

reflexion

ANNIVERSARY ISSUE 25 YEARS LEIBNIZ INSTITUTE *of* PHOTONIC TECHNOLOGY

25
YEARS
ipht jena



Our thanks to all our sponsors and supporters, in particular,

*the Free State of Thuringia, the Leibniz Association,
the Federal Ministry of Education and Research,
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the Foundation for Technology, Innovation and Research Thuringia,
and the Carl Zeiss Foundation.*



Prof. Dr. Jürgen Popp // Scientific Director



Frank Sondermann // Administrative Director

Dear Reader,

» Twenty-five years ago, IPHT was founded under the name “Institute of Physical High Technology.” Today, a quarter of a century later, IPHT is firmly rooted in the national and international research scene as a member of the Leibniz Association under the name Leibniz Institute of Photonic Technology. With its clearly defined research profile “Photonics for Life,” along with the challenge of researching from the basic principles to practical solutions and systems used in environmental science, security applications, and the life sciences, Leibniz IPHT has taken on a central role in studying photonic health technologies.

The successful development and profiling of the Institute was especially confirmed in 2013 by the German Council of Science and Humanities in the course of their evaluation. As stated by the assessment report at that time, “Overall, IPHT has had excellent success in its strategic focus on biophotonics as its chosen area of research. This is true for the methodological range of its research activities, which encompass applied and basic research to an equal extent. The field of research has great future potential and displays a very high degree of social relevance.”

To us, however, an anniversary is more than just an occasion for acknowledging our achievements. We would much rather focus on the goals and milestones that lie ahead. In this regard, our exceptional technological facility and the scientific expertise of our colleagues provide a stable foundation upon which to build the future of IPHT.

Our thanks to IPHT’s employees for their high motivation and commitment to their work. We also wish to thank the Free State of Thuringia and the federal government for their decades-long, close partnership and continuous support along the way. In addition, we would like to thank all our sponsors, promoters, and partners in research, industry, and politics for the trust they have shown us.

Wishing you an enjoyable read,

Jürgen Popp
Scientific Director

Frank Sondermann
Administrative Director

PHOTONICS FOR LIFE
from Ideas to Instruments

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25 Years of Expertise for Meeting the Challenges of the Future

A conversation between former directors Prof. Eckhardt Hoenig and Prof. Hartmut Bartelt with Prof. Jürgen Popp on the historic pioneering efforts and new paths that IPHT is treading.



Approximately
1.800
published articles in
peer-reviewed journals
2005-2016

12

Photonics for Life – From Basic Research to Practical Application

The range of IPHT's spectroscopic techniques and system solutions is constantly being expanded. New spectroscopic methods of analysis and diagnosis will continue to shape the Institute's image in the future.



226
Issued patents
1992-2016

24

Fiber Optics – Of Know-How and High-Tech

The application areas for optical fibers have changed considerably since the founding of the Institute. They constantly provide new stimuli for creating innovative fiber types and technologies.



Approximately
€170 million
in third-party funding
2000-2015



Established
1992

2005-2006
Structural Commission under the direction of Prof. Dietrich Wegener (TU, Dortmund)



Profiling with focus on photonics in the life sciences

2007

2011-2013
Evaluation process for admission to the Leibniz Association



Admission to the Leibniz Association

2014

2014-present
Further profiling in the areas of security, health, and the environment within the field of photonic technologies for system solutions



2017

30

Micro- und Nanotechnology – From Cleanroom to Sensor Technology

Over 25 years, what was once a laboratory space about 60 square meters in size grew into a cleanroom measuring about 700 square meters: the technological heart of IPHT. The overview shows the development of the cleanroom as well as of the micro- and nanotechnologies and their applications.



Approximately

40
EU-sponsored projects,
of which more than
10
were
coordinated
2004-2016

13
Thuringian
research awards
1996-2015

38

SQUIDs – Low-Temperature Superconductors for High-Resolution Mapping

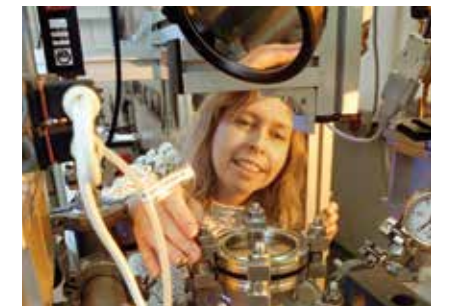
Precise and rapid magnetic mapping of archaeological sites is just one of the many applications for the SQUID-based sensors from IPHT. The story of their success began before the founding of the Institute.



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Silicon – From Photovoltaics to Biophotonics

A glance at the third-party funding projects of the past few years shows that the research into thin films and silicon nanowires leads to new technologies and applications outside of photovoltaics.



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"We should encourage more researchers to start companies with their ideas."

Eugen Ermantraut talks about his way of putting ideas into practice. He would love to see more young researchers daring to take the step to set up their own companies.



" As an EU project manager, I communicate with researchers from across Europe, supervise international research networks, and help IPHT employees acquire new projects. Our success is seen in our large European research projects and our publications, almost half of which come from our collaboration with international authors from a total of 30 countries.

GABRIELE HAMM

At IPHT since 2011

EU Project Manager

Scientific Coordination



My work place is Europe

"



Prof. Dr. Eckhardt Hoenig

From his research group in Frankfurt am Main, Eckhardt Hoenig moved to the Siemens research laboratory in Erlangen, where he was involved in the areas of superconductivity and biomagnetism. In 1993, Hoenig was awarded the Chair of Cryoelectronics at Friedrich Schiller University Jena (FSU). At the same time, he took over the management of the research department for cryoelectronics/ microsystems at IPHT, along with the position of Scientific Director and Chairman of the Board of Directors. His research interests are superconductive electronics, magnetoelectronics, infrared sensors, and microtechnology for applications in biotechnology. In 1999, after relinquishing the position of Scientific Director and Chairman of the Board at IPHT to Prof. Dr. Hartmut Bartelt, Hoenig became the head of research department magnetics / quantum electronics.

25 Years of Expertise for Meeting the Challenges of the Future

» 25 years at Leibniz IPHT. That's reason enough to reflect not only on its development so far but also to define its strategic goals for the future. With that in mind, former Institute directors Prof. Dr. Eckhardt Hoenig and Prof. Dr. Hartmut Bartelt met with current Scientific Director Prof. Dr. Jürgen Popp for an interview.

Looking at the present situation, what makes IPHT stand out?

Jürgen Popp: IPHT's research profile can be very simply described as "Photonics for Life." We research photonic and biophotonic solutions for urgent social issues in the areas of health, environment, and security.

The objective of our research, among other things, is to use our photonic and biophotonic solutions to advance in new directions in terms of resolution, sensitivity, specificity, speed, accuracy, and automation. In this way, it lays the foundation for faster and more precise medical diagnosis, a new caliber of food and water analysis, and innovative security technology, for example. Ultimately, it serves to make life safer and healthier.

Take a look at IPHT's key performance indicators. We have a third-party funding rate of 50 %. This is largely derived from the DFG, the EU, the BMBF, the state of Thuringia, and industry. When you look at the number of our employees, we now have around 330 employees. Among those, about 90 to 110 are doctoral candidates.

We can see the scientific success of the Institute in our major European research projects, our published work, and our patents. Of our approximately 200 published articles annually, almost half have come from our collaboration with international partners. In addition, about five patents are granted per year.

Mr. Hoenig, as the founding director, how closely do you need to look in order to see some remnant of the IPHT that you headed until 1999?

Eckhardt Hoenig: IPHT was much more broadly positioned at the time. We dealt with topics in the areas of materials science and low-temperature physics and electronics. Even though much of this is no longer part of the Institute, I still recognize it. Our strategy of focusing on photonics from 2007 onward was a good one.

Jürgen Popp: What constitutes IPHT today was established at a very early stage. Ten years ago, when the profile formation process began, IPHT had already built an outstanding technological base in the areas of optics, magnetic components, micro- and nanotechnology, and fiber drawing technology. It's true that the IPHT of today is very different from its earlier version in terms of its public impact and image, but our unique technological position had already gotten off the ground by 1992. Our goal, in accordance with the new profiling, was to employ these high-quality technological skills in profitable ways for the new topics.

Mr. Bartelt, you came to IPHT in the early years to further expand the area of fiber optics and fiber technology. What were your expectations?

Hartmut Bartelt: Back when I started in Jena in 1994, it was a time of upheaval and also of departure. It was very clear that there was a lot of potential. Fiber technology and micro- and nanotechnology were well established here. With the new technical equipment, we could successfully perform the research at an even higher, international level.

Mr. Hoenig, how did you feel at the time of IPHT's founding? Was it an adventure for you to go to Jena?

Eckhardt Hoenig: I was extremely motivated to go to Jena. It was generally known that no other place in the east had done so much work in the field of quantum electronics. In the years that followed, we brought this area of research to a point of technical success. It's an entirely different thing when a whole new generation of young people gets going than when trying to forge ahead with new developments in an established environment.

The focus was on using their own talents and expertise. At the former Institute, the Physical-Technical Institute (PTI), there had been solid growth in many areas, as in thermosensors. This was the nucleus of the cleanroom and led to our first successes with industrial partners.

In the mid-1990s, there were plans to relocate IPHT to the Beutenberg campus. The first project was the construction of the cleanroom. In 1999 the main building was added. What were the reasons for the move?

Eckhardt Hoenig: At the original location on Helmholtzweg, everything was built close together. There was no way to find room for a new building there. On the Beutenberg campus, on the other hand, we found open space. But the growth had to be financed in reasonable phases, which had to be fought for and justified every time. The state and the federal government were financially very committed to IPHT's regeneration.

Hartmut Bartelt: Although there was no guarantee that the Institute would have a main building on the Beutenberg campus. There were plans to renovate the buildings on Helmholtzweg during day-to-day operations. It was not until relatively close to the last minute that the Ministry suggested that it might be better to implement a unifying solution at Beutenberg rather than going through this renovation process. After that, everything happened very quickly. We commissioned the planning for the building, secured the financing, and could then move to the Beutenberg campus, into what was one of the first large institutes.



Prof. Dr. Jürgen Popp and Dr. Tobias Meyer at CARS laboratory

Prof. Dr. Hartmut Bartelt



Hartmut Bartelt left the Siemens research laboratory in Erlangen in 1994 to accept an offer for the position of Professor of Modern Optics at Friedrich Schiller University Jena. From 1999 to 2006, he was Scientific Director and Chairman of the Board at IPHT, in addition to heading the research department for optics. During this time, Bartelt performed research on the development of optical fibers with new properties and applications for information technology and sensor technology as well as fiber light sources and fiber amplifiers based on innovative micro-optical fiber structures. After Prof. Jürgen Popp took over the directorship of the Institute in 2006, Bartelt became head of the department of Fiber Optics.

Prof. Dr. Jürgen Popp

After his habilitation in physical chemistry at the University of Würzburg, Jürgen Popp received an offer for the Chair of Physical Chemistry in Jena in 2002. Since 2006, he has been the Scientific Director at IPHT and also heads the Department of Spectroscopy and Imaging. Among Popp's research focuses are Raman spectroscopy and imaging used in solving biophotonic problems.

Since then there have always been new construction projects ...

Jürgen Popp: Technology depends on renovation. The technological infrastructure depreciates within approximately 10 to 15 years, and the available equipment has to gradually be replaced. With our focus on photonic technology, we needed to think carefully about how to move forward with the cleanroom. Could the available equipment and machines really be useful to our new orientation? With the financial support of the federal government and the state as well as European funding, we were able to do a complete and appropriate renovation and expansion of the cleanroom. Since then, we have had a cleanroom of the highest quality in a 1000-square-meter space. A 14-meter-high fiber drawing tower was built at the same time. As a result of this, we are able to fabricate fibers comparable to the ones produced in an industrial drawing process. If we want to transfer our applications to the market, we need to have the capability to meet industrial standards.

Hartmut Bartelt: Relatively soon after IPHT had learned to "walk," we were already thinking about how IPHT could remain sustainable long-term within the funding and research structure of the Federal Republic of Germany. With the self-confidence and incentive to make the Institute internationally competitive, we concentrated on our strongest areas.

Because of the surroundings, photonics was an obvious focus that would allow for very attractive and, above all, integrative projects here in Jena. This orientation has consequently been recognized and pursued as a strategic research focus.

Jürgen Popp: In 2005, a structural commission was set up to assess the situation. Its task was to identify the Institute's strengths and weaknesses, along with the integrative component of the research. The analysis showed that our focus should be on optical and photonic technology. It also became apparent that our research primarily addresses issues in the life sciences.

It was our task to work out and implement a concept with the co-workers. With our excellent scientific results, we can not only give our knowledge back to society but also develop solutions that will directly benefit consumers and patients or provide new practical foundations for society. This includes transfer in the form of company spin-offs from IPHT.

IPHT's aim was to join one of Germany's major research associations, in keeping with the beginning of the restructuring measures. How has this process been carried out?

Jürgen Popp: When I took over the Institute's scientific directorship in 2006, my main goal was to contribute to our becoming an excellent institution in the new subject matter areas. The first question we asked ourselves was about our research profile. What were our priorities?

