Leibniz ipht
LEIBNIZ INSTITUTE of PHOTONIC TECHNOLOGY

reflexion

Annual Report 2022

Solutions with Light

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Collaborate & Create

Leibniz Association

jenaphotonics

PHOTONICS FOR LIFE

from Ideas to Instruments

Dear Readers,

Prof. Dr. Jürgen Popp © Sven Döring

Frank Sondermann © Sven Döring

The Leibniz Institute of Photonic Technology as one of the world's leading research institutions in photonics, strives to enable all people to live a healthy life in a healthy environment with sustainable light-based technologies – in short: *"Photonics for Life"*. This vision is what gives meaning to our research work, what drives us, what unites us, and what we work on as a team. But why are collaborations, partnerships and teamwork important in order to achieve our goals? How do they promote the emergence of innovation?

Excellent scientific work requires not only a motivated workforce, but also an environment that enables scientists to achieve their full potential. Here, the close cooperation within our institute plays an important role, both by promoting the exchange of knowledge and expertise as well as by generating synergies and new ideas.

Moreover, collaboration with external partners is of great importance. By cooperating with other institutions, universities and companies, we can expand our expertise and broaden our research. In doing so, it is important for us to meet on an equal footing and benefit from each other.

In addition to collaborations with external partners, mutual exchange with society plays an important role. Our goal is not only to make our research results accessible to the public, but also to make them useable for the society. In this regard, collaboration with stakeholders and interest groups is essential to understand the needs of society and to align research goals accordingly.

In our annual report, you will find numerous examples of successful collaborations at different levels, which illustrate how important such cooperations are for scientific excellence, innovative strength and the implementation of research results.

We hope you enjoy reading our annual report, and would like to thank all our internal and external partners for their constructive cooperation over the past year.

With kind regards

Jürgen Popp
Scientific Director

Frank Sondermann
Administrative Director

Content

Close cooperation and a successful, inspiring exchange between science and industry produces revolutionary findings and achievements that contribute to solving global challenges. © Sven Döring

Researching Together to Make Life Safer and Healthier

Inspiring Collaborations Create Conditions for Technological Progress and its Translation into Practice

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The American industrial magnate and automotive pioneer, Henry Ford, described the cornerstone of pioneering developments and achievements in the late 19th and early 20th century. His words "Coming together is a beginning, staying together is progress, working together is success" have not lost their validity even today, more than 100 years later.

An efficient collaboration that combines creative minds, many years of expertise and knowledge from different disciplines is still the foundation for successfully exploring innovative ideas today. A trusting cooperation of all partners allows sophisticated new technologies or pioneering processes to grow from an initial idea.

Close cooperation between research departments and scientific teams is also practiced at Leibniz IPHT in order to promote innovative strength and pave the way for ideas for novel solutions, for example for better medical diagnostics or safer medicines. If technological competences are required for the realization of a project, which are not available at the institute, these competences are supplemented by strategic cooperations with partner institutions.

To this effect, Leibniz IPHT is involved in various projects, networks and clusters as part of external collaborations, and works together with its partners on technological advances that have regional, national and international appeal. This issue's cover story – "Collaborate & Create" – presents some of these successful collaborations, to which researchers of Leibniz IPHT contribute their scientific expertise, in more detail on the following pages. The described projects, alliances and networks highlight how the success factor of collaboration is used to shape new creative and light-based solutions for societal challenges in the fields of health, medicine, environment, and security.

Internal Innovation Projects

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The innovation projects at Leibniz IPHT are an internal institution. They enable the researchers at the institute to unleash their creative potentials, and create the necessary freedom to explore new solution approaches.

Regional Cooperations

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Together with local actors and in the context of regional research collaborations, scientists at Leibniz IPHT can develop groundbreaking new technologies and build the bridge to marketable products.

National Activities

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In nationally significant projects and networks, Leibniz IPHT, together with its partners, develops new innovation potentials.

International Collaboration

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Added value with social relevance is also generated together with international research partners from science and industry around the globe.

Inspiring Ideas and Strengthening Internal Cooperation

Institute-internal Innovation Projects Promote Inventiveness

Today's increasingly complex world is facing a multitude of challenges: Climate change and the pollution of our planet, the risk of increasing infectious diseases, antibiotic resistance and cancer, as well as global crises are just some of the serious problems of concern to society as a whole that need to be addressed.

In order to be able to answer these pressing questions efficiently and in a future-oriented way, and to break new ground in the fields of environment, health and safety, space is needed to unleash creative potential for the development of effective technological solutions.

This freedom to implement unusual ideas and innovative solutions has been granted to the scientists at Leibniz IPHT for more than a decade as part of the institute's own innovation management. In an open and cooperative atmosphere, employees have the opportunity to explore promising technologies, test previously unknown experimental approaches, and explore their potential.

The framework for this is provided by internal innovation projects, which the institute supports annually with a total of 50,000 Euros in a competitive process. A feature that all projects have in common is that the project proposals must be submitted jointly by at least two research departments, or junior research groups. This enhances collaboration within the institute and promotes emergence of creative approaches.

Beyond the boundaries of the departments, the researchers thus have the opportunity for professional exchange, for cooperative collaboration with complementary competences, and for generating new research findings independently of third-party funded projects. For many years, these stimulating results of joint scientific work have resulted in various publications, patents and publicly funded follow-up projects on a regular basis. Thereby, the institute's internal innovation projects lay the creative foundation for further developing the knowledge and technology base in the long term, and for preparing technological answers to tomorrow's problems already today.

Two selected Leibniz IPHT innovation projects are presented on the following pages.

"An incubator for fresh ideas – that's what the innovation projects at Leibniz IPHT offer me. They allow me creative freedom, create a meeting place that brings together researchers from different research departments, and can be a starting point for the emergence of fundamentally new solutions that can change our world with light.

Dr. Vladimir Sivakov, Head of the Silicon Nanostructures Work Group in the Functional Interfaces Research Department at Leibniz IPHT and coordinator in the innovation project "Hydrogen Generation on Nanostructured Silicon (HyGS)" on pages 12-13

"Breaking new technological ground requires inspiring impulses that can be generated through intensive exchange and institute-wide collaboration. The innovation projects allow us to test unconventional research projects. This knowledge enables us to let new ideas mature into promising technologies.

Dr. Andrea Csáki, Head of the Molecular Plasmonics Work Group in the Nanobiophotonics Research Department at Leibniz IPHT, and participant in the innovation project "Hydrogen Generation on Nanostructured Silicon (HyGS)" on pages 12-13

"Within the framework of the internal innovation projects, we were able to develop and build up highly specialized and valuable know-how for the production of complex and functional micro- and nanostructures together with our colleagues, from which all research departments of the institute will also benefit for future research projects. The resulting close networking with the actors involved is, in my experience, a win-win situation for everyone.

Dr. Uwe Hübner, Head of the Competence Center for Micro- and Nanotechnologies at Leibniz IPHT and participant in the innovation project "Miniaturized infrared spectrometer in the wavelength range 8-14 µm" on pages 10-11

16 Innovation Projects

20 Publications

5 Patents

7 Follow-up Projects

The data given here refer to the period 2013-2021.

Henry John, engineer in the Sensor Research and Systems Integration Group at Leibniz IPHT, places the optical gratings in the Raman2Go system with great sensitivity. © Sven Döring

With the Magic of Light

In Search of the Molecular Signature

Spectroscopy offers enormous potential for medical diagnostics to quickly and reliably determine the unique molecular fingerprint of biological samples and thus identify infectious agents, as an example. Optical gratings form the technological heart of spectroscopic systems, and help to optimally fan the light spectrally.

Conventional spectroscopy systems are generally unsuitable for portable as well as point-of-care applications due to their size. Therefore, Leibniz IPHT has been working intensively since the early 2000s to miniaturize commercially available spectroscopic devices and make them universally usable for laboratory diagnostics.

To achieve this goal, scientists from three research departments of the institute worked together on a compact spectroscopic design as part of an internal innovation project. The research activities were aimed at developing a small, lightweight and mobile grating spectrometer that would stand up to existing instrument concepts but would not be inferior to them in terms of spectral resolution.

A central element of such a small spectrometer is the optical grating. Installed inside a spectrometer, these diffractive optical elements (DOE) ensure that the light is split into its spectral components by diffraction. Via another optical unit, the light separated into different wavelengths is imaged onto a sensitive detector, which converts the generated spectrum into detectable signals. These can then be used, for example, to detect infectious agents.

Research into such specialized grating structures and their sophisticated technological fabrication processes was successfully advanced in the innovation project. By using wafer-scale electron beam lithography and plasma-based deep etching processes, sophisticated and highly efficient optical grating structures and geometries were made, which opened up new possibilities for spectrometer design. The thus built oval-shaped optical gratings are about the size of a 5-cent coin and, with their special architecture of curved grating lines and a specially structured grating profile, ensure extremely efficient light diffraction. They make it possible to reduce the complexity of the optical components required in a spectrometer and thus to make it significantly smaller despite its high resolution.

