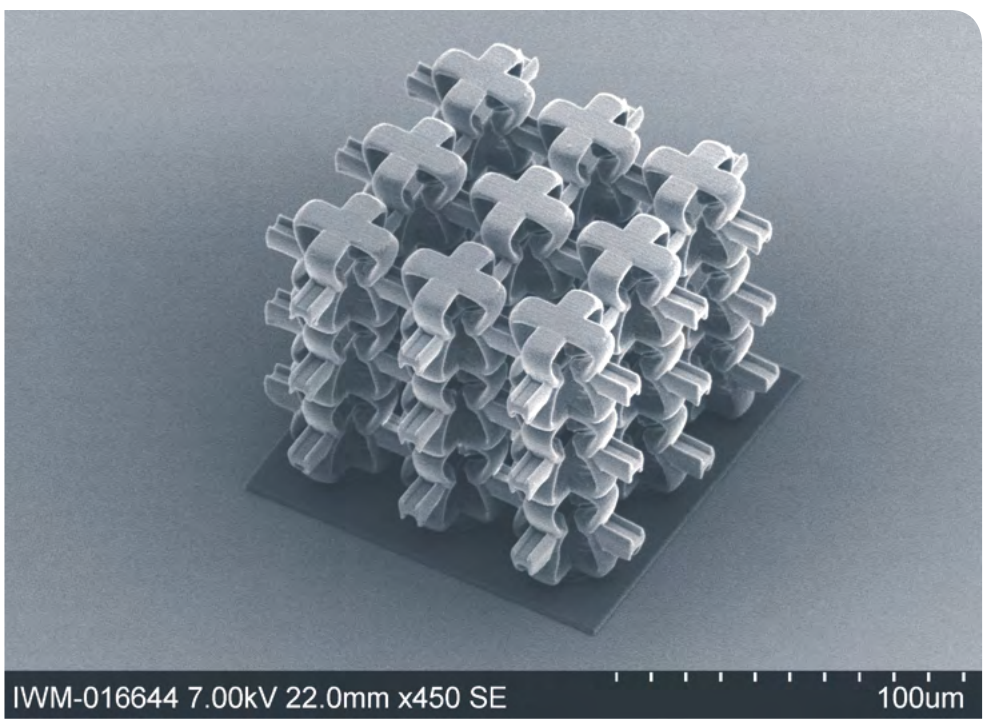
Reserve capacities, however, will be required to secure the supply in all weather conditions and at all times of the year. Suitable candidates for the purpose include cogeneration plants, low-emission gas-fired power stations or fuel cells powered by hydrogen, natural gas or synthetic methane.

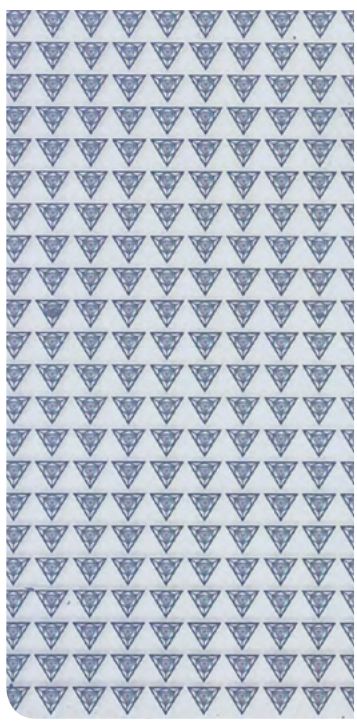
Restructuring the energy system will be an extremely expensive process. ESYS experts estimate that the supplemental annual costs involved will amount to one to two percent of Germany's gross domestic profit. As a fundamental control mechanism, the experts advocate a standard, effective CO_2 price. Only this way will renewable energies be able to compete with fossil fuels in the market. Another important consideration the experts highlight is certainty in planning, which is a key factor for investment in environmentally friendly technologies. For this reason, policy makers must commit to meeting binding climate protection targets. According to the experts, an integrated energy system will be in place by 2050. This system will have zero CO_2 emissions, yet will remain affordable and ensure a stable and reliable power supply. ■

Programmable materials

Researchers at the Fraunhofer Institute for Mechanics of Materials IWM have come up with a process to fabricate polymers with a specific structural design, which they later intend to apply to metals and ceramics as well. This structural patterning enhances the functionality of conventional materials, in effect creating what scientists call programmable materials. They open the door to a whole new range of applications.