The analysis showed that we have two major technological focus areas. On the one hand, we have fiber technology for fiber optics. On the other, we have the entire spectrum of micro- and nanotechnology, system technology, and thin-film technology, which are related to quantum detection. These two focuses are united by biophotonics, which in recent years has been established and built up at IPHT and is being pursued from an application-oriented perspective. Through these three areas of research, we address central social issues in the environmental sciences, life sciences, security, and medicine. This in turn developed into the IPHT motto "Photonics for Life." Over the past 10 years, we have succeeded in imbuing this approach with life by encouraging our employees from the individual research areas to collaborate on the issues in an interdisciplinary way. The Leibniz Association was the right address for our scientific and technological orientation, which on the one hand encompasses basic research and, on the other, applied research with the aim of transfer.

The path to acceptance was not easy. We had to undergo a lot of evaluations. First, the Leibniz Association evaluated whether we were at all able suitable and whether we would be an enhancement. Once this was done, the Leibniz Association's committees had to agree to our proposal. The case then became even more complicated, since it also had to be approved by the Bund-Länder Commission. Not until then



Fiber drawing tower at Leibniz IPHT



^ Clean room at Leibniz IPHT v Doctoral candidate Sophie Thamm

uses plasmonic metal structures for bioanalytics.



was the science council dispatched to visit and evaluate the Institute, which it did for two days in January 2013. Based on the very positive verdict, which highlighted IPHT's scientific excellence and the national importance of our research activities, we were admitted.

How do you manage to transfer the scientific findings from your basic research to concrete solutions, laboratory prototypes, or even market-ready products, in line with the credo "from ideas to instruments"? How can this process be further optimized in the future?

Jürgen Popp: Ideally, we would collaborate with an industrial partner once we have demonstrated the basic principle, or "proof of principle." The industrial partner then develops a product from the laboratory prototype. However, we determined relatively quickly that while industry often eyes new technologies with interest, manufacturers shy away from the entrepreneurial risk involved in converting them into products.

We need to think about how to raise this conversion process to a new quality grade. With the establishment of the InfectoGnostics research campus, we have taken the first important steps in relation to this. In a public-private partnership, representatives from science, business, and the hospital are researching new approaches to the diagnosis of infection, all at one location, namely, the Zentrum für Angewandte Forschung (ZAF) at FSU. This close collaboration within the research campus is aimed at bridging the gaps in the value chain. Together with FSU, the University of Applied Sciences Jena (EAH), the Hans Knöll Institute, and the Jena University Hospital as well as with the companies Alere and Analytik Jena, we submitted our proposal in an application to the BMBF (the Federal Ministry of Education and Research).

The Ministry had received a total of 96 applications of this sort, of which only ten ultimately received grants. We can feel proud that the InfectoGnostics proposal was among those that was positively assessed. The research campus now receives funding for a period of up to 15 years. With InfectoGnostics, we have created an organizational structure that enables us to convert photonic technologies into medical applications with greater efficiency. Our first product is now on the market.

Where do you see IPHT in the next 25 years?

Jürgen Popp: I see the Institute as being well prepared for future challenges. We will continue to pursue this path and further sharpen our research profile "Photonics for Life." For this task, we have an outstanding technological facility at our disposal. But the key to success are our competent employees, along with constructive and friendly cooperation. In this area, too, I see us as being well positioned. The Institute's workforce identifies with the content of IPHT's profile and is highly motivated and committed. I am convinced that on this basis we will jointly contribute solutions to issues in the fields of health, medicine, security, and the environment.

From Basic Research to Application

» How can we detect disease-causing bacteria quickly and easily? Which mechanisms enable molecular catalysts to generate hydrogen using light? How do we obtain accurate insights into the molecular processes of living cells? Can healthy tissue be distinguished from diseased tissue already during sur-

gery? Optical spectroscopy is a universally applicable tool that enables IPHT's scientists to get to the bottom of a variety of questions in the areas of health, environment, and security. Dr. Dana Cialla-May is also looking for traces of antibiotics in the Saale River.



The Search for Traces

Dr. Dana Cialla-May takes water samples from the Saale. These are later examined for traces of medication in the laboratory. Patients excrete residues of administered antibiotics in their urine. The substances are then transported through the wastewater into sewage treatment plants, where some antibiotic classes are removed either incompletely or not at all. These residues are found in watercourses or groundwater, where they can damage both ecosystems and humans. To detect tiny concentrations of antibiotics in the water, the chemist and her team use surface-enhanced Raman spectroscopy (SERS).

The Origin of Optical Spectroscopy at IPHT

» In one of the first projects funded by the State of Thuringia, Dr. Rainer Riesenbergs team researched an infrared photometer with an extremely high dynamic range of 104 for carbon dioxide detection. Another focus was on the miniaturization of optical spectrometers for use aerospace. To this end, the IPHT group, in collaboration with industrial partners, researched and developed what are called HADAMARD spectrometers - spectrometers exhibiting entrance slit arrays. As a result of this innovative optical concept, the spectrometers could be reduced to fit the palm of a hand. In 2001, Riesenbergs received the Thuringian Research Prize for his scientific achievement.

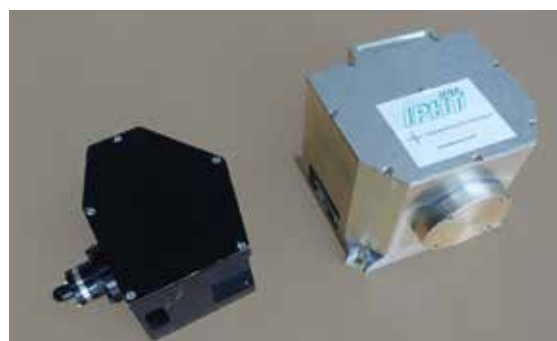
and life sciences, security, and medical applications. One of their goals in this is to further miniaturize the utilized components and to automate the processes so that they can also be used on-site by non-specialists, or in other words, outside a specialized laboratory setting.

In relation to this, we currently develop a Raman spectrometer about the size of a smartphone. This handy device should enable quick and unambiguous point-of-care detection of infectious pathogens in patient samples and their potential resistance to antibiotics.



System solutions from the Riesenbergs team

Non-dispersive infrared photometer (1992) for CO₂ detection with a new planar infrared emitter and an extremely large dynamic range



Space-tested HADAMARD spectrometer with entrance micro-slit array for the European Space Agency (ESA). 2001 The world's smallest spectrometer for ozone detection



Portable UV Raman spectrometer for use in biotechnology (bacterial and mineral detection), based on a micro-slit array. It replaces a large commercial tabletop device with the equivalent performance capacity.

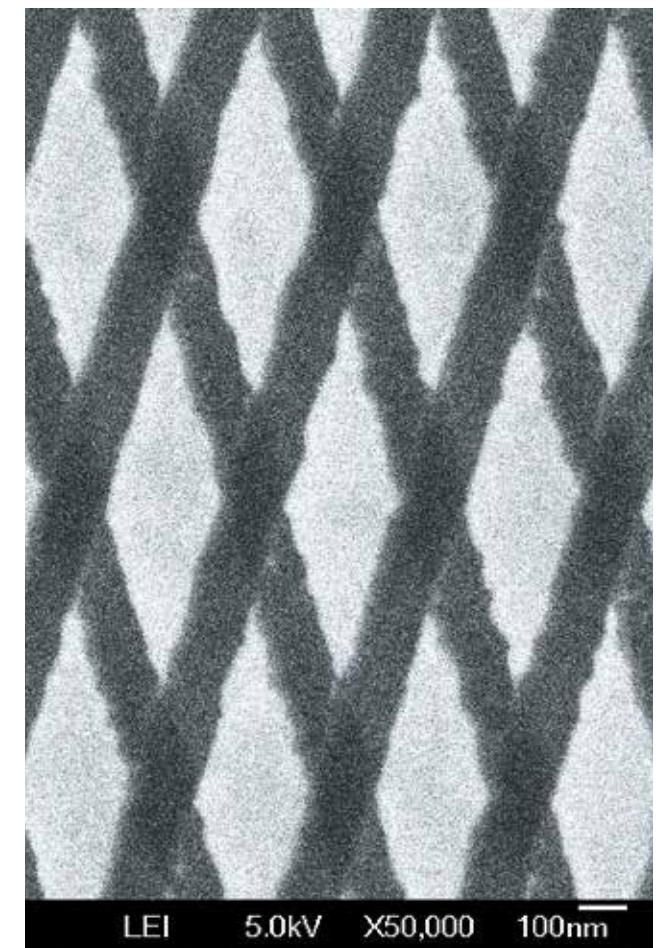


Future iPhone-compatible Raman spectrometer with new planar, microstructured diffractive element instead of the usual grating

A new research era for the Institute began because of the involvement of Prof. Popp (2005) and the appointments of Prof. Deckert and Prof. Dietzek (2009 and 2011, respectively) to IPHT. These three scientists expanded the range of spectroscopic methods with various Raman spectroscopic techniques as well as non-linear and time-resolved spectroscopy. IPHT's expertise in these research areas is a key factor in its national and international image. Today, scientists at IPHT are working closely with the Institute for Physical Chemistry at Friedrich Schiller University to research and develop a wide range of optical spectroscopy methods for environmental



Lab-on-a-Chip-SERS setting



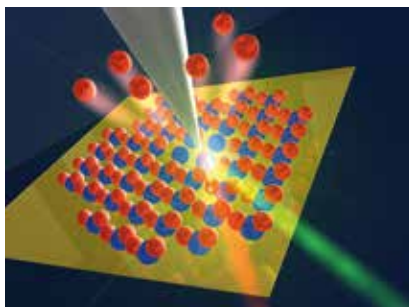
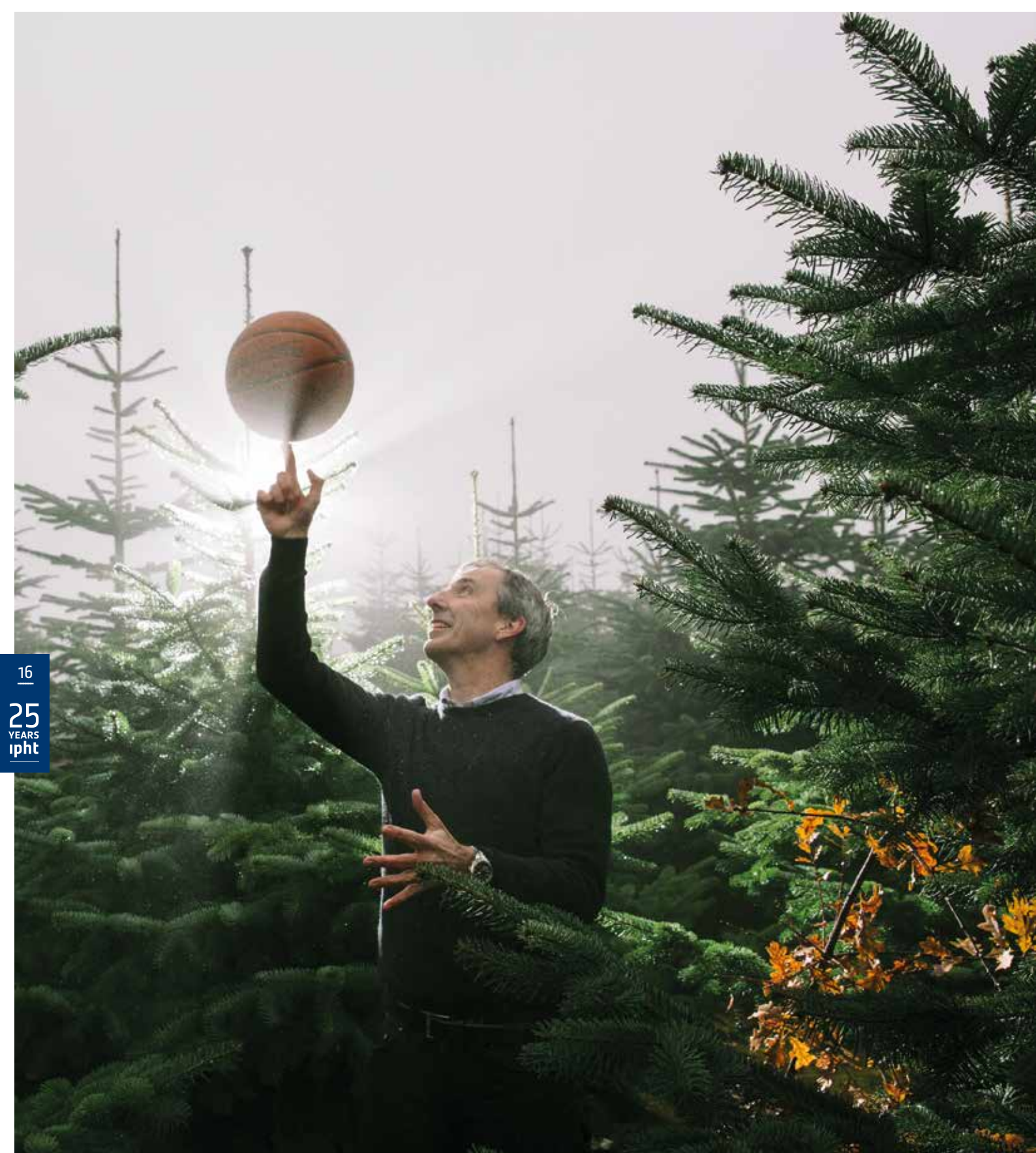
Nanostructured SERS substrate manufactured in the cleanroom

Optical Spectroscopy Meets Micro- and Nanotechnology

» How does Dr. Dana Cialla-May and Dr. Karina Weber's team manage to detect tiny traces of contamination in water, food, or minute quantities of a drug in body fluids? The researchers use surface-enhanced Raman spectroscopy (SERS) as a powerful and sensitive analytical method for their biological, clinical, and environmental-analytical questions. In the process, they bring the analytes to the surface of nanometer-scale silver or gold metallic structures that amplify the Raman signals of the analyte molecules by several orders of magnitude. The investigation and examination of customized gold and silver nanostruc-

tures that are produced with the aid of microstructuring techniques, for example, are a current research focus at IPHT. But it is only the combination of SERS analysis with microfluidic lab-on-a-chip systems (LOC-SERS), produced in IPHT's cleanroom, that enables the detection of fewer single molecules in a sample. The ultra-sensitive LOC-SERS systems address the most important demands placed on modern analytical methods: they are fast and simple, in addition to being robust, cost-effective, and automated. This allows the systems to analyze a large number of samples in real time. For example, the LOC-SERS technology enables on-site

rapid and quantitative determination of drug levels, i.e., the measurement of the concentration of a medication in the body fluids of a patient. This analysis directly affects the subsequent dosage of the drug. To determine the concentration, physicians usually send patient samples to a clinical laboratory. Since the standard procedure takes a long time, the drug's therapeutic effect on the patient cannot be monitored immediately. For example, the LOC-SERS method enables the quick and easy identification of low, but nevertheless toxic to a patient, concentrations of a cancer therapeutic agent.