The grating is crucial – as an important central element of spectroscopy systems, its task is to optimally split the light into its spectrum. © Sven Döring

The know-how gained enabled the researchers to develop Raman2Go, a miniaturized and portable spectroscopic setup. As an easy-to-use complete solution, Raman2Go is suitable for spectroscopic investigations in mobile use as well as for applications outside specialized laboratories.

Work is currently underway on the next generation of the mobile spectroscopy system Raman2Go, which is being further developed into a marketable product at the newly established Leibniz Center for Photonics in Infection Research (LPI). The aim is to provide researchers with a fast and simple tool when assessing biological samples and near-patient infection diagnostics.

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Publication:

Jahn, Grjasnow, John, Weber, Popp & Hauswald, Sensors, 21 (15), 5067, 2021, https://doi.org/10.3390/s21155067

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Patents:

Popp, Weber, Riesenberg, Wuttig & Hübner, DE 10 2019 107 924 A1

Popp, Weber, Riesenberg, Wuttig & Hübner, WO 2020 193 677

Popp, Weber, Riesenberg, Wuttig & Hübner, EP 3 948 184 A1

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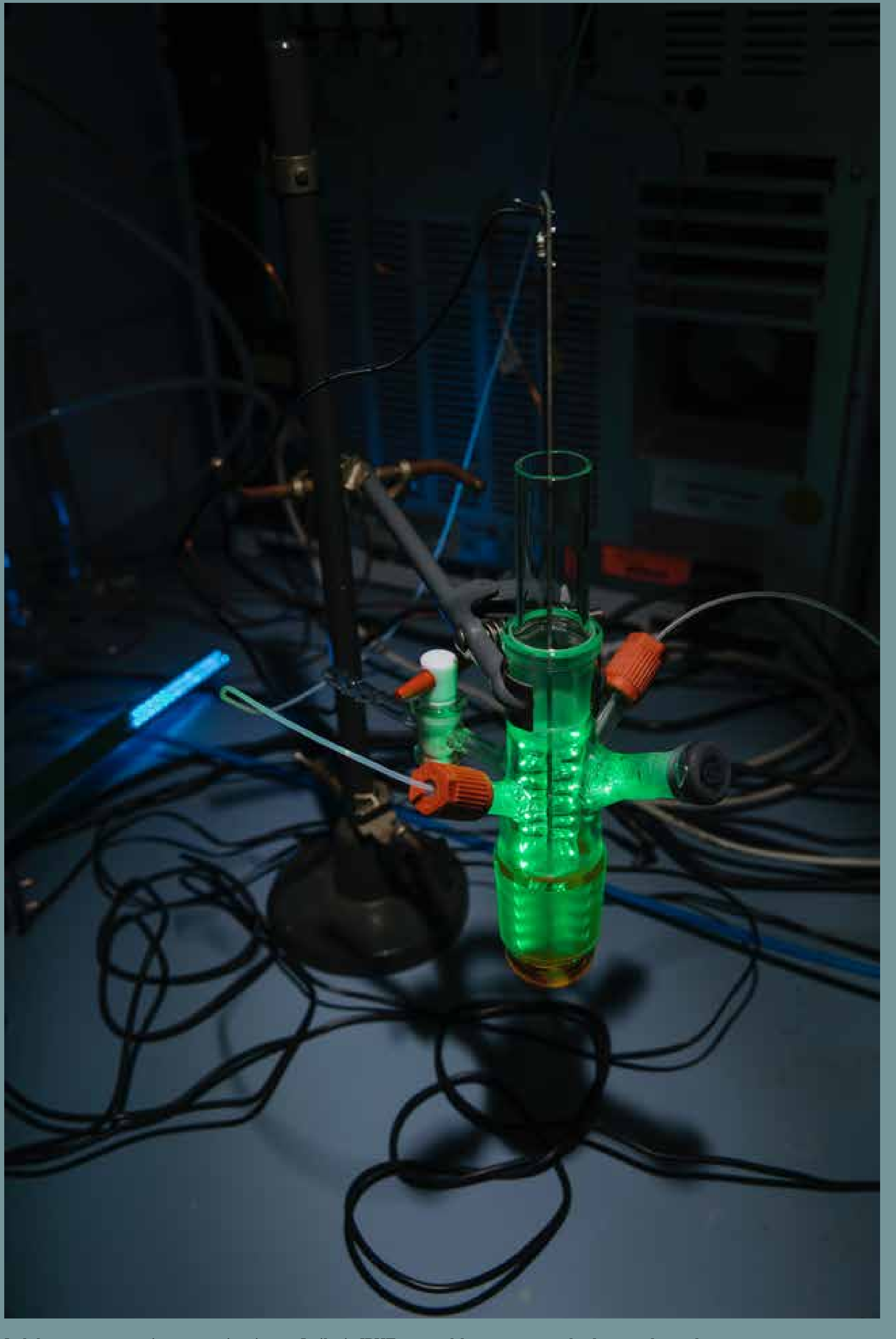
Innovation project:

Miniaturized infrared spectrometer in the wavelength range 8-14 µm



In laboratory experiments, scientists at Leibniz IPHT were able to generate hydrogen through refined silicon nanostructures.

© Sven Döring

Nanostructured

Shaping the Energy and Water of the Future

In recent years, hydrogen has become more and more the focus of energy policy discussions, and promises to play an important role in energy supply in the future. At Leibniz IPHT, scientists are researching how hydrogen can be successfully obtained by light-driven water splitting as part of an internal innovation project.

At Leibniz IPHT, silicon-based nanostructures and their interaction with light have been researched for many years. Such semiconductor structures on the nanometer scale are of interest, for example, as components for solar cells in photovoltaics, as biocompatible and innovative structures in cancer theranostics, or as self-cleaning surfaces in materials science.

Semiconductor materials have also proven to be valuable key technologies for the splitting of water into its components, hydrogen and oxygen, using light, the so-called photocatalytic water splitting. Researchers around the globe are working to further improve the production of hydrogen by separating water by experimenting with different catalyst materials.

Silicon nanostructures represent a promising option. In order to develop their potential for photocatalytic water splitting as well as to identify ways for efficient hydrogen production, Leibniz IPHT scientists from the Research Departments Functional Interfaces, Nanobiophotonics and Nanooptics investigated silicon nanostructures under laboratory conditions. For this purpose, ultrafine nanowires of less than 100 nanometers in size were structured from a silicon layer, or on a wafer using "top-down" wet chemical etching processes and decorated with silver nanoparticles. By means of this structuring and refinement method, the chemical-physical properties of the silicon can be specifically modified. The thus created silicon structures refined with metallic nanoparticles, were then brought into contact with an aqueous solution and artificial light.

In scientific investigations using microscopic and spectroscopic methods, the researchers found that the silicon nanowires coupled with silver nanoparticles were able to significantly increase the efficiency of hydrogen production. Thanks to the silicon nanostructures functionalized with silver, the amount of hydrogen produced was significantly increased during the chemical processes and the simultaneous formation of silicon suboxides on their surface. The rate of hydrogen generation produced in this way is at least five times higher than the values described in the literature, and thus comparable to hydrogen generation based on titanium oxide, a semiconductor which has been known as a catalyst material for many years.

The detailed understanding of the nanomaterial surface down to the atomic level gained during the project, the interaction processes at its surface during the chemical reaction, and the ongoing photocatalytic processes provide an important contribution to further research into effective hydrogen production. The hydrogen produced basing on these principles could be stored, used for energy generation, but also for water purification.

The innovation project laid the foundation for subsequent projects funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) and the Central Innovation Programme for small and medium-sized enterprises (Zentrales Innovationsprogramm Mittelstand, ZIM) of the German Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz, BMWK).

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Publications:

Ming, Dietzek-Ivanšić, Lu, Zuo & Sivakov, 2022, ACS Applied Energy Materials, https://doi.org/10.1021/acsaem.2c00968

Ming, Turishchev, Schleusener, Parinova, Koyuda, Chuvenkova, Schulz, Dietzek-Ivanšić & Sivakov, 2021, Small, https://doi.org/10.1002/smll.202007650

Turishchev, Parinova, Pisliaruk, Koyuda, Yermukhamed, Ming, Ovsyannikov, Smirnov, Makarova & Sivakov, 2019, Scientific Reports, https://doi.org/10.1038/s41598-019-44555-y

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Innovation project:

Hydrogen Generation on Nanostructured Silicon (HyGS)

View of the Optical Valley Jena, the cradle of optical and photonic technologies and high-tech location in Central Germany.

© Sven Döring

Regional Cooperation in Jena

Tradition and Innovation

Jena is also known as Optical Valley and has developed into an internationally renowned research and business location over the past decades. Interdisciplinary collaboration is a key success factor here.