Text: Tim Schröder





It's smart: This auxetic cube is structured for a dynamic response to different loads. It gives under slight pressure, but remains rigid when the load rises above a defined threshold.

The lotus effect in action: The surface's special structure makes this material remarkably water-repellent.
© Fraunhofer IWM

Glass is unyielding and brittle. Ceramics are smooth and hold up well to corrosion. Synthetics can be as flexible as the sole of a sneaker or as rigid as a CD. With so many materials to choose from, one can almost always be found to suit any product's intended purpose. But each has its limitations. Countless materials that perform well under normal circumstances fail to meet the requirements of more demanding operating environments. Many synthetic plastics cannot withstand high temperatures and not all steels are suitable for use in aggressive environments. Of course, there are ways to enhance a material's properties and fine-tune its performance or composition to fit specifications – you could come up with a smarter design, modify the production process or even swap out the atoms in alloys. But this only works to a limited extent, because every material possesses inherent properties that restrict its use in certain applications.

Scientists at the Fraunhofer Institute for Mechanics of Materials IWM in Freiburg aim to push these limits a little further than nature wants them go by lending old materials new capabilities – not by altering the material itself but by modifying its structure. "We do use legacy materials, but we fabricate them in a different way. Plastics, for example, are usually cast in one piece, but we take a different approach in which we start by designing precisely ordered lattice structures that prompt the material to behave in different ways," says Christoph Eberl, micromechanics expert and deputy head of IWM. He and his colleagues Matthew Berwind, Hamideh Jafarpoorchekab and Felix Schiebel used this method to create microscale polymer lattice structures. One such polymer is designed to enable the thin walls of its lattice structure to give under pressure, stretching in a certain direction when a certain amount of force is applied. This action carries over from one cell in the lattice to the next, enabling the polymer's response to pressure to be defined precisely.

A synthetic material that acts like a system

Elastic polymers have been on the market for decades, but Eberl is taking this to the next level. "With our process, we can structure and modify a small area and specific points of a component made from synthetic material." One of the applications he has in mind is a new type of vehicle dashboard that is mostly rigid but contains areas that have been micro-structured to be flexible. These areas could serve as pushbuttons. Piezoelectric ceramic switches and other controls that generate electrical pulses require an entire switching system consisting of a receiver, conductor and actuator to trigger an action. Eberl says: "But we want the material itself to be the switch." In that way, the material itself becomes part of the operating system.

Another application that researchers are currently looking into is a lining for the inner surface of prosthetic limbs. For this purpose, the team is designing a material that remains pliable under normal conditions but stiffens when subjected to a higher load. "This is another promising application of microstructured polymers," says Eberl. "Prostheses need to be padded with a soft material to prevent pain at the point of contact between the prosthesis and the stump of the amputated limb. On the other hand, if the wearer lifts a heavy load, it's better if the material is sufficiently rigid to resist the pressure of being pressed against the soft tissue of the stump." This kind of material could also be used as a shock buffer in exoskeletons. These robotic suits help people with mobility issues to walk or could be worn by workers to help them lift heavy objects.

Fabricating materials with a 3D nanoprinter

Christoph Eberl uses the term "programmable materials" a lot when talking about how he intends to integrate new functions in legacy materials. His tool of choice for this kind of project is a 3D nanoprinter, with which it is possible to design and program tools to an accuracy of a few hundred nanometers. The Karlsruhe Institute of Technology developed this printer. "This device is the perfect complement to our micro-structuring skills. We can use it to grow 3D structures or burn structures into polymer layers," says Eberl.

These researchers work with jaw-dropping precision. They recently developed a 40-micrometer wide polymer damper that expands under pressure, stretching to different degrees in different directions. When the pressure decreases, the elastic component snaps back into its original shape. With the benefit of this property, it could relay pressure-related information in any given direction. "I can imagine many potential applications for this technology," says Christoph Eberl. One of these is micro-joints.