During TERS analysis, researchers focus a laser on a silver nanoparticle-coated AFM tip, which scans the sample. The Raman-scattered light from the sample is amplified at the AFM tip and then collected with a microscope objective and subsequently imaged. The nanometer-scale resolution is clearly below the diffraction limit, the natural limit for conventional far-field microscopy and spectroscopic methods.

TERS – Molecular Fingerprint with Nanometer-Precise Resolution

» Years of experience and intensive basic research provide the basis for IPHT's considerable competence in the research and application of spectroscopic methods. This is apparent, for example, from the work done in the area of tip-enhanced Raman spectroscopy (TERS). The method combines the molecular selectivity of Raman microspectroscopy with the atomic resolution of scanning tunneling or atomic force microscopy (AFM). The researchers, led by Prof. Volker Deckert, one of the world's leading experts in the field, use this technology to gain completely new molecular insights into the nanocosmos. Using TERS, Deckert was the first to succeed in the direct molecular identification of an individual tobacco mosaic virus, which is only about 300 nm long. Classic virus detection is based on mostly complex and time-intensive microbiological methods such as ELISA (enzyme-linked immunosorbent assay) or PCR (polymerase chain reaction). Although imaging techniques such as transmission electron microscopy (TEM) and AFM are faster, they only enable the visualization of viral morphology, but not assignment to a specific species. Via the typical Raman spectrum, the TERS method provides all the information required for molecular characterization of the viruses and can appropriately classify new mutations for which, for instance, no antibody tests yet exist.

"The whole is worth more than the sum of its parts." What Aristotle already knew is now opening up a new range of research possibilities for today's scientists, who are making use of the effects of mutually complementary spectroscopic methods. Using a combination of TERS and ultrafast spectroscopy, Volker Deckert's and Benjamin Dietzek's research teams are able to map and track structures and dynamic processes with nanometer precision at heterogeneous interfaces. These interfaces between semiconductor nanostructures and molecular sensitizers form the active unit for light absorption in catalysts that generate hydrogen by means of light. Only the high spatial resolution of TERS combined with ultrafast time-resolved absorption spectroscopy enable us to understand the light-induced mechanisms at the semiconductor-sensitizer interface, an important step in the direction of efficient catalysts for sustainable energy generation.

IPHT's outstanding competence in the area of TERS was honored with the 2011 Thuringian Research Prize in the "Basic Research" category and also earned the award "Selected Landmark in the Land of Ideas 2012."

On the challenge of imaging nanoparticles, TERS tips, and molecules in one picture

"The portrait of Volker Deckert required many conceptual attempts. Once again, it seemed impossible to produce a graphic rendering of a scientific subject. Deckert succeeded in surmounting optical boundaries and making things visible that even a microscope cannot reproduce because of its naturally limited diffraction of the light. He enjoyed using the needle of a record player to explain how nanoscopy works. At some point, Christmas trees also entered the conversation. They have tips as well.

It seemed too complicated to me to get Mr. Deckert to fit under the lens of a microscope. I couldn't even imagine him lying on a record player. But the scene became clearer. Sometimes science is an inverted world. So we switched the worlds around. Volker Deckert became small. Or rather, the scientific world became incredibly large. What was still missing were huge molecules. How about a basketball?

I cannot remember making a portrait of any scientist who did not take pleasure in a trip to another optical world. Deckert demonstrated not only unexpected skill with the basketball, but he also withstood the terrible cold with genuine cheer. While we stood warmly wrapped in the drizzling rain, behind the camera or the flash, he even took off his jacket for the picture. For that, we are very grateful to him.

At the award presentations for my pictures, the jurors always mention how refreshing it is to see that scientists are fun, lively people. Such are the views of the two worlds."

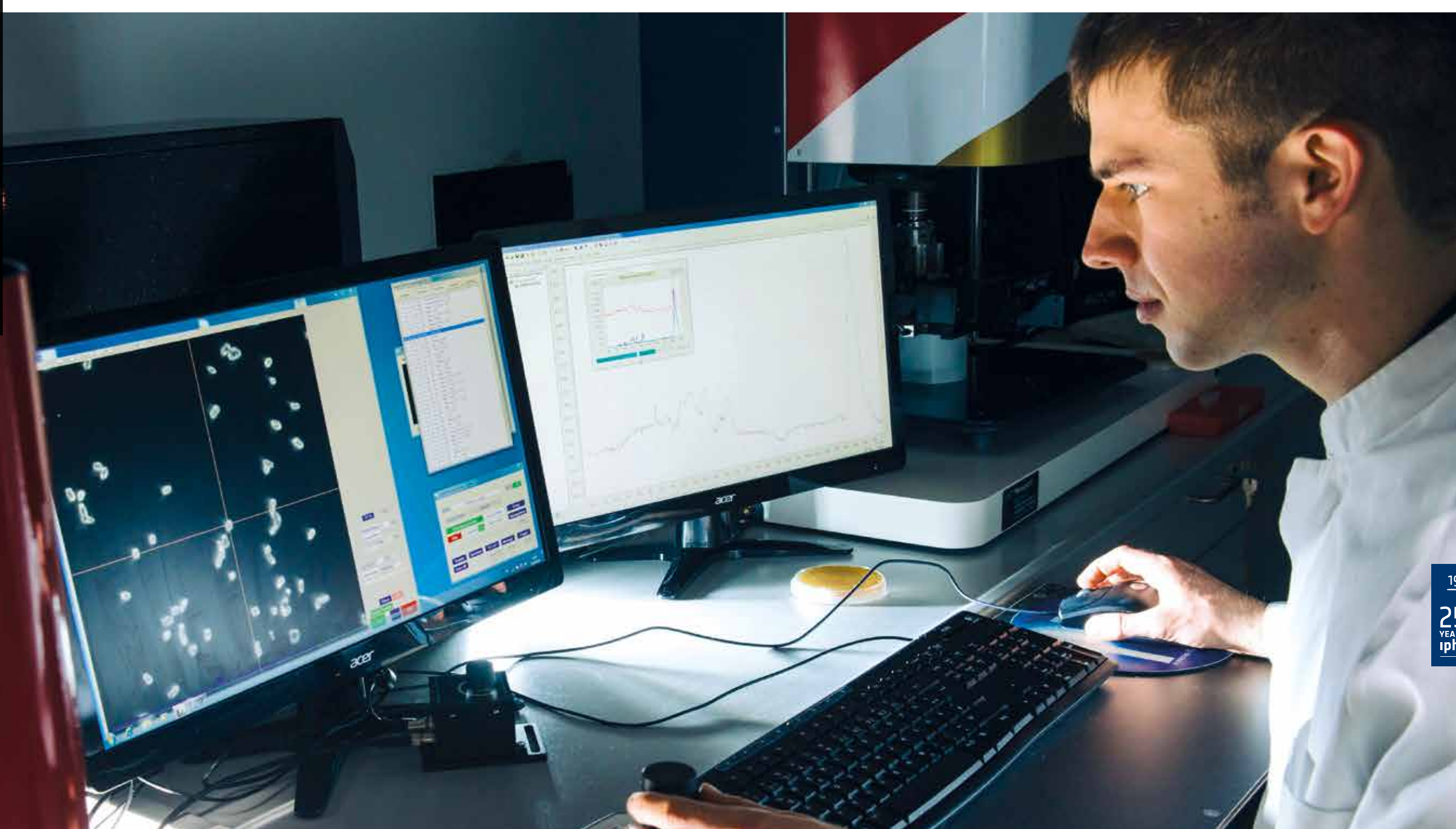
Sven Döring



Dresden photographer Sven Döring has been documenting IPHT's research work since 2010. He has received numerous awards for his work. Döring has taken photographs for Spiegel, Focus, and the New York Times, among others.

Telltale Fingerprints

Every pathogen has a characteristic molecular fingerprint that can be measured by means of Raman spectroscopy. Doctoral candidate Björn Lorenz compares the spectra with the information stored in a database and in this way can identify the bacteria from the urine sample of a patient.



Culture-Independent Detection of Infectious Agents

» The symptoms of sepsis patients are not always obvious and at times are difficult to distinguish from flu symptoms: rapid pulse, chills, and high fever. But without proper treatment, the consequences of sepsis are far more dramatic and deadly. Caused by a bacterial infection, it brings the immune system out of balance and attacks the organism. „Without prompt treatment, sepsis is almost al-

ways fatal,” explains Prof. Dr. Michael Bauer, Director of Anesthesiology and Intensive Care at Jena University Hospital (UKJ) and also spokesman for the Center for Sepsis Control and Care (CSCC) located there.

One possibility is treatment with a broad range of antibiotics, against which the pathogen may display resistance. Reserve antibiotics remain an

alternative therapy, although they could also result in resistance. Without a sure diagnosis, it is difficult for doctors to make a sound therapeutic decision.

Medical professionals in Germany confront this problem roughly 150,000 times a year because the standard microbiological procedures for determining the cause of infection and its resistance sometimes requires more

than 48 hours. More than half the patients die of septic shock before the laboratory results are even available.

IPHT first investigated the approach of identifying pathogens with Raman spectroscopic methods shortly after the turn of the millennium, in collaboration with colleagues from the Institute for Physical Chemistry at Friedrich Schiller University Jena as well as partners from industry. The goal of OMIB, a BMBF-sponsored joint project, was the spectroscopic detection of biological particles without first using

a microbiological method to cultivate them. After three years of research, the project partners were able to prove its technological feasibility. They developed a compactly designed initial laboratory prototype, which the Berlin company rap.ID further developed into a product and then marketed—as the BioParticle Explorer. One of the first application areas was the monitoring of the air in cleanrooms during the manufacture of medication.

With the BioParticle Explorer, new possibilities for the investigation of

pathogen detection methods in biological samples now opened up for the scientists at IPHT. The focal point of the research activities in the years that followed was the degree to which Raman spectroscopy was suited to infection diagnosis. In close collaboration with the CSCC, databases were created in which several tens of thousands of spectra from different sepsis-inducing pathogens were recorded from various sample materials. Using these molecular fingerprints, the pathogens can be detected with a predictive accuracy of 95 percent in less than one hour.



Prof. Michael Bauer (left) and Prof. Dr. Andreas Kortgen at the bed of a sepsis patient

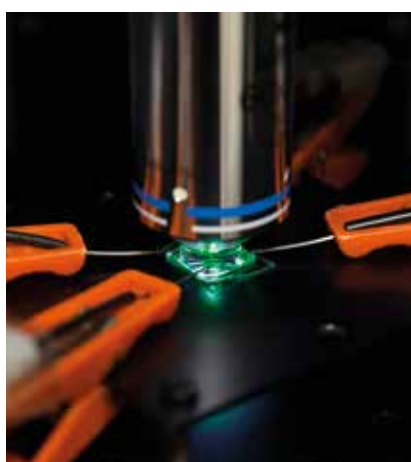
An additional focus of the research work are the methods used in the detection of potential resistances. Prof. Ute Neugebauer, Head of the Research Group for Clinical-Spectroscopic Diagnostics, uses antibiotics on previously identified and isolated pathogens. Depending on whether the bacterium

exhibits resistances, the subsequently recorded spectra may differ from those measured in an untreated control group. Neugebauer and her team require less than four hours for the entire procedure, from the initial sampling to the identification of the pathogens to the determination of resistances. For a treating physician, this means a time gain of as much as two days to make a sound treatment decision.

In conjunction with other teams from IPHT as well as with partners from the EU network „Hemospec,“ the

current research concentrates on automating the procedures during sample preparation and analysis by combining them with microfluidics and lensless microscopy. The focus is on investigating the host response in the patient to the infection by examining the white blood cells and serum samples.

Biophotonics Diagnostics, IPHT's most recent spin-off, optimizes the computer-based evaluation of recorded spectra. The company develops software solutions and database systems, which it markets for endusers in research.