The origins of this collaboration go back to the 19th century when Carl Zeiss, Ernst Abbe and Otto Schott jointly revolutionized microscopy and laid the foundation for the today's site. Even back then, their technological solutions addressed applications in life sciences and enabled groundbreaking discoveries in this field. The spirit of Zeiss, Abbe and Schott is still omnipresent in the city on the Saale today.

As a non-university research institution, Leibniz IPHT plays a central role in the regional scientific landscape. Together with academic partners such as the Jena universities and non-university institutes, medical researchers and users at the Jena University hospital, as well as partners from industry such as Zeiss, Jenoptik and numerous medium-sized companies and start-ups, the researchers at Leibniz IPHT work on innovative optical solutions for applications in life sciences. In doing so, they drive the translation of their results into marketable products.

Examples of such close regional cooperation are the InfectoGnostics Research Campus Jena, which combines competencies from research and industry (page 20-21), the Leibniz ScienceCampus InfectoOptics, which enables cooperation between Leibniz institutes and universities, the newly emerging Leibniz Center for Photonics in Infection Research (page 16-19) or the Cluster of Excellence Balance of the Microverse (page 22-23). With the Center for Translational Medicine (CeTraMed) and the Abbe Center of Photonics, the City of Light Jena has further established infrastructures for cutting-edge research. In addition, Leibniz IPHT is involved in the training of young researchers in regional graduate schools.

In addition, Leibniz IPHT is integrated in numerous regional research networks and is actively engaged in teaching as well as in training and promotion of young scientists at the Jena site.

The success of Jena as a research and business location is based on a culture of cooperation and innovation that has grown over years. The legacy of Zeiss, Abbe and Schott continues to inspire researchers and inventors in Jena. Regional cooperation remains a crucial success factor for future growth and development of the city as a center of excellence for science and technology.

After its scheduled completion in 2028, LPI will be available to international research and industry partners as a translational infrastructure. © Sweco GmbH

Cutting-edge Research with Light: Market-ready Solutions in the Fight Against Infections

The LPI Combines all Developmental Steps from a Concept to a Certified Medical Device in a Holistic Process

With the Leibniz Center for Photonics in Infection Research (LPI), a globally unique infrastructure is being created in Jena in order to develop solutions for infectious diseases. During the start-up phase, the four core partners will have to work together on a regional level. This is not only about cooperation at project level, but also about teamwork. Only through close cooperation and regular exchange it is possible to optimally harness the potential of the individual partners and achieve synergy effects.

Infectious diseases result in an ever-increasing number of deaths and threaten the advancement of modern high-performance medicine. In addition to the emergence of previously unknown pathogens, the global spread of antibiotic resistance is an increasing problem, which the WHO has declared to be one of the greatest health threats to mankind. Photonics is a powerful tool for researching new diagnostic methods and therapeutics, and has the potential to revolutionize infection research in order to meet the global challenge. As a globally unique translational infrastructure, the LPI will drive the development of compact devices and innovative solutions.

The LPI brings excellent research, technology development as well as everyday clinical life in close proximity to each other. It combines the expertise of the four core partners, Jena University hospital and Friedrich Schiller University Jena, Leibniz Institute of Photonic Technology (Leibniz IPHT), and Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute (Leibniz HKI). After its scheduled completion in 2028, the center will be available to international research and industrial partners.

The center is funded by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) as part of the National Roadmap for Research Infrastructures. The BMBF supports the development of the LPI as a reliable partner and advisor. Jürgen Popp, LPI spokesperson, met with Ministerial Counselor Dr. Ulrike Geiger last June at the LASER World of PHOTONICS trade show in Munich to talk about the basic features of the LPI.

Ulrike Geiger: Mr. Popp, for the diagnosis of pathogens you apply a novel approach with the use of light – and get results within a very short time. This can be life-saving in many cases, and reduces the use of broadband antibiotics. How does the collaboration of the LPI supporting institutions work?

Jürgen Popp: In Jena, optics and photonics research has been conducted at the highest level for a long time. These areas cooperate more closely than other locations with users in the field of life sciences and medicine – and have done so for many years. One example: We know that our white blood cells, our immune cells, change chemically by interacting with pathogens. We can make this change visible using light-based methods. As part of the LPI funding, researchers at Leibniz IPHT have worked with physicians to build a laboratory sample that can visualize this change much faster than before. It is already being used in scientific studies.

Geiger: We are pleased that with the LPI we are giving researchers the opportunity to realize something that they would otherwise not be able to realize as an individual institution. In the operating phase, the LPI will be self-supporting and available to science and industry. What services will it then offer?

Popp: We are currently establishing a legal form for the LPI that will enable it to implement publicly funded projects on the one hand, and privately funded projects on the other hand. In the operational phase, LPI technology scouts will continuously evaluate photonic ideas for infection research. Appropriate approaches will be further developed at LPI; LPI will provide everything: Are microfluidics or a special readout device needed, or are patient samples missing? The LPI also takes care of opinions of the ethics committee and quality management, so that users can quickly get to a prototype.

Prof. Dr. Jürgen Popp in conversation with Ministerial Counselor, Dr. Ulrike Geiger, Head of the Department Quantum Technologies, Quantum Computing at the Federal Ministry of Education and Research during the LASER World of PHOTONICS trade show in Munich in June 2022. © Leibniz IPHT

We also involve the industry. If we all work together on an equal footing, we can accelerate translation.

Geiger: Translation, i.e. transfer strategies, are very important to the BMBF. We often see that research results do not reach marketability because critical phases have to be overcome. We can bridge this gap with the infrastructure at LPI. I find the interdisciplinary collaboration in the LPI's development phase fascinating. Because researchers are addressing the challenges from different perspectives at the same time, we have an even better chance of combating future epidemics more quickly.

Popp: At the moment, more than 100 researchers as well as colleagues from technology and administration from the four different supporting institutions are working on the development of the basic technologies. The close cooperation with the BMBF and the project sponsor VDI-TZ is also beneficial, and it is fun to overcome one hurdle or another together. Being able to set up this special center is particularly motivating for the younger employees, but I, too, did not have the chance to shape something like this before in my entire scientific career.

Geiger: LPI is also something special from our point of view. I would like to encourage all employees to remain curious and to keep in mind the vision of LPI of working together to find solutions for dealing with infectious diseases.

Popp: We will use the potential of photonics to revolutionize diagnostics, monitoring and treatment of infectious diseases. The BMBF's funding is necessary, because on such a large scale it could never be done without it.

Geiger: Keep up the successful work!

Popp: Thank you very much. I look forward to our continued cooperation.

Federal Research Minister Bettina Stark-Watzinger talking to the institute's director, Prof. Dr. Jürgen Popp

© Katrin Uhlig

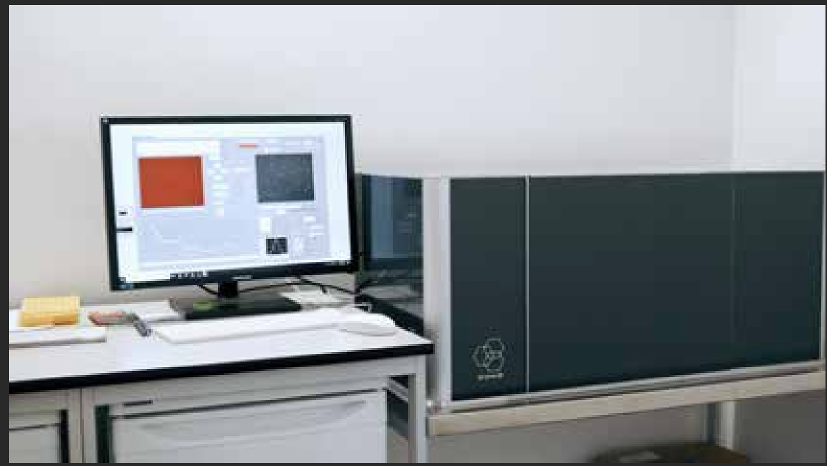
Photonics for Infection Research

Federal Research Minister and Thuringian Science Minister Visit Leibniz IPHT

In order to gain an overview of the research location Jena as a driving force for smart photonic innovations, especially in the field of infection research, the Federal Research Minister, Bettina Stark-Watzinger, visited the science city and Leibniz IPHT together with her Thuringian counterpart, Wolfgang Tiefensee, in November 2022.

The Federal Research Minister, Bettina Stark-Watzinger, was impressed by the work of the Jena scientists: "The Corona pandemic has shown us how important excellent infection research is. In order for Germany to be able to further expand its leading position in this field in the future, we want to establish the Leibniz Center for Photonics in Infection Research (LPI). The LPI will be highly innovative and unique in the world: Optical technologies, artificial intelligence and medical technology will work together to bring research results into market-ready applications more quickly, thus helping Germany to remain internationally leading. The location in Jena, surrounded by the extensive expertise from the Leibniz Institutes of Photonic Technology and for Natural Product Research and Infection Biology, the Friedrich Schiller University and the Jena University hospital, creates ideal conditions for this."