An erector kit chock-full of structures

Right now, he is less concerned about where exactly this or that component will end up being used. As Eberl explains it: "We're upending the development process with our method. Usually, you define a goal and then consider what materials you'll need to achieve it. Instead, in the years ahead, we will be offering a lot of programmable materials and developing a whole erector kit of structures that take over system functions and let you come up with entirely new ideas for products" – like the dashboard with the integrated button.

A vast playground

The Freiburg team is not just thinking of micro-structured components. Smart materials can also be structured on a larger scale. "In many applications, it is sufficient if the cells of a lattice structure measure one or more centimeters in diameter. We want to see to how far we can upscale structures; that is, we want to learn at what dimensions certain effects occur and use these to integrate functions," says Eberl. At present, the IWM experts are working mainly with polymers, but intend to move on to ceramics and metals later down the line."We have several variables that we can tweak: the material, the structure and the scale," notes Eberl, adding that this is a vast playground for creating new functions with legacy materials. "I can't wait to see what promising applications the future holds in store." ■

Magnets without rare earths

For electric cars and wind turbines, we will need large amounts of permanent magnets in the future. However, they contain rare earth elements, which come almost exclusively from China. To reduce our dependence on these imported materials, experts from Fraunhofer and Max Planck have now jointly developed an alternative.

Text: Tim Schröder

Our future will be electric. That is something experts are certain about. Worldwide, more and more wind turbines will generate electricity. And cars will not be powered by gasoline and diesel engines but by electric motors. This will boost the demand for high-performance magnets in particular – because almost anywhere you convert electrical energy into motion or vice-versa, you need magnets: in the generator of the wind turbine, which converts the rotary motion of the rotor into electricity; or in the electric motor, which is started using electrical energy. Strong permanent magnets are needed particularly, because they retain their magnetic alignment over the long term – unlike, for example, a magnetized iron needle, the polarity of which can be easily reversed through contact with a strong magnet.

Monopoly over rare earths

The problem with permanent magnets today is that they contain rare earth elements, over 90% of which are mined in China. Accordingly, China has a monopoly over these minerals. For this reason, industrial countries are searching intensively for alternative materials to use in the production of permanent magnets. In a cooperation project, experts at the Fraunhofer-Gesellschaft and the Max Planck Society have taken an important step in this direction: using sophisticated computer simulations and experiments, they have found suitable combinations of chemical elements that have the desired magnetic characteristics and do not contain any rare earth elements.

Specifically, these materials are Heusler compounds, a class of intermetallics which was discovered more than 100 years ago by German chemist Fritz Heusler. Heusler materials have a fascinating property: they consist of chemical elements which themselves do not necessarily have to be magnetic. If you bond these elements into a crystalline Heusler structure, however, the compound can take on magnetic properties.

In the HEUSLER joint project between Fraunhofer and the Max Planck Society, the researchers began by using simulations to investigate a range of promising Heusler materials to determine whether they could be used for high-performance permanent magnets. Max Planck scientists systematically combined the various chemical elements on the computer. Using simulations, they were able to calculate the interactions of the different elements and predict their magnetic properties. These investigations supplied important indications of suitable candidates for subsequent chemical synthesis experiments.