Pathogen identification in a dielectrophoresis chip

Multimodal Imaging– The Future of Clinical Diagnosis

» The ability to distinguish between healthy and pathologically malignant tissue – a tumor, for example – requires a great deal of experience for surgeons and pathologists. In order to make the diagnosis, the tissue is collected and stained. Hematoxylin-eosin staining (HE staining) makes tumors visible under a microscope. It takes several days to obtain a reliable result.

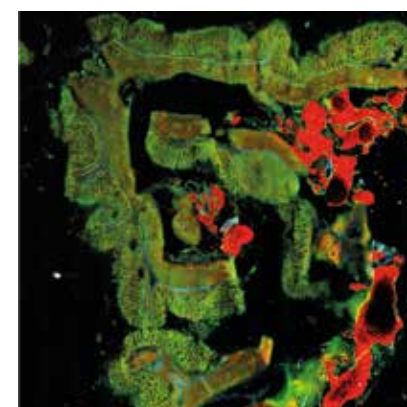
Multimodal imaging provides a faster alternative. As part of the BMBF-funded project “Medicars,” scientists at IPHT have collaborated with partners from Dresden, Heidelberg, Stuttgart, Konstanz, and Jena to design a compact microscope for tissue diagnostics. This enables medical professionals to take high-resolution multimodal images of tissue samples without the need for prior staining. Diseased tissue can be clearly located and selectively removed. In contrast to HE staining, the multimodal images can be obtained within a few minutes.

The technological basis of the Medicars microscope is the imaging

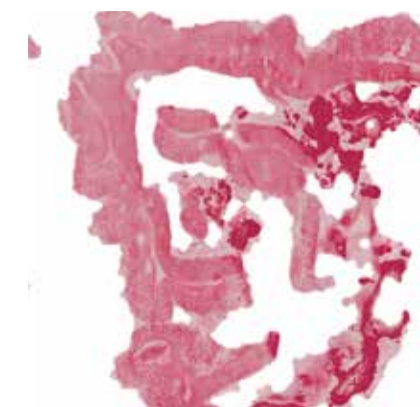
method known as coherent anti-Stokes Raman spectroscopy (CARS), with which various tissue types can be differentiated on the basis of lipid content, as in the epithelial, connective, or adipose tissue, for instance. The process is supplemented by two-photon fluorescence microscopy (TPF) and second harmonic generation (SHG). Used in conjunction, the three contrast methods provide chemical, structural, and functional information about the tissue. The image data are digitally processed and virtually colored in the manner of an HE image.

Due to the compact design of the Medicars microscope, the system is suitable for use in the operating room. It can be operated by trained but non-specialist staff members. The evaluation is performed alongside the surgical procedure and is available to the surgeon during the intervention.

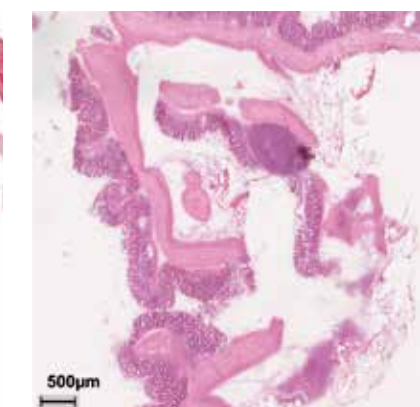
Scientists are currently working on a fiber-based endoscope to expand the system. This opens up the possibility of invasive tissue diagnosis without the need for a prior biopsy.



A) High-resolution multimodal image of a cross-section of a mouse colon



B) Pseudo-HE stained image derived from the multimodal image in A



C) HE-stained image from the same cross section as in A

“ Even if it's usually dark inside my laboratory, at IPHT I've found optimal working conditions and an excellent technical facility. I am one of the first contact points for many of our colleagues when it comes to developing new methods and experimental setups for time-resolved, nonlinear spectroscopy.

DR. DENIS AKIMOV

At IPHT since 2008

Researcher

Group: Molecular Imaging



Even in the dark, I never lose sight of the big picture.

Raman Fiber Probe for the Identification of Atherosclerotic Plaque

» Arteriosclerosis and its aftereffects – stroke and heart attack – are among the most frequent causes of death in the Western industrial nations. In the case of the chronic progressive disease, deposits called plaque occur on the blood vessel walls. Whether and how the deposits are treated depends on their biochemical composition. A better risk assessment would be possible if the plaque composition were more closely understood. Dangerous, unstable plaque could be diagnosed with greater accuracy.

In standard diagnostic procedures, the molecular and biochemical composition of the plaque remains unknown.

An accurate diagnosis and individualized therapy is consequently more difficult to achieve. Fiber-based Raman spectroscopy offers one possibility for obtaining the required information. IPHT's Scientists Dr. Christian Matthäus, Dr. Iwan Schie, and their team are designing a fiber probe for an initial pilot test. "We were able to show that we could use light during a cardiac catheter examination to provide accurate information on the molecular composition of the plaque," says Matthäus.

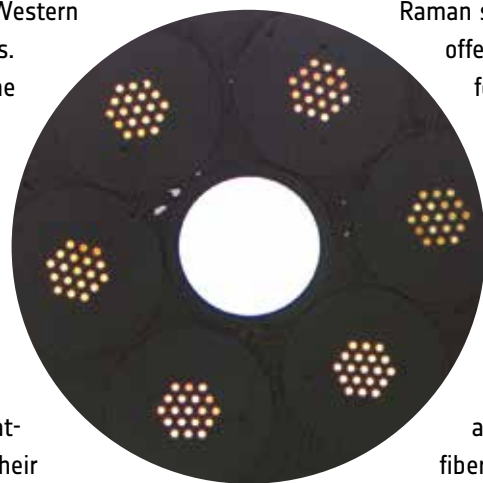
The fiber-spectroscopic probes available on the market are not suitable for use as a heart catheter since the

probe head is inflexible because of its filters being integrated over a length of 5 to 6 cm. The risk of injuring the delicate coronary arteries during an examination is too great. Our colleagues from the departments of spectroscopy/imaging and fiber optics are consequently working together to find a solution that can satisfy both medical and technological requirements.

IPHT's own design uses fiber Bragg gratings, periodic structures inscribed in the core of the fiber, instead of the commercially available filters. This approach, which eliminates the need for a rigid probe head, only works with single-mode fibers, i.e., fibers with a small core. The light collected with the latter is too weak to record a Raman spectrum. The multimode fibers commonly used in this field have a core with a larger diameter, but the light that is injected into them cannot be filtered in a targeted manner.

"What we need are tailor-made fibers that allow us to collect and filter a lot of light," says Christian Matthäus. With multi-core fibers, the light is directed in a parallel manner through several cores and then bundled at the end. For their production, IPHT is equipped with a nearly unmatched technological facility – from its scientific knowledge of the materials through every phase of the fiber-production process to characterization.

Cross section of a Raman probe developed at IPHT (top)
Plaque deposits obstructing the blood flow in an artery (below)



Although the process of fiber optimization is not yet complete, the IPHT team is already thinking one step ahead. By combining Raman spectroscopy and optical coherence tomography (OCT), it may be possible in the future to use only one instrument to obtain both chemical information and information on the shape and size of the plaque.

Interdisciplinary Research in Strong Networks



Staff at Center for Applied Research (ZAF)

» IPHT is involved in several research networks and groups dedicated to modern photonic health technologies. From the on-site detection of pathogens to medical imaging, topics are researched from the interdisciplinary principles to their potential application for patients.

For example, the InfectoGnostics Research Campus, a public-private partnership, is breaking new ground in the area of infection diagnostics and infection research. At ZAF (Center for Applied Research), partners from science, medicine, and industry are collaborating to systematically

develop new diagnostic approaches and convert them to market-ready products. This is how technologies are developed for rapid and cost-effective on-site analysis (point-of-care testing) of infections in human medicine, for test systems for animal diseases, and for pathogen detection in foodstuffs. The project, begun in 2013, has been sponsored by BMBF for a period of almost 15 years.

In addition, through the Leibniz Health Technologies research alliance, IPHT links various scientific disciplines with medical users and stakeholders from business, politics,

and society. In this network, the participating 14 Leibniz institutions are working together on the development of concrete technological solutions for urgent medical issues in the fields of prevention, diagnosis, and treatment. The various research facilities combine their expertise, which ranges from photonics and medicine to microelectronics and materials research to economics and applied mathematics. At the same time, the alliance is investigating the social and economic impact of new technology in order to optimize its application for users and to achieve broad social acceptance.

"My motivation? I want to make the potential of lab-on-a-chip technology available to all users and in this way contribute to the solution of current social issues. Combined with innovative photonic methods, our microfluidic lab-on-a-chip systems can help to create a faster and easier diagnosis of life-threatening pathogens or better environmental analysis in the future."

DR. THOMAS HENKEL

At IPHT since 1997

Researcher

Head of Work Group: Microfluidics



I research the laboratory of the future.



Teamwork

Dr. Jens Kobelke and Dr. Jörg Bierlich are a well-trained team when pulling an optical fiber the thickness of a hair from a several centimeter-wide glass cylinder, or preform. As soon as a drop of viscous glass begins to exit the opening of a 1900 °C drawing furnace at a height of 14 meters, first slowly and then gradually faster, each move has to be just right.

Both scientists then run down the narrow stairs of the fiber drawing tower to guide the resulting fiber along the drawing line. Until it has been wound on a coil on the ground floor, the timing of both technologists is critical to the success of the process. Drawing a fiber requires not only manual skill but also a lot of experience and specialized knowledge.



Dr. Jens Kobelke and Dr. Jörg Bierlich at the exit of the drawing furnace

Fiber Optics

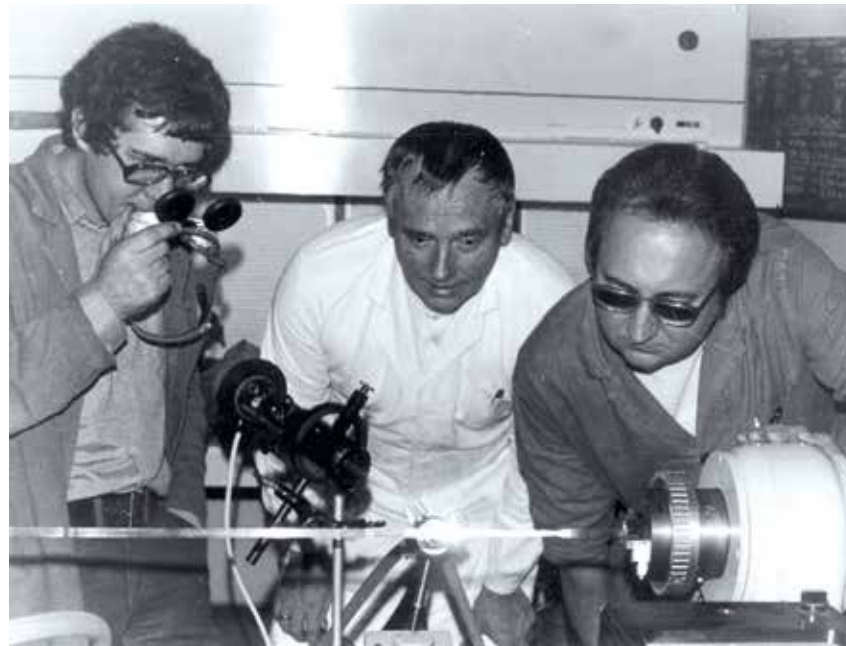
Of Know-How and High-Tech

» Decades of systematic research and an enormous treasure trove of experience and knowledge as well as a unique research infrastructure enable IPHT to research, develop, and produce optical fibers of the highest quality.

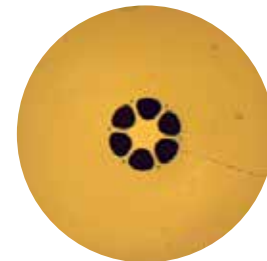
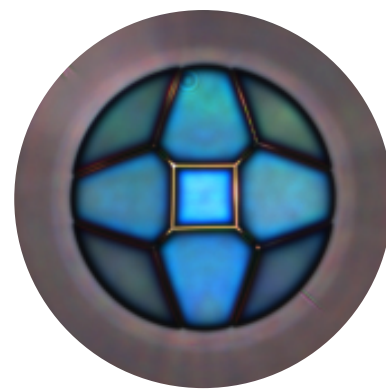
In the field of fiber optics, IPHT can draw on a broad range of technologies and competencies to an extent that only few facilities can match worldwide. Its research activities encompass the entire value chain, from materials development to preform and fiber production, from characterization and modeling to fiber modification and system integration. This diversity is one of the Institute's unique selling points and is appreciated by project partners from science and industry alike.

Fiber Technology and Fiber Optics at IPHT From the Start

» At the end of the 1970s, Jena researchers began to develop optical quartz glass fibers for communications technology. The employees at IPHT's predecessor institutes started from "zero" and first established appropriate production technologies.



Team during the early period: (left to right) Dr. Johannes Kirchhoff and Dr. Peter Kleinert with glassblower Horst Sauerteig by the first MCVD system for preform production in 1978



Cross-sections of microstructured fibers



Employees from the department of fiber production and characterization before the founding of the Institute

A system for modified chemical vapor deposition (MCVD) designed by the Jena researchers themselves was the starting point in the late 1970s for the reliable production of the preforms used in drawing telecommunication fibers. From 1982 onward, a similarly self-designed drawing tower enabled the single-handed drawing of the preforms into optical glass fibers.