New Approach to Early Detection of Severe COVID-19



Tracking the immune response: High-Throughput Screening Raman Spectroscopy (HTS-RS)

© Leibniz IPHT

An interdisciplinary team of researchers at LPI is investigating the extent to which spectroscopic methods are suitable for predicting the further course of a corona disease at an early stage. They examine infected white blood cells with a high-throughput Raman system in order to analyze the immune response.

The symptoms of a COVID-19 infection can vary widely, ranging from mild respiratory symptoms to life-threatening lung dysfunction. Already at an early stage of the disease, conclusions about the further course of the disease could be drawn on the basis of the immune response. As part of joint projects and clinical studies, scientists from the Leibniz IPHT together with colleagues from the Jena University hospital investigate the potential use of photonic technologies for the early detection of a severe COVID-19 course of disease. The findings could help to better understand and predict the course of the disease and to take life-saving measures at an early stage.

For their studies, the researchers used Raman spectroscopic methods to detect changes in the molecular composition of white blood cells. To do this, they infected neutrophil granulocytes in the laboratory with the corona virus and stimulated the immune response by adding inflammatory messenger substances. Neutrophil granulocytes are the most common type of white blood cells. They respond rapidly to inflammation and infection by absorbing and destroying bacteria or other pathogens. Using High-Throughput Screening Raman Spectroscopy (HTS-RS), the researchers examined the white blood cells at different time intervals. The spectra obtained in this way were then analyzed using machine-based learning algorithms.

Significant changes in the Raman spectroscopic fingerprint of the infected immune cells could be observed and distinguished from each other after three and after 24 hours. The measurement data indicate a phenotypic change of neutrophil granulocytes caused by an increased production of cytokines. An increased release of this messenger substance could be biochemically detected in the cells infected with SARS-CoV-2 after three hours. After a further 21 hours, the production of the proteins responsible for the immune response had increased significantly.

The Raman data can therefore not only be used to distinguish whether a cell is infected or not. The conclusion that the Raman signature correlates with the cytokine level is also obvious. Based on these findings, the methodology and data analysis will be further trained and improved by using artificial intelligence. In the long term, this may result in a new diagnostic tool for the early detection of a severe COVID-19 course of disease, which could be an alternative or complement to existing biochemical methods.

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Publication:

Pistiki, Hornung, Silge, Ramoji, Ryabchykov, Bocklitz, Weber, Löffler, Popp & Deinhardt-Emmer, Clinical and Translational Medicine, Volume 12, Issue 12, e1139, 2022, https://doi.org/10.1002/ctm2.1139

Employees of the Optical Molecular Diagnostics and Systems Technology Research Department performing mircroarray diagnostics.
© Sven Döring

Small Dots with Great Potential

How Microarrays from Thuringia Improve the Diagnosis of Infectious Diseases

Detecting infectious agents, recognizing resistance and virulence factors, or determining vaccination status – microarrays are the multifunctional talents of molecular diagnostics and can be flexibly adapted for many diagnostic applications. Experts for this technology at Leibniz IPHT are the scientists of the Research Department Optical Molecular Diagnostics and System Technology. In 2022, the team led by department head, Prof. Dr. Ralf Ehricht, has developed several new tests based on microarray technology together with the developers of INTER-ARRAY by fzmb GmbH from Bad Langensalza, Germany.

In the RESISTOVAC project of the InfectoGnostics Research Campus in Jena, a new test platform was developed with the support of the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF), which can be used to determine the vaccination status against a wide range of infectious pathogens. A single drop of blood from patients can be used to test whether the immune system has responded to a vaccination and antibodies against the infectious agent are still present.

The focus was particularly put on the immune response to diseases against which vaccinations are recommended: mumps, measles, tetanus, or diphtheria, but also simultaneous testing for possible corona antibodies due to vaccination or natural infection.

Microarray for all STIKO vaccinations could unveil individual vaccination gaps

For this purpose, Leibniz IPHT scientists are developing a special protein microarray together with fzmb researchers: On this chip, which is only a few millimeters in size, various capture molecules are applied and bound in small dots. If antibodies from the patient's blood are brought together with the matching antigens on the chip, corresponding test fields on the microarray change color – hence, a sought-after antibody must have been present in the blood. The resulting tiny pattern on the microarrays can be optically analyzed within a few minutes using special evaluation equipment.

In addition to various surface structures of the corona virus, antigens from the pathogens for diphtheria, measles, and tetanus, to which vaccinated persons typically react, were also brought onto the test. Again, a corresponding antibody response was successfully detected in vaccinated individuals. "We were thus able to show that we can flexibly extend the test, and detect different antibodies in the patient's blood in the course of a single test. In the future, a microarray could be designed for all vaccinations recommended by the Standing Committee on Vaccination (Ständige Impfkommission, STIKO), which could be used to screen for possible vaccination gaps quickly and inexpensively," explains Sindy Burgold-Voigt, doctoral student in the Optical Molecular Diagnostics and Systems Technology Research Department at Leibniz IPHT.

Versatile microarray principle can also be transferred to strip test formats

However, the underlying microarray system can also be flexibly adapted to other tests: If, for example, resistance factors are to be detected, or subgroups of a bacterial species are to be determined, researchers can define suitable capture molecules that are applied to the microarray as a dot matrix, and enable parallel measurement of several parameters.

In this way, fzmb GmbH has already been able to develop a market-ready test together with Leibniz IPHT researchers that can be used to investigate genetic properties of the bacterium *Staphylococcus aureus* and distinguish between more than 700 strains of this pathogen. Virulence factors and resistance genes, including those of the "multidrug-resistant" variants (MRSA), can be rapidly identified with this so-called "INTER-ARRAY Genotyping Kit S. aureus" test kit. The company cooperated with the Leibniz IPHT scientists Prof. Ralf Ehricht and Dr. Stefan Monecke to select the target genes and sequences, and to build the database of strains.

Microarray systems also offer the great advantage that they can be implemented in various diagnostic test formats. Thus, the principle can also be transferred in a simplified form to a low-cost strip test format, as is known from corona rapid tests. In the RESISTOVAC project, this further development is being undertaken by Senova GmbH in Weimar, Germany, which specializes in such lateral flow test methods.

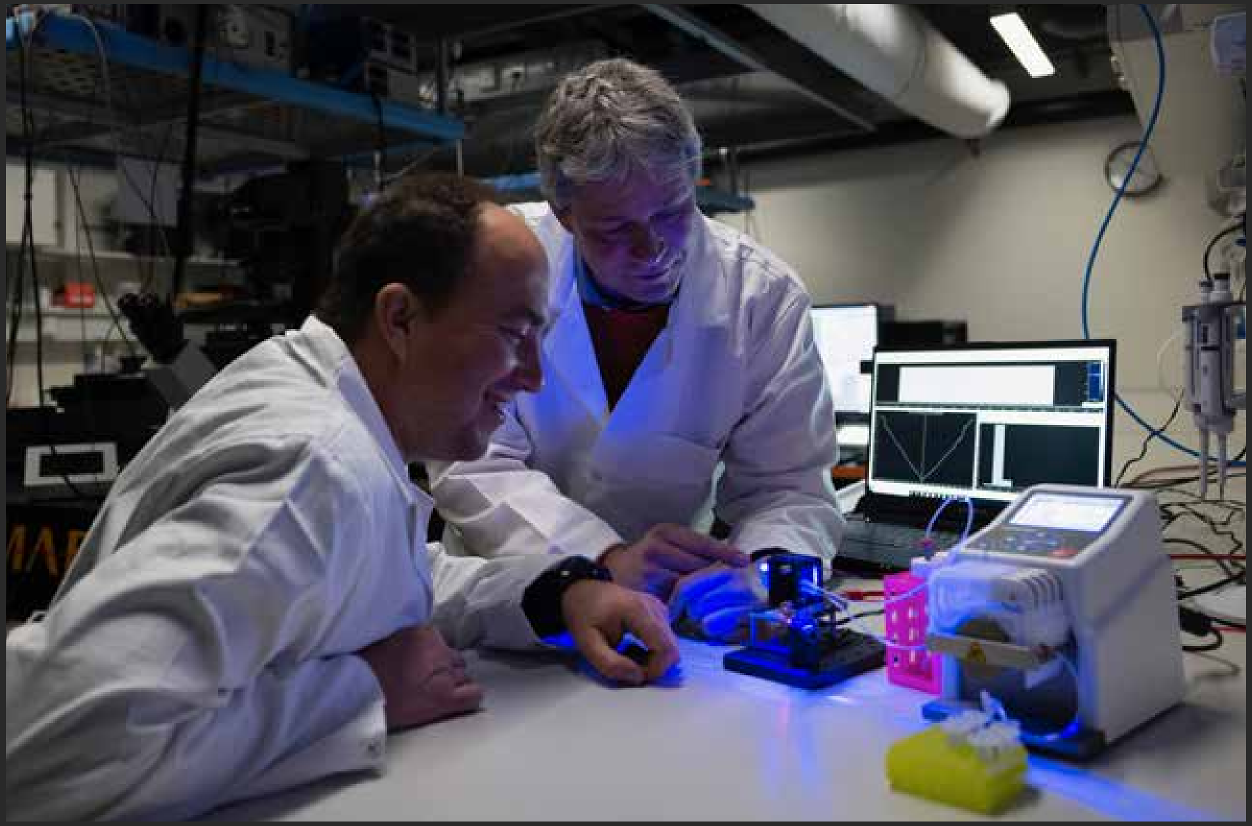
InfectoGnostics Research Campus Jena

Leibniz IPHT is a founding member of the InfectoGnostics Research Campus, which is a Thuringian innovation cluster for diagnostics and biotechnology that initiates joint translational projects in public-private partnership, and accompanies them until application. More than 30 partners from industry, research and clinical practice develop and combine photonic and molecular biological methods in the research campus in order to reliably detect infectious agents and antibiotic resistance, and to better understand the host response (for example in sepsis). In the triad consisting of technology, application and production, laboratory and rapid tests are created for use in human and veterinary medicine as well as for food safety.