Targeted modification of defects

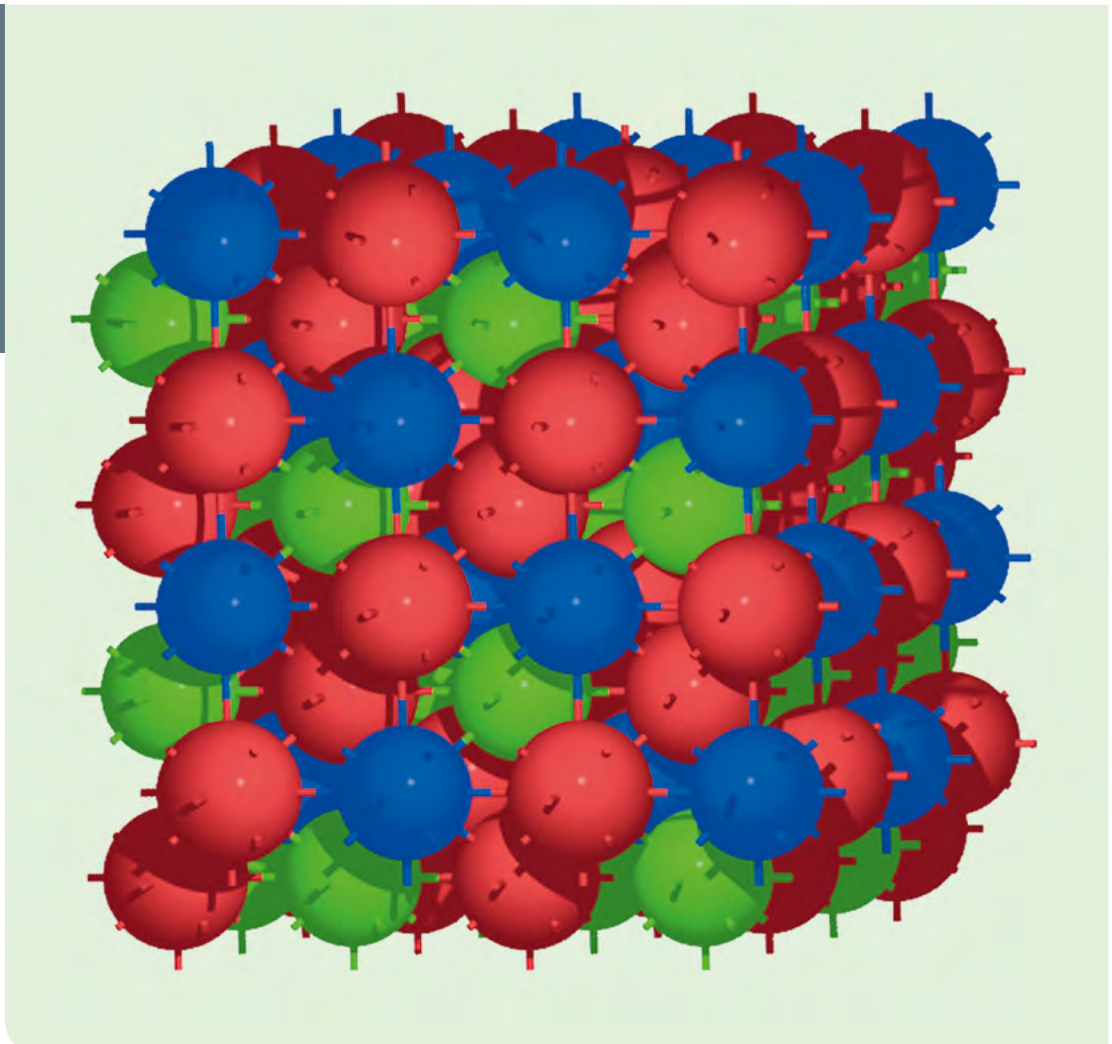
Like many other substances, magnetic materials are made up of crystal structures in which the atoms are arranged in lattices. These lattices almost always have irregularities, so-called structural defects. It is known that such defects play an important role in the magnetic properties of materials. “If you can successfully alter the defects in a targeted way, in other words fix the microstructure of the material in a controlled manner during manufacture, this represents a key to optimizing permanent magnets and to improving magnetic properties,” explains Dr. Georg Krugel, who handled the project in the Material Design business unit headed by Prof. Christian Elsässer at the Fraunhofer Institute for Mechanics of Materials IWM in Freiburg.

In a perfectly structured crystal lattice without defects, interferences from outside can have a domino effect. If the material is demagnetized in one place, then the magnetization of the entire crystal shifts from atom to atom to another direction. “This can cause the polarity of a material to suddenly reverse due to external influences,” says Krugel, “but that is precisely what we want to avoid happening with permanent magnets, because magnets installed in motors or generators must of course retain their polarity.” By building certain defects into the material, however, you can block this switching of magnetization – and so prevent an unwanted reversal of the polarity of the permanent magnet.