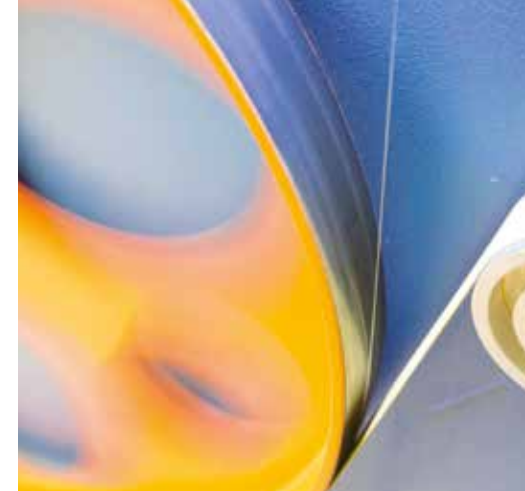
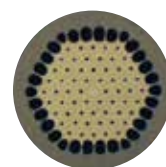
When the Institute for Physical High Technology was founded ten years later, the development of standard telecommunication fibers had been largely completed, and the technology was passed on to commercial manufacturers. The focus now resided with the production of specialized optical fibers. The key component for a new generation of laser light sources

required quartz glass fibers with a rare-earth doped core.

To be able to introduce sufficient quantities of various rare-earth ions into the preform cores, over the next few years, the scientists and engineers at IPHT successfully refined the solution-doping process in conjunction with the MCVD process. Thereby, they shaped the global development of high-performance fiber lasers that today are used as highly flexible tools in the processing and fabrication of a variety of materials.

In the research branch of fiber-optic sensor technology, which likewise dates back to the beginnings of the Institute, a combination of pioneering work and goal-oriented

industrial cooperation brought the first fiber-optic moisture detector to the global market in the mid-1990s. Modern sensors often use fibers with special grating structures, or fiber Bragg gratings, to register changes in temperature or strain, e.g., in bridges, roads, and power lines or in large components such as aircraft wings. For a long time, researchers searched for ways in which to inscribe the fiber Bragg gratings in the fiber cores with a high amount of quality and quantity for industrial sensor production. The results of the work at IPHT was an interferometric experimental setup that, from 1995 onward, enabled Bragg gratings to be inscribed directly and without contact during the fiber drawing process.



Today

» New areas of application such as medical diagnostics and environmental analysis place high demands on the structure of optical glass fibers and call for alternative production methods.



Institute Director Jürgen Popp with Christoph Matschie, the Thuringian Minister of Education, Science, and Culture at the time, and Hartmut Bartelt, Director of the Fiber Optics Department, at the launch of the fiber drawing tower

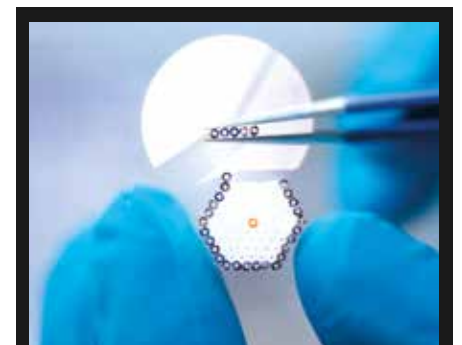


Optical fiber upon exiting the furnace

In order to realize more complex and smaller structures or special designs, IPHT is constantly improving and modernizing the processes for preform and fiber production. The driving impetus for the investigation of alternative manufacturing processes is, among other things, the need of industry for high-performance fiber lasers. The REPUSIL process developed at IPHT allows for the production of large batches of ultrapure, uniformly doped quartz glass. The process enables the fabrication of glass fibers with very large, doped cores. In 2012, IPHT received the Thuringian Research Prize in the area of applied research for this technology. The process, which was used industrially in the meantime, was made market-ready through the collaboration of industrial partners.

With the 14-meter-high fiber drawing tower now in operation since 2009, a large number of parameters could be controlled during the drawing process and the fibers also refined while still in production.

The technical possibilities and expertise benefit the ongoing development of microstructured optical fibers (MOF), among other things. With their customized, complex internal structures, these specialized fibers are suitable both as a new type of light source and for applications in sensor technology. In its work within the AquaDiva research project, IPHT is studying new fiber-optic sensors for continuous parallel measurement of biogenic gases such as oxygen, nitrogen, and carbon dioxide, for instance, in soil samples.



Microstructured Optical Fibers (MOF)

Before the fibers can be drawn, the researchers have to assemble the MOF preforms from as many as 270 glass capillaries and/or glass rods in what usually amounts to hours of manual work. The delicate internal structures and optical properties of the resulting MOFs are the ultimate product of a sophisticated adjustment of the parameters during the drawing process.

New Perspectives

» The growing demand on the optical properties of specialized fibers account for further development of production methods.

In the current research projects, scientists are working to profitably combine the advantages of individual technologies involved in the production of high-quality optical glass and glass fibers, in addition to augmenting them with new methods. The goal of one of these approaches is to produce and homogenize glass from powdered basic materials through the use of microwave plasma.

A further focus has arisen from the increasing application of glass optical fibers and the related demand on their optical properties. Innovative optical fiber solutions for the ultraviolet and infrared wavelength range are especially needed for sensors and new light sources. Conventional quartz glass types in the mid-infrared range lack sufficient transparency for these areas of application. The research and production of alternative glass materials for this spectral range will consequently be a focus of IPHT's future efforts.

The guiding idea is the development of ever more complex microstructured optical fibers and the realization of their customized functionalities. Researchers are increasingly using theoretical models and elaborate simulations for the design and practical implementation as well as for a deep physical understanding of how MOFs work.

Combined Expertise

IPHT derives further stimulation from its ongoing participation in several regional growth cores and from the fiber competence center. There, the Fraunhofer Institute for Applied Optics and Precision Mechanics, Leibniz IPHT, and FSU as well as local industrial partners are combining their existing expertise in the field of fiber technology to align their advances with the specific needs of the region. With its links to new concepts in technology for assembly and connection, from design to integration, the fiber competence center makes it possible to research the entire process chain for the development and supply of high-performance fibers and fiber-optic components.

Homogenization of REPUSIL material in a microwave plasma furnace



“ The colleagues with whom I work every day are like a big family to me. Each person has a different set of competencies and areas of responsibility. Our intensive teamwork allows us to make optimal use of them in order to develop the entire technology chain for the production of optical glass and glass fibers. This enables us to produce an enormous variety of innovative optical glass fibers for the most varied applications in industry and research.



ANKA SCHWUCHOW

At IPHT since 1994

Researcher

Group: Optical Fiber Technology

With teamwork, we can create the exceptional “

From Cleanroom to Sensor Technology

» For over 25 years at IPHT, micro- and nanotechnology has been the technological basis for the research and development of innovative processes and systems in the

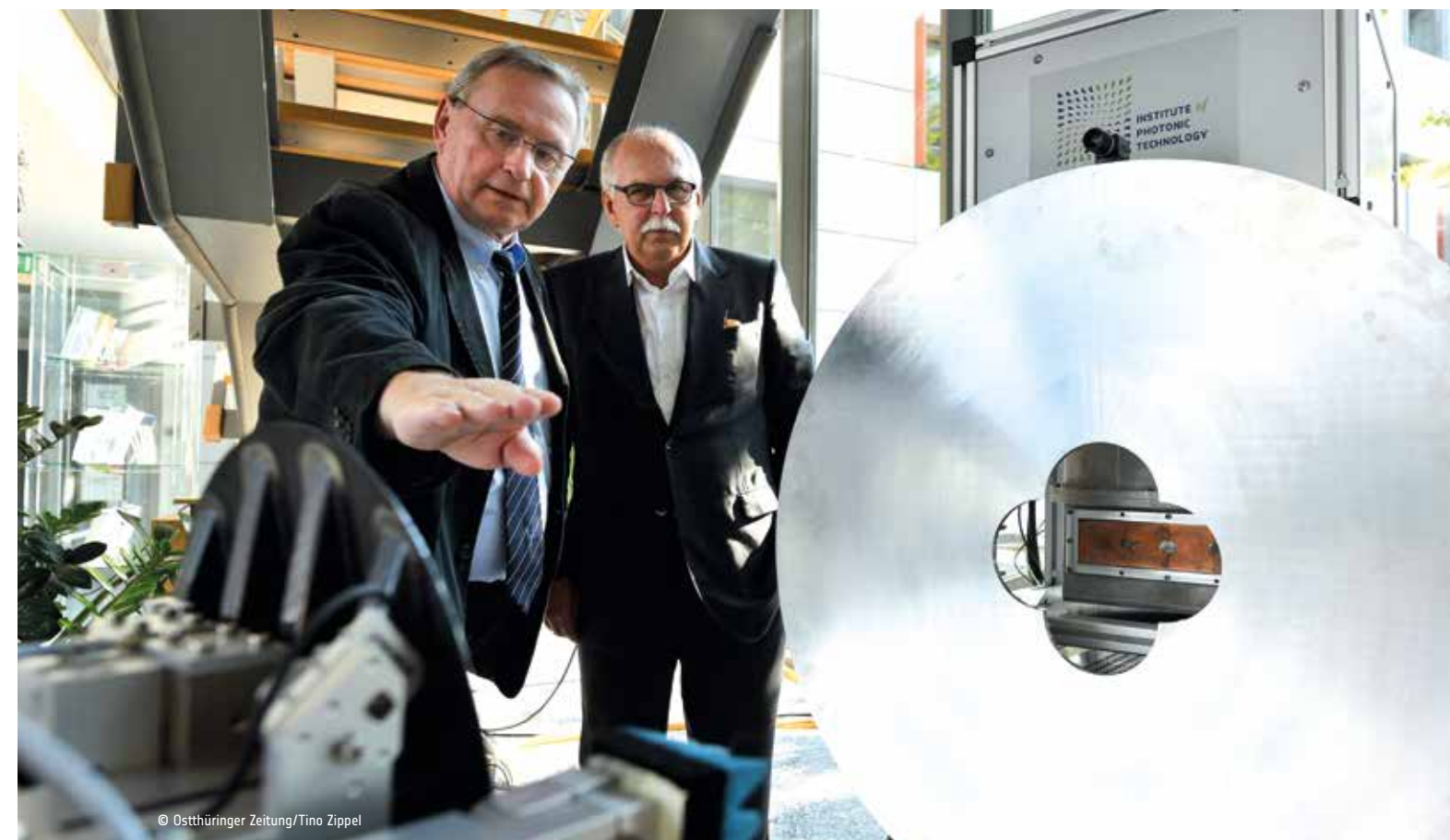
socially important areas of health care and medicine, environmental science, and security. A major part of this technology originated in IPHT's cleanroom.

Microtechnological processes such as design, vacuum coating, lithography, etching, characterization, and encapsulation are fundamentally similar to those of the billion-dollar, highly specialized semiconductor industry. At IPHT, however, the emphasis is on the development of thin-film sensors and microstructures made of what for semiconductor technology are atypical materials, such as gold, silver, niobium, titanium, or glass, as well

as special technologies for microfluidic devices. Our strength lies in the multitude of different approaches we take for the development of increasingly compact, integrated, and multifunctional sensor and detector designs, with an emphasis on radiation sensors and biophotonics.

As in the semiconductor industry, the structures are reduced to the nanometer range using *top-down* meth-

ods. Today, it is possible to fabricate metallic nanostructures corresponding to the structural size of nanoparticles that have likewise been researched at IPHT and produced through *bottom-up* processes, in billions and well-arrayed at wafer level. For new sensor technology and detection methods, these *top-down* methods will be combined with *bottom-up* processes in the future.



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Prof. Dr. Hans-Georg Meyer with Prof. Dr. Matthias Kleiner, President of the Leibniz Association, by the terahertz camera

Colleague at the ALD facility

Thin Films for High-Sensitivity Sensors

» The sensors produced by IPHT's cleanroom have a wide range of uses in high-sensitivity measuring devices such as the passive THz camera for security applications, the thermo-

electric IR temperature sensors in the Mars rover Curiosity, and instruments used in APEX, the ESO-operated radio telescope in Chile.

Researchers at IPHT use atomic layer deposition (ALD) to produce ultra-thin and precisely dimensioned dielectric layers. During the plasma-assisted process, monolayers of precursor materials deposit on the wafer surface in an alternating, self-limiting manner. In this way, just a few atomic layers thin, defect-free, and homogeneous oxide and nitride layers arise. Among other things, they provide the basis for single-photon detectors and are used as free-standing, structured membranes in the production of high-sensitivity, stable radiation sensors for the infrared and terahertz (THz) spectral range.

The THz radiation sensors from the IPHT cleanroom are what is behind the large reflector in the detector of a passive security camera. Through cooling to less than 1°C above absolute zero, these sensitive sensors can detect even the slightest differences in thermal radiation. The principle, otherwise used by astronomers to measure infrared radiation in outer space, is being employed by IPHT scientists in their research on an innovative body scanner. The THz security camera is a ethically harmless and health-uncritical alternative to the controversial "naked" body scanners

used in security control at airports. In contrast to these scanners and active THz cameras, the IPHT system passively measures the body's own THz radiation. Potentially hazardous objects worn on the body, such as weapons or bundled explosives, cause a suspicious shadow on the recorded radiation image. No other institute in the world has produced comparable results in this field.