Publication:

Burgold-Voigt, Müller, Zopf, Monecke, Braun, Frankenfeld, Kiehntopf, Weis, Schumacher, Pletz, Ehricht & The CoNAN Study Group, Scientific Reports, 12, 8067, 2022, https://doi.org/10.1038/s41598-022-10823-7

Further information on *InfectoGnostics Research Campus Jena*: **www.infectognostics.de**



The lensless interferometric scattering microscope was developed as part of the Microverse Imaging Center by Dr. Ondrej Stranik (in the picture left) and Prof. Dr. Rainer Heintzmann (in the picture right) from the Microscopy Research Department. The extremely compact optical system makes it possible to determine the distribution of molecules and bacteria without labeling, and thus to understand the interaction between microorganisms via their molecular messengers.

Listening Carefully

Communication in the Microuniverse

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The importance of communication becomes apparent in daily interactions: It is used to exchange information, to express feelings, to solve problems, or to celebrate successes. Communication is essential for making contacts and staying in balance. But communication is not only indispensable for us humans, it is also crucial for the microuniverse. Research into the interaction and communication of microorganisms is the subject of the Jena Cluster of Excellence Balance of the Microverse.

Millions of microorganisms can inhabit the human body – whether on the skin or as part of the natural intestinal flora. In most cases, they are completely harmless to healthy people, and contribute to our well-being. But for people with a weak immune system, some organisms that are actually harmless can cause diseases. The extinction of certain plants, or the pollution of waters by unexpected enormous algae growth are further indications of sudden imbalances in nature that have an enormous impact on the functioning and health of entire ecosystems.

Scientists in Jena are trying to uncover the causes of such imbalances in the coexistence of microorganisms in the Balance of the Microverse Cluster of Excellence. The focus of their research is on the smallest living beings – the microorganisms. Those live together in microbial communities, so-called microbial consortia consisting of a multitude of tiny organisms. Both, in the human microbiome as well as in water or in the plant world, they form complex networks in which they interact and communicate with each other and with their environment via molecular messengers. Their interactions and interplay is being studied by the ten research institutions involved in the Cluster of Excellence.

"How do harmonious balances arise in such microbial universes, which are essential for the functioning of a healthy environment? What are the key factors that upset these balances and result in negative effects for humans and entire ecosystems? And what regulatory mechanisms do microbial consortia have to regenerate after a disruption? All these issues are addressed by the Cluster of Excellence Balance of the Microverse. In order to find answers to these questions, Leibniz IPHT provides high-resolution and highly sensitive imaging methods with microscopy and spectroscopy, or continuously develop them further together with the partners involved. In this way, we create the technological prerequisites for gaining insights into the communication of microorganisms," explains Prof. Dr. Christian Eggeling, head of the Biophysical Imaging Research Department at Leibniz IPHT and subproject leader in the Cluster of Excellence.

The Microverse Imaging Center, which is currently under construction, will contribute to this understanding. The state-of-the-art microscopy center for imaging technologies is intended to support the participating institutions of the cluster on their journey of discovery through the microcosm. Here, researchers will not only find commercial Raman spectroscopic and microscopic instruments to answer their research questions, but new forward-looking solutions will also be created in the Imaging Vision Room in close collaboration with the optics experts at Leibniz IPHT.

"Our bioimaging methods, and the insights into the interplay of microorganisms gained, open up new potential, for example for research into alternative healing and treatment methods for diseases that specifically combat infectious pathogens while bacteria that are indispensable for the immune system are not attacked, thus maintaining the balance in the microbiome," says Prof. Dr. Christian Eggeling.

The Jena School for Microbial Communication (JSMC) at Friedrich Schiller University Jena is affiliated to the Cluster of Excellence. The excellence graduate school supports young scientists on their academic career with a comprehensive interdisciplinary training program. Doctoral students are given the opportunity for further education and networking as well as scientific exchange with various workshops, training courses and research stays.

Projects of Leibniz IPHT within the Cluster of Excellence Balance of the Microverse:

Microverse Imaging Centre // Investigation of microbial interactions using Raman spectroscopy // High-throughput multicontrast spectroscopic imaging platform

Prof. Dr. Jürgen Popp, scientific director and head of the Spectroscopy and Imaging Research Department at Leibniz IPHT

Microverse Imaging Centre // Quantitative imaging of microbial dynamics in organ-on-chip models // Molecular communication involving membranes and lipid rafts

Prof. Dr. Christian Eggeling, head of the Biophysical Imaging Research Department at Leibniz IPHT

Microverse Imaging Centre // Etalon-enhanced mapping of small molecules

Prof. Dr. Rainer Heintzmann, head of the Microscopy Research Department at Leibniz IPHT

The Balance of the Microverse Cluster of Excellence is funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) with 38 million euros.

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Publications:

Matanfack, Taubert, Reilly-Schott, Küsel, Rösch & Popp, Analytical Chemistry, 94, 7759–7766, 2022, https://doi.org/10.1021/acs.analchem.1c04097

Wallace, Kopycinski, Yang, McCully, Eggeling, Chojnacki & Dorrell, Scientific Reports, 12, 18366, 2022, https://doi.org/10.1038/s41598-022-23228-3

Quansah, Ramoji, Thieme, Mirza, Goering, Makarewicz, Heutelbeck, Meyer-Zedler, Pletz, Schmitt & Popp, Scientific Reports, 12, 20416, 2022, https://doi.org/10.1038s41598-022-24846-7

Salehi, Ramoji, Mougari, Merida, Neyret, Popp, Horvat, Muriaux & Cuisinier, Communications Chemistry, 5, 85, 2022, https://doi.org/10.1038/s42004-022-00702-7

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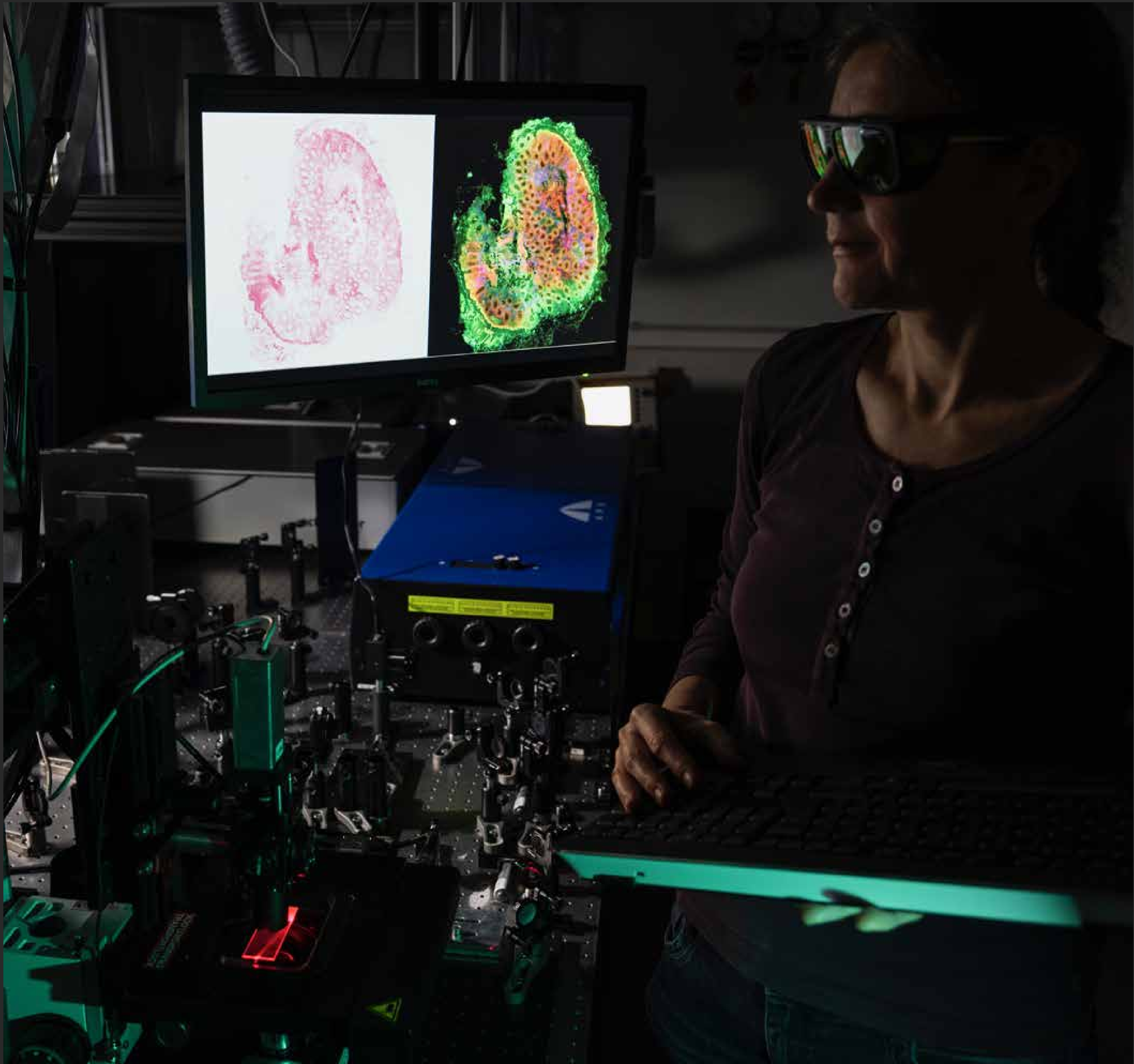
Further information on the *Balance of the Microverse*: **www.microverse-cluster.de/en/**