Step by step to a new magnet

The route to the permanently magnetic Heusler material consisted of several stages. In the first step, researchers at the Max Planck Institute of Microstructure Physics in Halle employed computer modeling to determine which elements could be combined to make a Heusler material with permanent magnetic properties. This information was then used by their colleagues at the Max Planck Institute for Chemical Physics of Solids in Dresden to synthesize initial samples

The cooperation partners in the HEUSLER project, which concluded last year, comprised the Fraunhofer Institutes for Mechanics of Materials IWM in Freiburg and for Microstructure of Materials and Systems IMWS in Halle and the Max Planck Institutes for Chemical Physics of Solids in Dresden and of Microstructure Physics in Halle.



The crystal structure of the magnetic Heusler phase Fe_2CoGa (red: iron atoms; green: cobalt atoms; blue: gallium atoms), which the project scientists researched intensively. © *Fraunhofer IWM*

of permanently magnetic Heusler materials. Next, the Fraunhofer Institute for Microstructure of Materials and Systems IMWS analyzed the material samples under an electron microscope to decipher the precise arrangement of atoms. "At Fraunhofer IWM, we used this information about the atomic arrangement in the material and particularly at the defects, and transferred it to computer simulation models," says Krugel. By means of these models, he and his colleagues were then able to explore various arrangements of the atoms. "We analyzed the atomic scale using quantum mechanical computer simulations," he adds.

And finally, the results of these simulations were sent back to the Max Planck Institute for Chemical Physics of Solids, where the researchers used them to optimize the Heusler crystal structures in the laboratory. By virtue of this experimental synthesis, it was possible to manufacture a new material with very promising magnetic properties.

Although a marketable product is still a long way off, the results show that there are alternative materials for permanent magnets which do not need rare earth elements – and that Heusler compounds are a very promising material class for making these alternatives. ■

The silicon sphere, here awaiting coating, must be handled with great care. One of the three-point mountings can be seen on the right in this image. © *Fraunhofer IST, Falko Oldenburg*

Alternatives for the original kilogram

The international prototype kilogram used to calibrate all existing scales is losing weight, and researchers around the world are searching for alternatives. Plans to redefine the kilogram are currently in progress.

Text: Britta Widmann

A kilo no longer weighs 1000 grams. The standard for mass, the international prototype kilogram, is becoming lighter and lighter. It has lost 50 micrograms over the past hundred years and no-one knows why. International efforts are underway to redefine the basic unit of mass, to decouple it from the platinum-iridium cylinder stored in a vault in Paris and base it on natural constants instead.

To achieve this, one promising approach uses the Avogadro constant, which indicates how many particles there are in an amount of substance. One material that is suitable for this purpose is ultrapure silicon shaped into a sphere. Researchers at the Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig succeeded in giving the surface of the sphere a homogeneous coating, making it possible, for instance, to limit the measurement uncertainty to a range of less than ten micrograms.

Counting atoms

A team at the National Metrology Institute of Germany (PTB) is conducting experiments with spheres made of isotope-enriched silicon that could serve as a new calibration standard. "We calculate the number of atoms in a sphere, then use mathematical equations to obtain the number of atoms per mole. In simple terms, we determine what a silicon atom weighs and from this we can then calculate how many silicon atoms are needed to make a kilogram," explains Dr. Ingo Busch, a physicist at PTB in Braunschweig.

When producing the spheres, a natural oxide layer forms from silicon dioxide, SiO_2, which also influences the mass and volume of the silicon spheres. The problem with this is that the native layer grows slowly and, in some cases, unevenly, making it very difficult to measure the actual weight of both the oxide layer and the sphere. So they needed an alternative, homogeneous coating that would reduce measurement uncertainties and enable the volume and mass of the sphere to be determined precisely.

Defect-free coatings for silicon spheres

Researchers at Fraunhofer IST, next door to the National Metrology Institute of Germany, succeeded in coating a silicon sphere with just such an alternative SiO_2 surface whose quality meets even the highest standards. "Our method enables us to apply an SiO_2 layer to the spheres with a defined roughness and customizable layer thickness. And the layer is stoichiometric, meaning that the ratio of the individual atoms to one another, or the ratio of silicon to oxygen, is constant," says Tobias Graumann, a scientist at Fraunhofer IST.