The colleagues in the quantum detection division received the 2009 Thuringian Research Prize for their outstanding research work on the THz safety camera.

Milestones in Cleanroom Technology at IPHT

1991-1993

The beginning

Cleanroom with horizontal airflow in the present laser technology building

Approximately 60 m² of laboratory space, with 40 m² planned for lithography and 20 m² for wet chemistry

The coating and etching systems were housed in other laboratories



Cleanroom till 1993



Cleanroom 1995

1993-1995

Construction of the cleanroom building

Construction and commissioning of the cleanroom building, which is also used by the Institute for Applied Physics (IAP) at FSU

Approximately 360 m² of laboratory space is available with low turbulence displacement air flow.

The entire technology chain, which consists of coating, lithography, etching, and characterization, is carried out under defined cleanroom conditions.

2008-2011

Renovation of the cleanroom building and technology through EFRE-Invest and BMBF funding

Renovation and conversion of the cleanroom building into a two-story cleanroom with energy-efficient operation

Expansion of the laboratory area to approx. 700 m²



Cleanroom today



11 Working at one of the Germany's most modern research cleanroom facilities, I am inspired on a daily basis to create technological solutions that enable us to produce increasingly small and complex structures in the micro- and nanometer range. It's these tiny details, invisible to the naked eye, that allow us to realize innovative processes and instruments.

DR. UWE HÜBNER

At IPHT since 2000

Researcher

Head of Work Group: Micro- & Nanotechnology



For me, the tiniest details are important

11

1991-1994

The existing equipment consists of contact and projection lithography systems, a pattern generator, coating and wet etching technology, sputtering systems, ion beam etching (IBE) systems and reactive ion etching (RIE) systems.

Since 1993, the equipment has been suitable for processing 100 mm wafers.

Microstructures down to 5 micrometers are routinely produced using photolithography.

Construction of the technological basis for cryoelectronic thin-film components



Coating of a 100 mm silicon wafer

1995-2008

Microstructures down to 2 micrometers are routinely produced using photolithography.

Electron beam lithography (LION system) enables sub-100-nm patterning.

IPHT colleagues produce own masks for photolithography and joint use of electron beam lithography (ZBA 21) with the Institute of Applied Physics.

Process development for ion beam and reactive etching of metals and dielectrics

Development of the hard mask technology for structuring of SQUID sensor elements in the submicron range

Coating technologies and RIE for the production of niobium-based low-temperature superconducting (LTS) SQUIDs and voltage standards

Manufacture of ceramic high-temperature superconducting (HTS) Josephson junctions through layer deposition and ion beam etching

Development of a fabrication technology for planar waveguides in FHD oxide layers (flame hydrolysis deposition) and structuring in quartz glass for the production of optical gratings

Development of a process (anodic bonding) for the assembly of microstructured glass substrates into components for microfluidic *lab-on-a-chip* (LOC) systems



Coating laboratory for cryoelectronic sensors



Ion beam etching chamber



Wafer stepper 2006

2008-2011

Extensive renewal and modernization of technological equipment and infrastructure with EFRE funding

Coating and etching systems, technological tools, and nanostructural characterization are fitted for 150-mm wafers

Joint use of the new electron beam exposure facility (SB350 OS) at Fraunhofer IOF location

New conformal coating methods for surfaces through atomic layer deposition (ALD)

Deposition of membrane layer systems for micro-electromechanical systems (MEMS) using chemical vapor deposition (CVD)

New etching technologies for metals, silicon, and glass using ICP plasma etchers with reactive gases

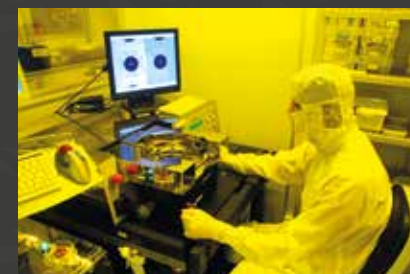
Development of packaging technologies for chip components



Spin-Coater for resist coating



Wafer stepper after 2006



Working at the anodic bonder

2011 to the Present

New aperture technology for electron beam system (SB350 OS) enables large-area nanostructuring at wafer level

Standard production of structures with 200-nm period and nanostructures down to 50 nm

ALD technology has proven to be an enabling technology for fabricating extremely thin, defect-free films, e.g., for superconducting single-photon detectors



Unit for ALD

Areas of Application for Cleanroom Technology

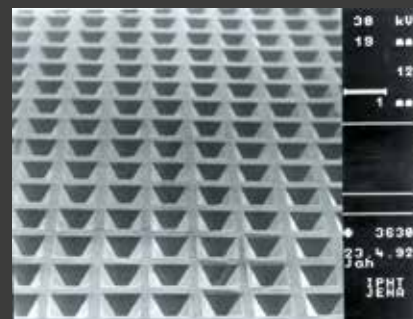
1991-1994

Production of thermosensors with up to 72 thin-film thermocouples for IR sensors

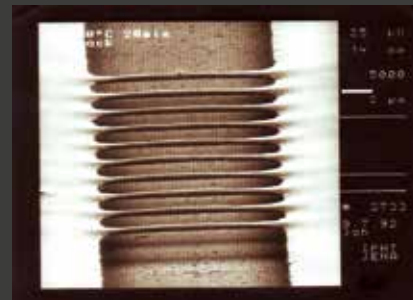
First technologies for deep etching of silicon and glass for the production of biochips and for microfluidics

Production of first LTS-SQUIDs and voltage standards using coating technologies and RIE

First functional HTS components for Josephson arrays and SQUIDs using layer deposition and ion beam etching



Silicon microchamber arrays for combinatorial chemistry



Metal micro bridges

1995-2008

Cryoelectronic multilayer circuits with up to 14 levels for ultrasensitive and magnetic field measurements that are suitable for fieldwork

Production of membrane-based sensors for THz detection

Line sensors with 2560 thermocouples per chip for IR sensors

Production of microfluidic flow sensors and LOC systems for DNA amplification (PCR chips)

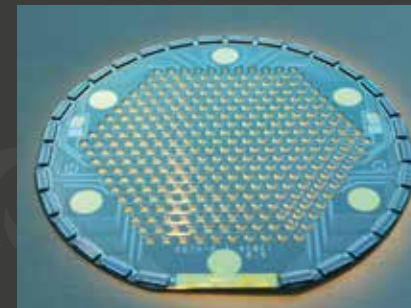
Generation of waveguides and photonic crystals for planar micro- and nano-optics

Preparation of calibration standards for deep-UV microscopy

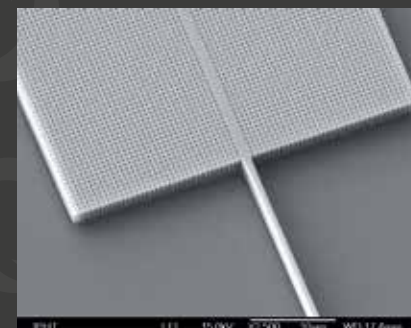
Basic research in the area of qubits



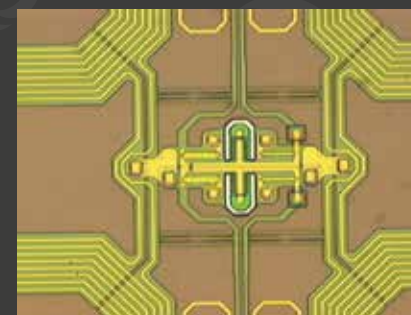
Interior of a thermosensor element for space travel



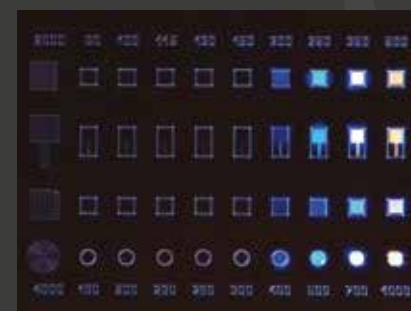
Wafer for THz radiation detection



Photonic crystal structure in $\text{Ta}_2\text{O}_5/\text{SiO}_2$



Center of an LTS SQUID



Calibration structure for DUV microscopy (periods of down to 160 nm)

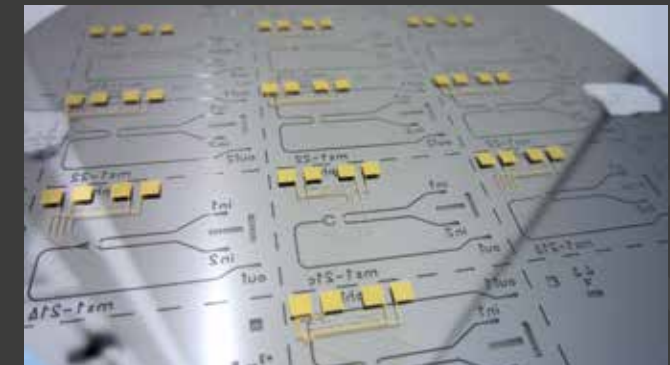
2011 to the Present

Interdisciplinary development of biophotonic sensor technology, single-photon detectors, and new Micro-Electro-Mechanical Systems [Surface Micromachining [SMM]] processes

Production of optical metamaterials and plasmonic substrates for surface-enhanced molecular spectroscopy

Production of microfluidic dielectrophoresis chip systems for Raman spectroscopy

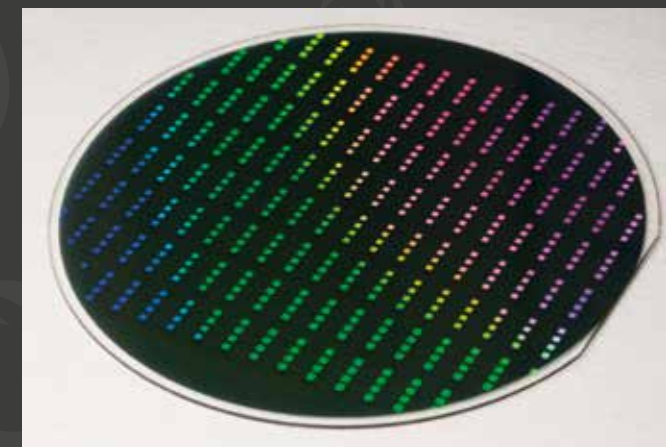
Production of micro-optical devices for lensless microscopy and multilevel imaging gratings for spectroscopy



Microfluidic dielectrophoresis chip systems



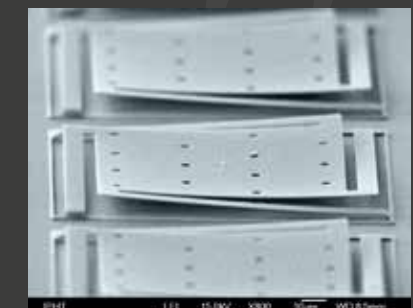
Microfluidic chip



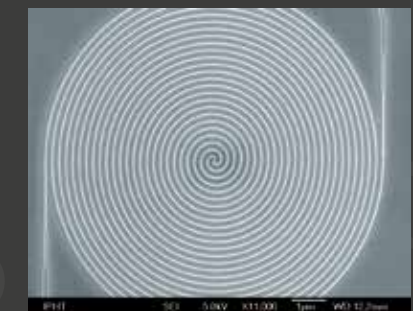
100-mm wafer with 250-nm grating for surface-enhanced molecular spectroscopy



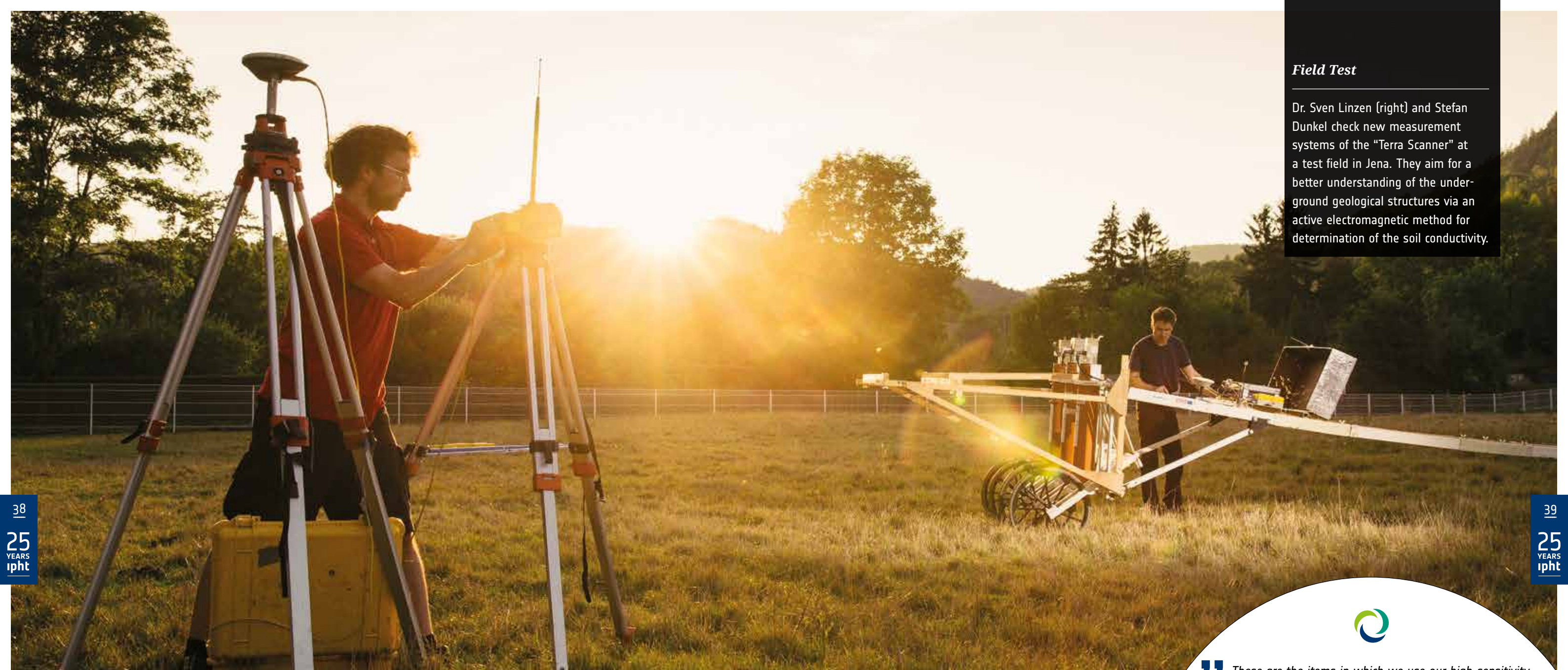
Detail from the above wafer, plasmonic structures made of silver



Example of SMM membrane technology



Planar coil for single-photon detection



Field Test

Dr. Sven Linzen (right) and Stefan Dunkel check new measurement systems of the "Terra Scanner" at a test field in Jena. They aim for a better understanding of the underground geological structures via an active electromagnetic method for determination of the soil conductivity.