Further information on the *Jena School for Microbial Communication (JSMC)*: **www.jsmc-phd.de**



The intravital microscope, pictured with Dr. Astrid Tannert, provides a deep insight into cells, such as intestinal tissue, which was microscopically examined and correlated with established histological stains in collaboration with the Jena University hospital and the Spectroscopy and Imaging Research Department of Leibniz IPHT. © Sven Döring

Pooling of Resources

Accumulated Research Infrastructure Sheds Light on Diagnostic Issues

In the search for pathogens, their resistances, or tumor tissue, researchers rely on high-resolution microscopy and spectroscopy. In order to shed light on such medical research questions, the Jena Biophotonics and Imaging Laboratory is an important address for scientists around the globe.

The DFG Core Facility Jena Biophotonics and Imaging Laboratory (JBIL) has been combining microscopic and spectroscopic technologies in the Thuringian city on the Saale since 2016. For this purpose, the participating partners of JBIL, namely Leibniz IPHT, the Jena University hospital as well as the Friedrich Schiller University Jena, combine their strengths. The user-open platform offers researchers from Jena as well as external partners state-of-the-art work and measurement stations for spectroscopy, fluorescence microscopy, and multispectral optoacoustic tomography. "We not only advise on the optimal imaging method that is tailored precisely to the respective scientific question, but also provide support in arranging laboratory contacts that expertly analyze and evaluate the samples," reveals Dr. Astrid Tannert, scientist in the Clinical Spectroscopic Diagnostics Research Department and manager of JBIL at Leibniz IPHT.

"For research issues that require new imaging methods or a combination of different techniques, we also develop innovative solutions and setups together with our partners, which can be of great benefit to other potential users, too. In this way, JBIL offers the opportunity to set new impulses when working on complex tasks," says Dr. Astrid Tannert.

An individual training program is also part of the JBIL service: Scientists from industry and research benefit from the long-standing experience of imaging experts, and are trained by them in the professional handling of scientific instruments, or the correct preparation of biological samples in the laboratories. In close exchange, they are thus enabled to perform measurements independently.

The promotion of young scientists in the field of biophotonics and imaging is another core concern of JBIL: For example, the technical infrastructure for the European training network IMAGE-IN (page 50-51) is provided, in which five doctoral students work together with project partners in Germany and Portugal to apply a wide variety of spectroscopic and imaging methods and develop suitable data analysis procedures. In order to make PhD students acquainted with the methods at an early stage, JBIL offers interested researchers the opportunity to continue their education during their academic career with summer schools, symposia or lecture series.

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Publication:

Dahms, Eiserloh, Rödel, Makarewicz, Bocklitz, Popp & Neugebauer, Frontiers in Cellular and Infection Microbiology, Volume 12, 2022, https://doi.org/10.3389/fcimb.2022.930011

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More information about *Jena Biophotonics and Imaging Laboratory:* **www.bil-jena.de**

Nationally Intertwined

Close Cooperation Network Allows Top-level Research to Thrive in Germany

Joint workshop of InfectoGnostics and Leibniz Health Technologies: Leibniz IPHT as a link between regional and national cooperation networks. © Leibniz IPHT

Germany enjoys an excellent international reputation thanks to its innovative strength. The key to this inventive spirit and scientific excellence is a strong research community. To this end, science and industry work closely together in the context of national networks and cooperations in order to combine complementary competencies and generate synergies.

Leibniz IPHT maintains close relationships with research institutions and industry throughout Germany and, together with its cooperating partners, shapes Germany as a center of science. As a member of the Leibniz Association (page 27), the institute is active within the Association in numerous networks, initiatives and work groups, such as the Research Alliance Leibniz Health Technologies (page 28-29). In this alliance, coordinated by Leibniz IPHT, various Leibniz institutes and partner companies concentrate their expertise in the diagnosis and therapy of diseases.

The institute is also regularly involved in work groups and professional societies, such as the German Society for Biophotonics and Laser Medicine (Deutsche Gesellschaft für Biophotonik und Lasermedizin, DGLM), which facilitates interdisciplinary exchange with physicians, technology developers, companies as well as political and social committees.

Furthermore, Leibniz IPHT actively provides political advice and contributes to the dialogue with political decision-makers at state and federal level on current topics relevant to society and research. In 2022, for example, Leibniz IPHT welcomed to Jena the Federal Minister of Education and Research, Bettina Stark-Watzinger, and the Thuringian Minister of Economics, Science and Digital Society, Wolfgang Tiefensee, for an exchange on optical health technologies (page 18).

The institute achieves national and international visibility by participating in important industry conferences, or lecture programs of relevant leading trade fairs, such as LASER World of PHOTONICS in Munich, or the medical technology trade fair MEDICA in Düsseldorf. Expert lectures and accompanying supporting programs create opportunities to establish valuable contacts with supra-regional partners.

Collaborative

Creating Sources of Inspiration for Excellent Research

House of the Leibniz Association, Berlin © Leibniz-Gemeinschaft/Oliver Lang

"Together with many people we can achieve more than alone" – this wisdom of the Dalai Lama is not only valid for the achievement of ambitious goals in private and professional environments. His guiding principle can also be applied to the world of science, in which team spirit and a culture of cooperation in the form of collaborations and partnerships are practiced. Under the umbrella of the Leibniz Association, Leibniz IPHT conducts research together with numerous institutes in a close network in order to generate scientific solutions for societal challenges of national and international significance.

The Leibniz Association brings together 97 independent research institutions from a wide range of disciplines, with Leibniz institutes focusing on socially, economically and ecologically relevant issues. They conduct knowledge- and application-oriented research, or maintain scientific infrastructures and offer research-based services. The Leibniz Association advises and informs politics, science, industry and the public. Leibniz institutions maintain close cooperation with universities – among others in the form of the Leibniz ScienceCampi, with industry and other partners in Germany and abroad. Due to their national importance, the federal and state governments jointly support the institutes of the Leibniz Association. The Leibniz institutes employ almost 21,000 people, including approximately 12,000 scientists.

Part of a strong alliance: Leibniz IPHT in the Leibniz Association

Since 2014, Leibniz IPHT has been part of the Leibniz Association. As a member of **Section D** "Mathematics, Natural and Engineering Sciences", Leibniz IPHT is involved in the academic-scientific dialogue, and actively shapes the scientific-political decision-making process.

Interdisciplinary cooperation with other Leibniz institutes and universities arise from the **Leibniz ScienceCampi**. The Leibniz ScienceCampus InfectoOptics, in which Leibniz IPHT is involved, combines optical and life science competencies of university and non-university institutions in Jena for research into infectious diseases.

In the **Leibniz Research Alliances**, member institutes and partners network across disciplines. Leibniz IPHT is involved in the Leibniz Research Alliance Health Technologies (page 28-29), which aims at improving diagnosis and therapy of diseases with innovative health technologies. In the Research Alliance "INFECTIONS in an Urbanizing World – Humans, Animals, Environments", in which Leibniz IPHT participates, the focus is on infection research.

An **initiative** of the Leibniz Association is the newly emerging Leibniz Center for Photonics in Infection Research (LPI) (page 16-19), which will revolutionize light-based diagnostic methods and novel therapeutic approaches for the treatment of infectious diseases.