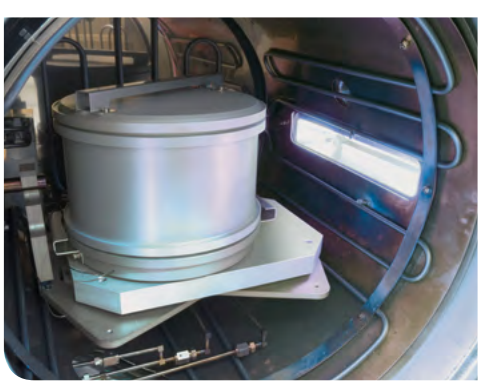
A fingerprint weighs more

The researchers at IST opted to use atomic layer deposition (ALD) to apply the coating. The advantage of this method is that it enables a reproducible, extremely thin oxide layer with a homogeneous thickness to be applied to the sphere. Potential impurities, such as carbon or nitrogen, are below the limit of detection. The roughness of the layers does not exceed one nanometer. "The coating does not increase the roughness of the sphere by any appreciable amount. This is a factor in keeping the measurement uncertainty below 10 micrograms. Even a fingerprint weighs more than that," says Graumann. The time factor plays an important role, as well. The process for producing the spheres can be accelerated by applying the alternative SiO_2 surface, whereas the native oxide layer would take several months to grow.

The coating of the silicon sphere has now been completed and measurements are currently being performed at PTB. The results are expected to be presented at the General Conference on Weights and Measures in fall 2018 and then, at the latest, the original kilogram will likely be retired as the standard. The new definition of the kilogram will be decided at this metrological meeting.

The researchers at Fraunhofer IST and their colleagues at PTB hope the silicon spheres will prevail as the new calibration standard. If all goes to plan, metrological institutes and calibration laboratories will soon be able to obtain copies of the spheres. ■

Inside the ALD coating plant at Fraunhofer IST: the coating chamber for three-dimensional objects. © *Fraunhofer IST, Jan Benz*



Atomic layer deposition (ALD)

When layers of single-atom thickness need to be applied to a substrate with extreme precision, atomic layer deposition (ALD) is the means of choice. The coating is applied step by step – the layers are essentially stacked on the surface. It's a tedious process, requiring numerous coating cycles.

The layers are formed by the chemical reaction of two precursors that are let into the reaction chamber in succession. The coating process at Fraunhofer IST also follows this principle: to produce the SiO_2 layer, in the simplest case, Tobias Graumann and his team use two chemicals that are fed in separate steps into the coating chamber in gaseous form. This results in two sequential, self-limiting surface reactions. In the first step, the surface in the chamber is exposed to reactive molecules in the gas phase. When these react with the surface, initially, only an intermediate product forms – a first monolayer. The researchers use nitrogen to flush the excess molecules and the resulting by-products out of the chamber to avoid an overdose and keep the reactions separate. The second chemical is let into the chamber and reacts with the intermediate product, leaving the desired coating product on the surface. When this reaction has taken place over the entire surface, additional chemicals can no longer adhere to the chemically saturated surface. Experts call this self-controlled and easily controllable growth, and it is a distinguishing feature of ALD. This reaction cycle can be repeated as often as necessary to achieve the desired layer thickness.

Science Campus – A springboard for women in research

Science Campus participants at Fraunhofer LBF.
© *Fraunhofer LBF*

Fraunhofer launched its Science Campus event ten years ago as a way to pique young women's interest in starting a career in research with Fraunhofer. This year's event, held in mid-March, was hosted by three Darmstadt-based institutes.

For the first time, the national and international parts of the Science Campus took place simultaneously in a single venue. Students from Israel were invited to attend and network with their German peers at the event, which ran over several days. The participants gained an insight into the diverse range of research projects underway at the Fraunhofer Institutes in Darmstadt. They also had the opportunity to talk to female researchers about their work and the challenges and opportunities a career at Fraunhofer offers.