SQUIDS

Low-Temperature Superconductors for High-Resolution Mapping

» A jeep with a trailer is driving through the wide, sparsely populated Orkhon Valley in the central Mongolian steppe, where Karakorum, the capital and center of the Mongolian empire, was located about 800 years ago. Founded by Genghis Khan, the town, with its dwellings, workshops, bazaars, and holy places, was destroyed around 160 years later. Once a hub for people of different cultures and religions, the city is now a UNESCO world heritage site. Using geophysical measurements and archaeological excavation, a team of scientists is reconstructing the life that once existed in this region that was already settled long ago.

On the other side of the globe, in Thuringia, a pilot is preparing his helicopter for an early-morning start. He flies it over the ground at a height of only 30 meters as it probes for magnetic anomalies in the earth's crust. Based on these magnetic signals, geoscientists can identify resources of raw materials, which they can then depict spatially.

In Finland, a group of geoscientists trudges through the snow in minus 40 °C weather to an area where they suspect the existence of ore deposits roughly one kilometer below the earth's surface. At specific points in the terrain, they place their measuring instruments on the ground to determine the exact position of conductive geological structures.

Accompanying every assignment are SQUIDS from IPHT, or superconducting quantum interference devices, which are among the most sensitive magnetic field sensors in the world.



“ These are the items in which we use our high-sensitivity magnetic field sensors. It fascinates me to overcome the technological obstacles presented by every area of application. That's why I monitor every development in relation to new sensors, from the basic research to the first field operation with the complete measuring system. We are using these new instruments to search for vestiges of our past, for mineral deposits, and for the smallest particles of the microcosm.

DR. RONNY STOLZ

At IPHT since 1995

Researcher

Head of Research Group: Magnetometry



I research on land,
in the water, and in the air. “



Measurement campaign in Mongolia 2010

In the Footsteps of Genghis Khan and Charlemagne

» Geophysical research methods are playing an increasingly important role in archaeology. Using SQUID-based instruments, it is possible to achieve high-resolution detection of hidden underground structures. Examples of where the signals come from include burnt clay bricks, open hearths, or products from decomposing wooden posts. With conventional handheld instruments, it took months or even years to map an archaeological site measuring several hectares. To be able to examine large areas within a

few days, IPHT pursued an alternative approach with the research and development of a motorized SQUID measuring system. As a basis for this, researchers used the sensors and

electronics of the airworthy SQUID systems. After four years of research, the system was implemented for the first time in a geomagnetic exploration in Peru in 2005. The method is suitable for both mapping archaeological areas and exploring for raw materials as well as in analyzing building ground and contaminated sites.

In the BMBF joint project "Geoarchaeology in the Steppe: Reconstruction of Cultivated Landscapes in the Orkhon Valley, Central Mongolia," the Terra scanner succeeded in proving its day-to-day practicality. In two measurement campaigns that took place between 2009 and 2010, scientists magnetically mapped a dozen areas measuring a total surface of 300

hectares. For the first time, details of extensive urban complexes became visible. The magnetic image shows the foundations of simple houses and elaborate palaces, precise road and drainage systems, and furnaces in craft industries for metallurgy and ceramics production. Because of this extensive data, archaeologists have been able to more closely examine the significance of the over 100-kilometer-long Orkhon Valley as a cultural melting pot. A current follow-up project with the University of Bonn is dedicated to the complete magnetic and topological survey and modeling of the former capital of the Mongolian empire, Karakorum, with a projected measurement area of 550 hectares.

The Thuringian Basin as Geophysical Open-air Laboratory

» About 1000 km² of the Thuringian Basin have been explored geomagnetically since 2010 with the help of Jena SQUID sensors. The means for accomplishing this was the world's first airborne system for deep electromagnetic exploration, called JESSY STAR. Among other activities, the INFLUINS project, funded by BMBF and the Free State of Thuringia, investigates the movement of liquids and gases at depths of down to 600 meters. The ability to trace magnetizable geological structures in the subsoil of the extensive research area was only possible through the use of a helicopter that dragged the measuring probe. The structures provide direct and indirect indications of the presence of minerals, liquids, and gases by detecting minimal changes in the earth's magnetic field.

The SQUID sensors detect these differences in the magnetic field, even in an environment disturbed by technical devices. IPHT's airborne magnetic field sensor systems have been used for geophysical explorations since the end of the 1990s. The technological basis for this is an appropriate sensor layout, suitable noise field compensation, and new electronic developments that enable a high dynamic and fast readout speed.

For their research efforts with JESSY STAR, the IPHT researchers won the prestigious Mining Research Award in 2007. To date, the measuring system has flown more than 100,000 kilometers. At present, the scientists are working on further developing the system for multi-sensor exploration of extremely low-lying mineral deposits,

along with an underwater platform for the instruments.

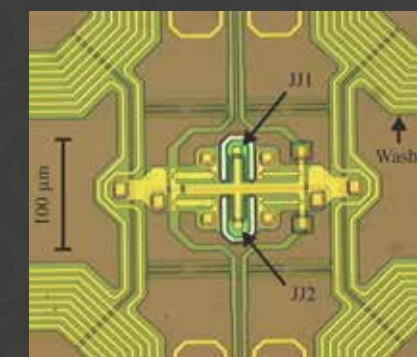
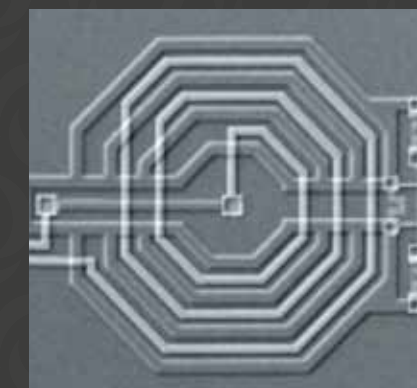


Preparations for the operation of JESSY STAR in the Thuringian Basin

Developments at IPHT

In 1963, with the availability of liquid helium and the discovery of superconducting materials and the Josephson effect, scientists at Ford Laboratories (USA) developed the first SQUID sensors. Just a few years later, they were used for the first time to record the magnetic field of the heart of a human being. The history of the Jena SQUIDs dates back to 1968 and is closely linked to the study of superconducting materials at Friedrich Schiller University in Jena. Initially, the SQUIDs' hair-thin structures were still scraped by hand under a microscope. From the 1970s onward, with the establishment of suitable nanotechnologies and electron beam lithography in Jena's first cleanroom, high-sensitivity SQUIDs were produced using thin-film technology. In contrast to their predecessors, these SQUIDs possessed reproducible properties.

Over the past 25 years, researchers at IPHT have succeeded in integrating the SQUIDs into high-sensitivity, compact measuring systems that provide reliable data over many hours of activity. Critical to this success was the 1995 completion of a modern cleanroom on the Beutenberg campus. There, thin-film and lithography techniques for the construction and integration of the SQUIDs were further developed. Using these methods, it is now possible to produce SQUIDs with structures smaller than one micron. These allow for magnetic field measurements with minimal noise and an extremely high magnetic field resolution, about eight orders of magnitude more sensitive than the earth's magnetic field.

Microscopic image of the central unit in a low temperature superconductor SQUID with 3x3 μm² window junctions from 1998Magnetometer with 0,8x0,8 μm² cross junctions

From Photovoltaics to Biophotonics

» *The first experiments in the laser crystallization of silicon took place in the field of applied laser technology a few years after the founding of the Institute. Since then, scientists have been researching this technology, which has produced the world's first multicrystalline silicon thin-film solar cells on glass substrates, along the lines of the Institute's orientation.*

Laser-Crystallized Silicon

11 / 1994 – 12 / 1998

Preparation of large-grained polycrystalline thin films for silicon solar cells (BMFT project)

Process development for gas-phase deposition and crystallization of silicon on glass substrates

At IPHT, coarse crystalline silicon with good electrical and optoelectrical properties for thin-film solar cells on glass with a surface area of up to 2 x 2 cm is produced for the first time worldwide.



Dr. Gudrun Andrä is working at the facility for plasma-enhanced vapor deposition of silicon

01 / 1999 – 12 / 2002

Thin-film solar cells from laser-crystallized silicon on glass (BMBF project)

Further development of crystallization processes for the reproducible generation of a seed layer for the epitaxial growth of an additional solar cell layer system

The world's first laser-crystallized silicon solar cell is produced on glass at IPHT



Crystal structure and orientation in a laser crystallized silicon layer

01 / 2003 – 04 / 2007

Multicrystalline LLC silicon thin-film solar cells on low-temperature glass (BMW/BMU joint project with ErSol AG)

Electron beam coating as an alternative method for the deposition of amorphous silicon

A high-performance diode laser system with a line beam allows for silicon crystal layers with larger crystal nuclei on glass supports of up to 5 x 5 cm.

Production of silicon thin-film solar cells using industry-relevant processes



LLC solar cell

01 / 2008 – 12 / 2010

HIGH-EF – Large-grained, low stress multicrystalline silicon thin-film solar cells on glass by a novel combined diode laser and solid-phase epitaxy process (EU project, with IPHT as coordinator)

Glass substrates with laser-crystallized seed layers up to 10 x 10 cm can be coated with amorphous silicon and simultaneously doped with boron or phosphorus.

Optimization of an industrial process for the production of silicon solar cells

The thin silicon layers, partly functionalized with nanowires, are now found in innovative photovoltaic systems, in sensor technology, and as electrode material in new types of batteries. In the past five years, silicon nanowires and nanoparticles have become useful tools

in biomedical imaging. They are used to visualize cells and to destroy cancer cells by means of ultrasound. The evolution of technologies and applications is demonstrated by selected research projects from the past 25 years.

02 / 2009 – 02 / 2011

SolLux – Optical technologies for the next generation of silicon thin-film photovoltaics; subproject of laser recrystallization of Si-layer systems on glass for high-efficiency thin-film solar cells (Thuringia)

Production of more efficient thin-film solar cells with a thickness of 5-10 µm



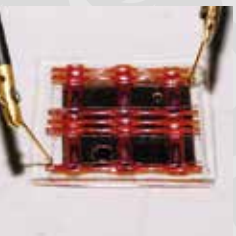
Diode laser (company LIMO) with line beam for crystallization of silicon

10 / 2011 – 09 / 2013

TexSiSolar – Textile silicon solar cells on glass-fiber interconnect systems (Thuringia/TAB)

Development of the material basis and production technology for silicon thin-film solar cells on glass-fiber cloth

Production of laser-crystallized silicon solar cells on textile fabric, with patented interconnection



Textile solar cell

01 / 2013 – 12 / 2014

OptiSolar – Increase of reliability and efficiency through optimization of critical interfaces in silicon solar cells (research group/Thuringia/TAB)

First hybrid thin-film solar cell with PEDOT:PSS emitter produced on a multicrystalline silicon thin-film absorber (record efficiency of 10.9 %)



Hybrid silicon-polymer solar cell

Ongoing Projects

Development of crystalline Si thin-film solar cells for bidirectional illumination (TAB research group Bi-PV)

Production of thermoelectric layers based on silicon nanoparticles on textiles (ZIM AiF project TerSiTex)

Growing Crystals with Lasers – an IPHT Patent

In the production of conventional solar cells from approximately 200-micrometer-thick silicon wafers, large quantities of valuable ultrapure silicon are wasted, since the effective conversion of light into electricity only takes place at the wafer's surface, which is tens of micrometers thick. Solar cells made of very thin multicrystalline silicon are suitable as a cost-effective and environmentally friendly alternative. For crystallization, the silicon must be melted at a temperature of more than 1400 °C. Though, glass as an inexpensive carrier material for solar cells, is only stable at temperatures of up to 600 °C. To be able to utilize glass substrates, IPHT researchers developed a new laser crystallization process that allows the production of thin-film solar cells.