The colleagues of Leibniz IPHT are also active in numerous **work groups** of the Leibniz Association, in which the member institutes regularly exchange results and advice on current topics.

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More information on the *Leibniz Association*: **www.leibniz-gemeinschaft.de**

Health economists from Leibniz ZEW (left) exchanging ideas about miniaturized imaging systems of the Leibniz Health Technologies Research Alliance.

© Steffen Walther

Combined Leibniz Competencies Improve Diagnosis, Therapy, and Monitoring

In the nationwide research network Leibniz Health Technologies, Leibniz IPHT plays a leading role and benefits from strong interdisciplinary cooperation. In Leibniz Health Technologies, 16 Leibniz institutes and three spin-off companies combine their strengths to bring research results into application more quickly.

Translating research results into medical devices is a challenging task: in addition to the complex development of health technologies, there are many obstacles in obtaining regulatory approvals or reimbursements from health insurance companies.

This is where the Leibniz Research Alliance comes in, building on one of the Leibniz Association's strengths – scientific diversity. In order to bring together diagnosis, therapy and monitoring, and thus improve patients' quality of life, Leibniz Health Technologies bring together expertise from a wide range of scientific fields: Starting with photonics, biology, and medicine, through microelectronics and materials research, to economic research and applied mathematics.

A total of 16 institutes and three Leibniz spin-offs combine their expertise in five fields of technology (competence areas): Imaging Methods, Biomarkers, Point-of-Care Technologies, Plasma Medicine and Bioactive Materials. Within these five central research pillars, the Leibniz partners develop interdisciplinary cooperation projects that can be coordinated with important decision-makers at an early stage thanks to the network's close ties with industry, clinics, insurance companies and politics. In this way, new technologies can achieve marketability more quickly along a seamless innovation chain.

In the research network, Leibniz IPHT uses, for example, sensor technologies or light sources from partner institutes such as the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (Berlin) or the Leibniz Institute for High Performance Microelectronics (IHP, Frankfurt/Oder) for further development of photonic technologies. In addition, it also directly opens up life science and medical application areas with partners such as the Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute (Jena), the Research Center Borstel, Leibniz Lung Center, or the Leibniz Institute for Neurobiology (LIN, Magdeburg).

Technologies from the five competence areas of the Leibniz Health Technologies Research Alliance.

© Leibniz Health Technologies

Leibniz Health Technologies now provide special funding instruments for working on interdisciplinary issues, enabling young scientists to do research at partner institutes, attend conferences, or conduct feasibility studies. For example, the network has already funded an intensive exchange between researchers from Jena and Magdeburg that brought together imaging and fiber-optic methods from Leibniz IPHT with a novel single-photon camera technology and the neurobiological expertise of LIN.

In cooperation with the Leibniz Institute for Plasma Science and Technology (INP, Greifswald), Leibniz IPHT contributes its imaging expertise in order to enable future therapy-accompanying monitoring of the therapy of wounds with cold plasma.

Interdisciplinary approach enables examination of social and economic issues

In parallel, Leibniz Health Technologies is researching the social and economic consequences of new medical solutions in order to optimize their benefits for users, and create broad social acceptance for new technologies.

With the Leibniz Centre for European Economic Research (ZEW, Mannheim) as a new partner, the research network has therefore specifically enhanced its activities in the field of health economics in 2022. "Promising approaches from medical research often fail because they are difficult to finance, or the exact needs in the healthcare system are not sufficiently addressed. With ZEW, we have gained a partner in the research network that can provide important analyses of the healthcare market and recommendations for the practical design of healthcare," explains Prof. Dr. Jürgen Popp, scientific director of Leibniz IPHT and spokesperson for the Leibniz Health Technologies Research Alliance.

The fact that the path from research to application can be successful is also demonstrated by two spin-offs of Leibniz IPHT that are already cooperating in the research network: Biophotonics diagnostics, a company founded for the analysis of spectroscopy data, and DeepEn, a start-up currently in the process of being founded, that is focused on the development of hair-thin endoscope fibers. Together with Leibniz Health Technologies, both companies were able to present their developments at trade fairs and conferences as a successful example of translation.

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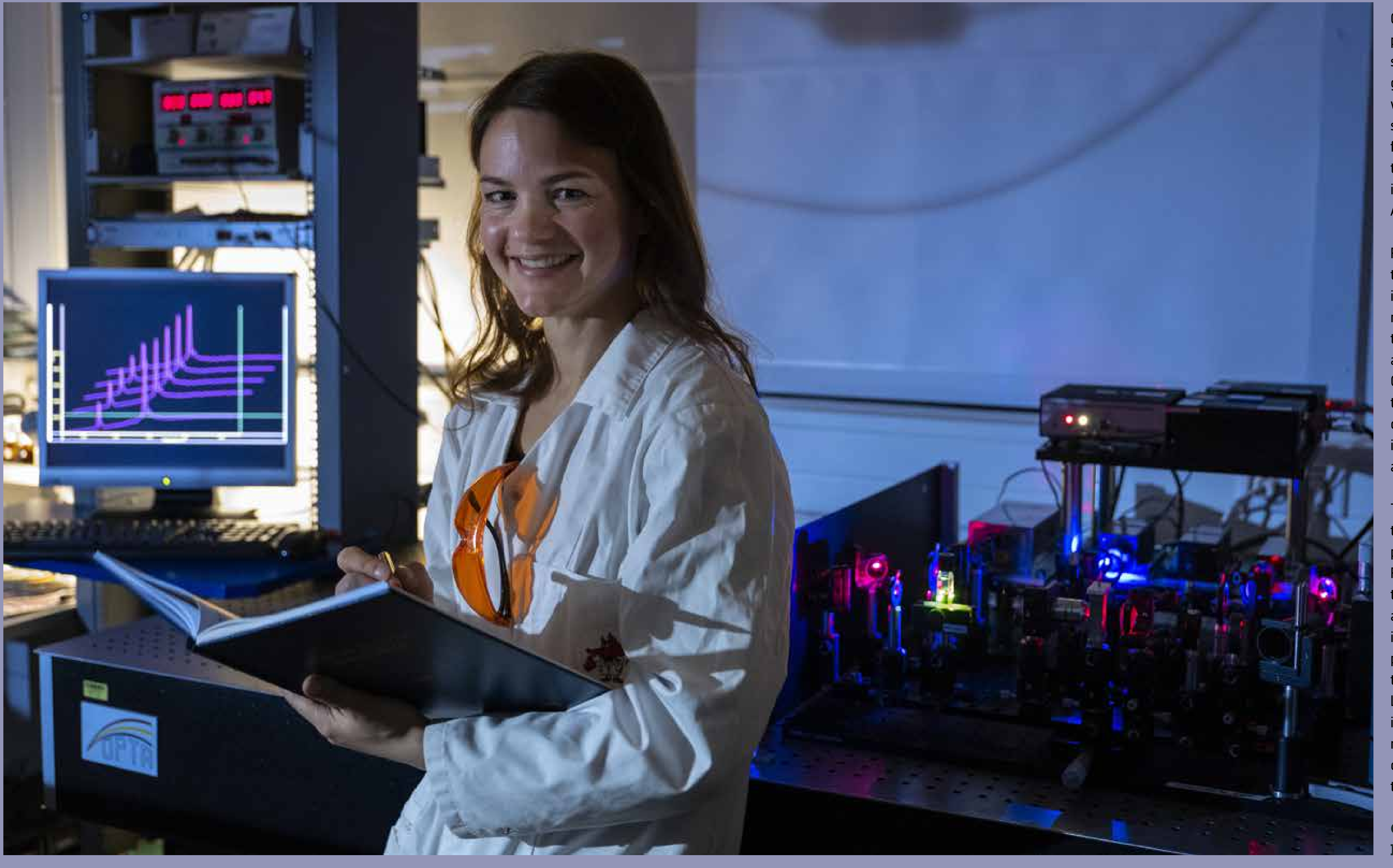
Further information on the Research Alliance *Leibniz Health Technologies*: **www.leibniz-healthtech.de**



Dr. Linda Zedler, scientist in the Functional Interfaces Research Department at Leibniz IPHT, is using spectroscopic methods in the Collaborative Research Center CataLight to investigate how photocatalysts can help split water into hydrogen and oxygen. © Sven Döring

Closely Interwoven Excellence Research

DFG Collaborative Research Centers Are Strategically Important for Leibniz IPHT

In order to achieve its long-term goals, Leibniz IPHT works with cooperating universities and regional networks to jointly advance research projects and to set priorities for its own research work. In this context, the Collaborative Research Centers (CRC) of the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) play an important role.

CRCs are multi-year research projects at universities in which scientists work on and research globally important topics together with researchers from non-university institutions. They are generally funded by the DFG for a period of up to 12 years. Currently, Leibniz IPHT is involved in the CRCs PolyTarget, AquaDiva, NOA and CataLight.