Video coding standard wins Technology Emmy

The resolution of television, cell phone and laptop screens is advancing all the time. In line with this trend, films and online video data must be transmitted in the highest quality and with a very high degree of efficiency. For their contribution to the development of the high efficiency video coding (HEVC) standard that makes this possible, researchers from the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institute, HHI, received the 2017 Emmy Award for Technology & Engineering in Hollywood.

The new HEVC standard, also known as H.265, is based on new coding techniques that increase the video compression efficiency. Researchers at Fraunhofer HHI were heavily involved in the development process. Compared with the previous standard, H.264/MPEG-AVC, HEVC reduces the data rate by 50 percent while retaining the same high level of image quality.

Prof. Thomas Wiegand, who is head of media technology in the Institute of Telecommunications Systems at TU Berlin and executive director of the Fraunhofer Heinrich Hertz Institute HHI, accepted the prize together with HHI researchers Benjamin Bross and Dr. Detlev Marpe.

Awarded by the National Academy of Television Arts & Sciences, the Technology Emmy is one of the most prestigious recognitions of excellence in the television industry in the U.S.

Prof. Thomas Wiegand, Benjamin Bross and Dr. Detlev Marpe at the Technology Emmy ceremony.
© *Fraunhofer HHI*

Industrie 4.0 Application Center in China

Researchers from the Fraunhofer Institute for Production Systems and Design Technology IPK will offer engineering services to Chinese companies at a Sino-German Intelligent Manufacturing Research Institute SGIMRI in the future, which is set to be based in the Jiangsu province, a hub for industrial manufacturing.

The Memorandum of Understanding for the establishment of the new institute was signed back in June 2015. It states the intention of the participating parties – Fraunhofer IPK and the Jiangsu Economic and Information Technology Commission JSEIC – to develop joint strategies for standardizing Industrie 4.0. They have also agreed to work together on intelligent manufacturing and ICT technologies. An Industrie 4.0 application center is currently being set up to showcase the latest technologies and use case scenarios. This will provide a platform for Fraunhofer experts to consult with their Chinese partners on matters concerning the strategic orientation of the business and to develop intelligent production demonstrators for the new institute.

New appointments

The senate of the Fraunhofer-Gesellschaft unanimously elected **Andreas Meuer** as the new executive vice president in charge of controlling and digital business processes. The financial expert succeeds Prof. (Univ. Stellenbosch) Alfred Gossner. A business administration graduate, Meuer joined the Fraunhofer-Gesellschaft in 1992, where he has since held various management posts. Most recently, he was in charge of finance, accounting and business planning. His responsibilities included managing the Fraunhofer-Gesellschaft's budget, which totals over two billion euros. In this role he also optimized annual financial reporting practices and established a new asset management system.

On January 1, 2018, **Prof. Claus Emmelmann** took the helm of the new Fraunhofer Research Institution for Additive Manufacturing Technologies IAPT in Hamburg. Established following the integration of LZN Laser Zentrum Nord GmbH into the Fraunhofer-Gesellschaft, IAPT is the first Fraunhofer research institute based in the Free and Hanseatic City of Hamburg. The center plays a key role in the development of future-shaping additive manufacturing and nanotechnology skills. Prior to assuming this position, Prof. Emmelmann was CEO of LZN Laser Zentrum Nord GmbH.

Prof. Ulrike Köhl is the new managing director at the Fraunhofer Institute for Cell Therapy and Immunology IZI. As the newly appointed professor of immuno-oncology at Leipzig University, Prof. Köhl has also managed the Institute of Clinical Immunology at Leipzig University Hospital since mid-December 2017. In her capacity as a researcher specializing in cellular immunotherapy, she previously worked as a professor at the Hannover Medical School. Köhl succeeds Prof. Frank Emmrich who founded IZI in 2005.

The Fraunhofer Center for Assistive Information and Communication Solutions AICOS in Portugal has a new managing director. **Prof. Liliana da Silva Ferreira** (PhD) took over at the helm of the center in September last year. She succeeds Prof. Dirk Elias who moved to a technology company. Ferreira, who is 37, is one of the youngest people to hold the top management position at a Fraunhofer Center.

Editorial notes

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