In the early years of the Institute, a layer of amorphous silicon up to 500 nanometers thick was deposited on a glass substrate using plasma-enhanced gas phase deposition or electron beam evaporation to produce the thin multicrystalline silicon layers. A laser beam subsequently generated a thin crystalline layer of several hundred micrometers to a few millimeters long crystal grains from the amorphous silicon. These crystallized layers were used as seed layers for the growth of the additional solar cell layer system.

With the layered laser crystallization (LLC) process, developed and patented at the end of the 1990s, deposition and crystallization occur in one step. As technology developed, thicker silicon layers could be crystallized with a continuous laser beam and then simultaneously doped with further chemical elements. Since the laser beam melts the silicon for only a few thousandths of a second, the underlying glass substrate remains unaffected during the process.

04 / 2005 – 03 / 2007

Vertical, distorted, one-dimensional silicon nanostructures and components (commissioned by FSU Jena / DFG)

Investigations on thermal and plasma-enhanced gas phase deposition of silicon nanowires on a gold nanoparticle-structured glass substrate

For the first time in the world, IPHT produces thin-film solar cells made of silicon nanowires. Compared to cells made of self-contained thin films, these cells have a perfectly monocrystalline structure and capture sunlight almost completely.

Dr. Silke Christiansen and Dr. Fritz Falk publish an article on silicon nanowire solar cells, which at the time is one of the most cited and downloaded articles from the scientific journal Nanotechnology. The article describes the production, using the VLS method, of silicon nanowire solar cells on silicon wafers as well as multicrystalline silicon thin films on glass (Stelzner et al. Nanotechnology 2008).



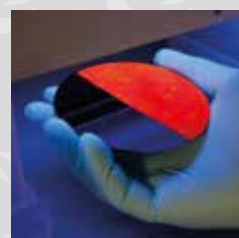
Silicon nanowires produced via VLS method (bottom-up)



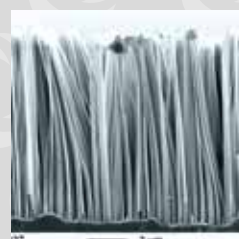
Facility for electron beam coating



Silicon nanowires embedded in a polymer matrix



Room temperature photoluminescence of silicon nanowires on a wafer



Silicon nanowires produced via the top-down method

08 / 2010 – 07 / 2013

SiNAPS – Semiconducting nanowire platform for autonomous sensors (EU project)

Atomic layer deposition is employed for the functionalization and interconnection of silicon nanowire-based solar cells to modules measuring only a few millimeters for use as a power supply for autonomous sensor systems

03 / 2011 – 02 / 2014

NanoPV – Nanomaterials and nanotechnology for advanced photovoltaics (EU project)

Atomic layer deposition of a conductive ZnO:Al film on silicon nanowires for the production of solar cells



VLS silicon nanowires with a shell made of ZnO:Al

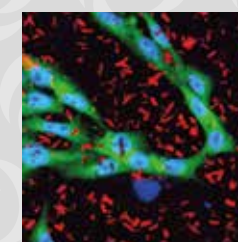
Current Research Topics

Investigation of silicon nanowires as catalysts for light-driven hydrogen generation

Investigation of the antibacterial effect of silicon nanowires

Investigation of the uptake, therapeutic effect, and biodegradability of silicon nanoparticles in cancer cells by means of spectroscopy and microscopy

Use of densely packed silicon nanowires with a special core-shell structure in high-sensitivity sensors that, depending on the design, detect light, X-ray, and gamma radiation or high-energy particles



Photoluminescence of silicon nanoparticles (red) in human lung cancer cells (Hep-2)

Silicon Nanocarpets

Originally designed for use in micro-electronics, silicon nanowires have a wide range of applications due to their unusual chemical and physical properties, large surface area, and ease of manufacture. While the main application areas at IPHT were initially concerned with new types of transistors and solar cells, for several years now, silicon nanowires and particles have become increasingly important as markers for multimodal imaging or for use in high-sensitivity particle-detection sensors. Silicon nanofiber carpets are produced through either a bottom-up or top-down process.

Both variants utilize thin-film techniques such as chemical vapor deposition, atomic layer deposition, electron beam evaporation, and pulsed laser deposition as well as wet etching methods. In the top-down process, the nanowires are etched from a monocrystalline or laser-crystallized silicon layer. This produces very dense carpets that demonstrate a high degree of light absorption. The process of wet etching alters the chemical-physical properties of silicon, with the results being specifically used for various applications. In the bottom-up variant, the silicon nanowires grow on a substrate by means of the VLS (vapor-liquid-solid) method. For this, gold particles with the same diameter as that of the envisioned nanowires are deposited on a substrate. During the gas-phase deposition of silane gas (SiH_4), which undergoes catalytic decomposition at the gold droplets, the silicon nanostructures grow lengthwise on the substrate. Since the process occurs at no more than about 500 °C, it is possible to use glass as a substrate.

08 / 2008 – 12 / 2011

HyPoSolar – Hybrid solar cell made of semiconducting polymers and Si nanowire structures (BMBF project)

Production of hybrid solar cells from photoactive polymers and silicon nanowires

01 / 2009 – 12 / 2011

ROD_SOL – All-inorganic nano-rod based thin film solar cells (FP7 EU joint project, with IPHT as coordinator)

Development of an etching (top-down) process for the production of silicon nanowires for solar cells

At IPHT, silicon nanowire-based thin-film solar cells are manufactured for the first time worldwide by means of wet etching from a laser-crystallized silicon layer. The entire solar cell is only 2.5 micrometers thick. The article on silicon nanowire solar cells on glass, published jointly by Gudrun Andrä and Dr. Vladimir Sivakov, is one of the most successful articles in IPHT's 25-year history and has been cited over 410 times. (Nano Lett., 2009, 9 (4), pp 1549–1554)



Eugen Ermantraut at the terrace of Bioinstrumentezentrum with place of business of BLINK AG (Beutenberg Campus Jena)

“We should encourage more of our Researchers to found Companies with their Ideas”

» In addition to application-oriented research, IPHT’s focus is on knowledge-oriented basic research in such fields as nanoscopy, point-of-care sensors, and fiber optics. This gives scientists the necessary space to develop new ideas and pursue their own research interests. With such fertile soil at IPHT, con-

crete visions can grow very quickly into ideas for conversion into applications, as shown by the example of Eugen Ermantraut. In an interview with Ermantraut, who has been involved in the founding of several companies that were spin-offs of IPHT, he describes the path he takes from idea to product.

As a scientist, Eugen Ermantraut has been conducting research on new types of substrates for electron microscopy since 1994, initially as part of his thesis at the Hans Knöll Institute (HKI). The microstructuring needed for this led him to IPHT, which back then was still new. The biologist was fascinated by the Institute’s technological possibilities and the atmosphere in the team that worked with Michael Köhler at the time. But what aroused his interest most of all was the cleanroom in the laser technology building: „The IPHT scientists had already moved into the new cleanroom building. An extensive arsenal of equipment was ready and waiting, and it was available to us for all sorts of possible things.” Together with Torsten Schulz and Michael Köhler, who headed the microsystems division at that time, Ermantraut performed initial experiments on biological sacrificial layers. “It was like an internship,” he says, describing the six months in which he learned everything about microsystems technology from Schulz and Köhler.

Eugen Ermantraut

Eugen Ermantraut, former colleague at IPHT, is one of the founders and directors of BLINK AG, whose goal is to decentralize in vitro diagnostics and to simplify and accelerate the development of new diagnostic tests through a cooperative business model.

Ermantraut has been involved in several business start-ups. While working on his dissertation, he developed new types of substrates for electron microscopy. These became the foundation of the business Quantifoil Microtools GmbH. Later, he undertook the development of processes for the production of polymer libraries. These efforts led to the founding of CLONDIAG GmbH in 1998.

Following the acquisition of CLONDIAG by the Alere group in 2006, Ermantraut managed the rapidly growing location in Jena and oversaw the development and launch of new products in the area of point-of-care diagnostics. He supervised a series of international collaborations with renowned partners from the Global Health community. In 2014, he left Alere and has since been concentrating his efforts on his new company.

“We came from different directions, but we wanted the same thing.”

“In the middle of the nineties, IPHT was very open to exploring new topics,” says Ermantraut. “They were looking for new fields of specialization and wanted to contribute to the development of biotechnology.” The Institute needed someone like Ermantraut, who knew something about biology and biotechnology and also enjoyed microsystem technology. Ermantraut was fascinated by new things, by the uncomplicated work style, and by the “playground” that was made available to him in the cleanroom. After graduating, he transferred to IPHT and brought his biological expertise to the development of new processes and techniques in the cleanroom. “We came from different directions, but we wanted the same thing,” Ermantraut said about what at the time was an unusual setup.

“Things developed a momentum of their own.”

“I had time and a stipend. I wanted to construct a substrate for electron microscopy. I absolutely wanted to have a thing that would allow you to stretch nucleic acids over a surface with holes. And there was none. You couldn't buy it.”

The scientists then developed the technology to produce these substrates themselves with a type of sieve plate. It rapidly became clear that the nitride membranes used at the time would have to be replaced by structured carbon. As an electron microscopist, Willem Tichelaar of the Institute for Molecular Biotechnology (IMB, the present Fritz Lipman Institute) was quick to recognize the potential applications for such substrates. And Ermantraut was glad “that there was someone who actually wanted to have this stuff.” Along with Klaus Wohlfart, who was earning his doctorate at IPHT at the same time, the scientists further developed the technique to obtain substrates with a well-defined hole size, shape, and arrangement. Interest in the new substrates grew quickly among retailers in electron microscopy accessories. And since this meant the manufacture of a product, the opportunity for founding a company presented itself. In 1996, together with Klaus Wohlfart and Willem Tichelaar, Ermantraut founded Quantifoil GbR.

The decision to found the company happened at the right moment. “The time period was ripe for the substrates. A lot of users wanted to have them, and the development went independent.”

“All things were possible.”

At about the same time, Ermantraut was researching various methods for the functionalization of surfaces in order to produce combinatorial polymer libraries. His plan was to do his dissertation on the possibilities of using printing techniques to produce biofunctionalized chips. To fabricate microstructured polymer arrays on the surface of technological substrates, the scientists had to search for suitable methods.



^ Leibniz IPHT cleanroom

^ Eugen Ermantraut in his office at BLINK AG



“Naturally, we used the existing technology and equipment. So with a mask aligner, we tried the targeted positioning of liquids, instead of light, at specific points on the wafer's surface. This worked some of the time, but it was also clear that we needed our own equipment for production.”

The scientists needed specially modified mask aligners to develop the process. Michael Köhler contacted the company Electronic Visions (EV), who had supplied the existing devices to IPHT, and he described the project. After meeting, EV indicated their interest in implementing the idea, and the notion arose of forming a joint enterprise. On April 1, 1998, CLONDIAG Chip Technologies GmbH was born. During the next two years, almost an entire work group left the Institute. “That was a bloodletting experience for IPHT, but the board of directors at the time had always supported this.”

The financing for the technological advance came from a variety of sources. The Free State of Thuringia provided a loan to finance collaborative research and was involved in the company later on. In 2002, CLONDIAG introduced its first product for end users with the Array-Tube, a new format for developing multiplex tests. In the following years, Ermantraut dedicated his work with the company to the creation of tube arrays for use in molecular and immunological diagnosis. One focus of the work was on the development of laboratory-independent in vitro diagnostics for on-the-spot detection. Following the acquisition of CLONDIAG by the Alere Group in 2006, the company evolved into a fully integrated developer and manufacturer of in vitro diagnostic products. The Pima CD4 system was the first mobile cytometry system to be commercialized in 2009. The development of manufacturing processes for the mass production of IVD tests now became a major focus of CLONDIAG's work.

“The Institute is much more visible than ever before.”

Today, Eugen Ermantraut has come full circle with application-oriented research and IPHT. In 2014, after his time at CLONDIAG and later at Alere, he founded a new company, BLINK AG. There, he researches new concepts aimed at realizing a sustainable, decentralized approach to in vitro diagnostics. And he sees parallels to his time at IPHT. “We intentionally planned for a discovery phase at Blink as well.”

As a long-standing collaborative partner and, more recently, as a member of the scientific advisory board at IPHT, Ermantraut is now giving back to the Institute with his experience and technologies. “Today, IPHT has a clear content focus, a clear structural setup, and plausible goals. Still, we should always be able to pursue new paths. Basic research will always come up with surprises and open up opportunities for researchers to take their own entrepreneurial paths. We should encourage more of them to start companies with their ideas.”



” *As a facilities manager, I love the diversity of my work as well as good scheduling, order, and friendly relations with my colleagues. This is the only way I can reliably organize my many daily tasks, such as gas canister replacement, key control, performing courier services, or ensuring the correct seating arrangement in meeting rooms. And if there's something to repair as well, my day is perfect.*

DETLEF SCHARF

At IPHT since 2005

Service Technician

Operating Technology



**You can
depend on me.**

“

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Phone | Fax:

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Editors:

Daniel Siegesmund, Dr. Anja Schulz, Britta Opfer (Leibniz IPHT)

Artwork:

Katrin Uhlig (Leibniz IPHT)

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Sven Döring _Agentur Focus, Hamburg, Leibniz IPHT Jena

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Leibniz Institute of Photonic Technology e. V.

Location:

Albert-Einstein-Str. 9
07745 Jena

Postal Address:

PF 100 239
07702 Jena

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