Participation in CRCs is of great strategic importance for Leibniz IPHT, as it enables close collaboration with renowned researchers and contributes to scientific excellence, networking and cooperation. In the context of CRCs, scientists have the opportunity to expand their expertise and exchange ideas with other researchers in order to jointly address challenges and find innovative solutions.

The DFG attaches great importance to the scientific excellence of the participating institutes in the CRCs. Participation in the CRCs contributes to improve the reputation, credibility and visibility of Leibniz IPHT. The involvement in the CRCs over the past years has helped to enhance the scientific reputation of Leibniz IPHT as an important player in the research and development of new photonic technologies, and to consolidate its leading position in this field in Germany and worldwide.

CataLight: Light-driven molecular catalysts in hierarchically structured materials

The CRC CataLight is an interdisciplinary research project with the aim of developing new and efficient materials for the conversion of light into chemical energy.

In nature, there are numerous examples of conversion of light into chemical energy, such as photosynthesis. The development of artificial materials capable of imitating this process could contribute to more sustainable energy production.

An important aspect of the CRC CataLight is the investigation of the role of catalysts in the conversion of light into chemical energy. Catalysts are substances that accelerate chemical reactions without being consumed themselves. By developing new catalysts, researchers can further improve the efficiency of converting light into chemical energy.

An important focus of the CRC CataLight is on the development of so-called hybrid materials. These materials consist of two or more different materials that are combined in such a way that they work together to efficiently convert light into chemical energy.

As part of the CRC CataLight, Leibniz IPHT illuminates photocatalytic processes with the help of spectroscopic methods, and thus contributes to a better understanding of the reactivity and stability of the novel materials.

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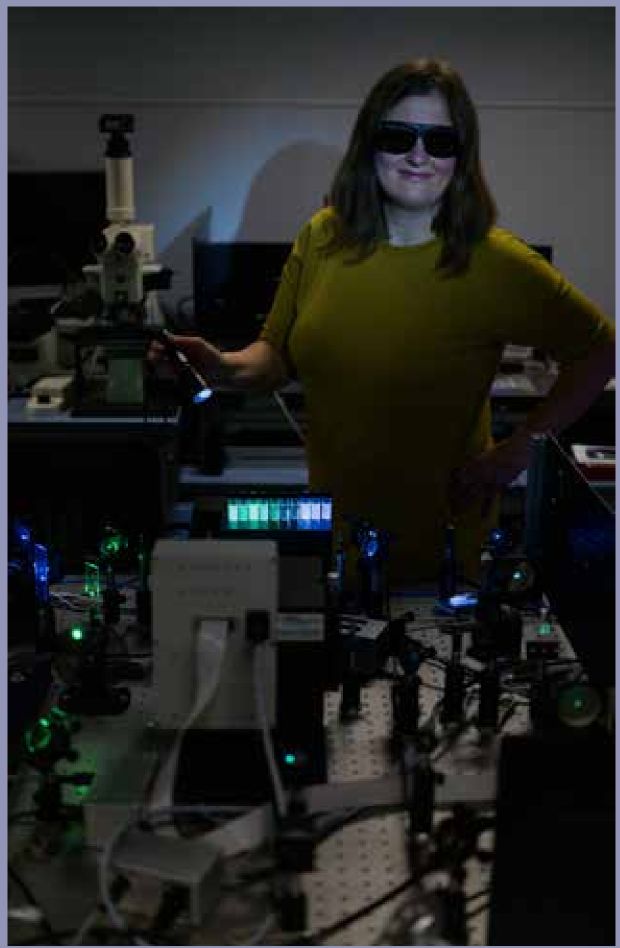
Partner institutions:

Friedrich Schiller University Jena, Ulm University, Johannes Gutenberg University Mainz, University of Vienna, Leibniz IPHT and Max Planck Institute for Polymer Research

PolyTarget: Polymer-based nanoparticle libraries for targeted anti-inflammatory strategies

Medicines often also attack healthy cells and cause undesirable side effects. The approach of the CRC PolyTarget is to package active substances in polymers that specifically bind to certain cells or tissues, and exert their effect there without damaging other areas of the body.



Scientist Dr. Maria Sittig researched nanostructures that react to light as part of the CRC PolyTarget. © Sven Döring

One focus is the research into polymer-based drugs for cancer therapy. Cancer cells often have specific characteristics that differ from normal cells and can be used as target structures for active substances. By specifically addressing these target structures, active agents are intended to solely attack diseased tissue, and spare healthy cells.

In addition, transport mechanisms are being researched in the CRC PolyTarget to enable polymer-drug constructs to penetrate the body and unfold their effect on the target cells.

As part of the CRC PolyTarget, Leibniz IPHT is dedicated to, among other things, light-activated particles, their spectroscopic characterization, and the mechanisms of light-driven reactivity. In addition, work is being carried out on the investigation of the nanoscale composition of polymer nanoparticles and the factors influencing the release of active substances.

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Partner institutions:

Friedrich Schiller University Jena, Friedrich-Alexander University Erlangen-Nuremberg, Leibniz FLI, Leibniz HKI, Leibniz IPHT and Jena University hospital

AquaDiva: Understanding the links between surface and subsurface biogeosphere

In the CRC AquaDiva, scientists investigate the interaction of above-ground and below-ground habitats, and how they influence biodiversity. The goal is to gain a deeper understanding of impacts of intense agriculture, pesticide use, and weather extremes on subsurface habitats. The CRC's research has important implications for various fields, such as environmental protection, drinking water supply and climate change, and forms the basis for sustainable use and protection of groundwater resources.

One focus is on the investigation of flow processes and the transport behavior of water and dissolved substances in the subsurface. Another goal of the CRC AquaDiva is to gain a better understanding of the behavior of microorganisms in the subsurface, and their role in the processing and degradation of organic as well as inorganic substances. For this purpose, state-of-the-art molecular biological and photonic methods are being researched and applied to investigate, better understand and monitor the microbial diversity and functionality of microorganisms in the subsurface.

Scientists from the Fiber Spectroscopic Sensors Group at Leibniz IPHT, led by Prof. Dr. Torsten Frosch, are researching optical gas sensors within the CRC AquaDiva, which help to decipher metabolic processes and exchange processes underground.

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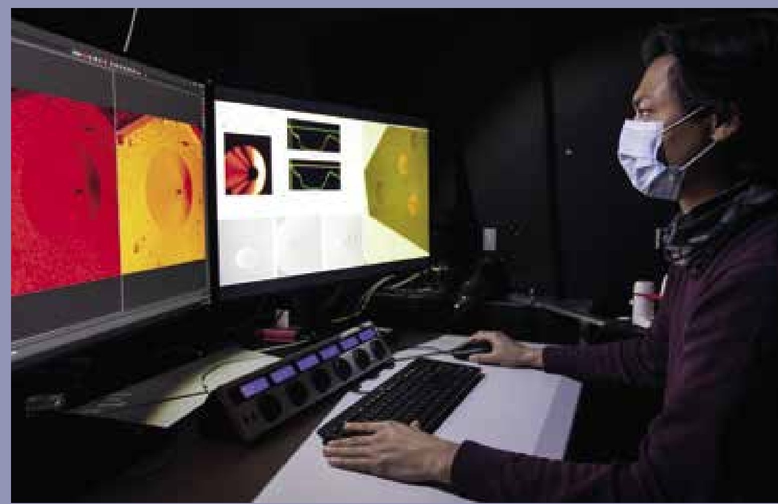
Partner institutions:

Friedrich Schiller University Jena, Helmholtz Centre for Environmental Research, Leibniz IPHT and Max Planck Institute for Biogeochemistry

The team of the Fiber Spectroscopic Sensors Group setting up the gas sensor system in the Hainich Critical Zone Exploratory (CZE), a research platform at the Hainich National Park that provides insights into above- and belowground habitats as part of the CRC AquaDiva. © AG Frosch



Parijat Barman, PhD student in the Spectroscopy and Imaging Research Department at Leibniz IPHT, is conducting research on the optimization of Raman spectroscopy in the CRC NOA. © Sven Döring

NOA: Nonlinear optics down to atomic scales

In the CRC NOA, researchers from the disciplines of physics, chemistry and engineering jointly investigate the interactions between light and matter on an atomic and molecular scale in order to lay the foundations for researching and developing new optical technologies. For this purpose, state-of-the-art laser and spectroscopy techniques are used, for example, to record and analyze the behavior of light and matter in real time.

An additional focus of the research is on the utilization of the results for further fields of applications, such as optical data storage, communication and sensor technology. To this end, new materials and technologies are being developed based on the findings of nonlinear optics.

As part of the CRC NOA, Leibniz IPHT is conducting research, among other things, to better understand and utilize surface-enhanced Raman spectroscopy, for example, in order to investigate chemical reactions of individual molecules and their interactions with unprecedented precision.

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Partner institutions:

Friedrich Schiller University Jena, Humboldt-Universität zu Berlin, Ludwig-Maximilians-Universität Munich, Leibniz IPHT, Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Helmholtz Institute Jena, Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy as well as Max Planck Institute of Quantum Optics

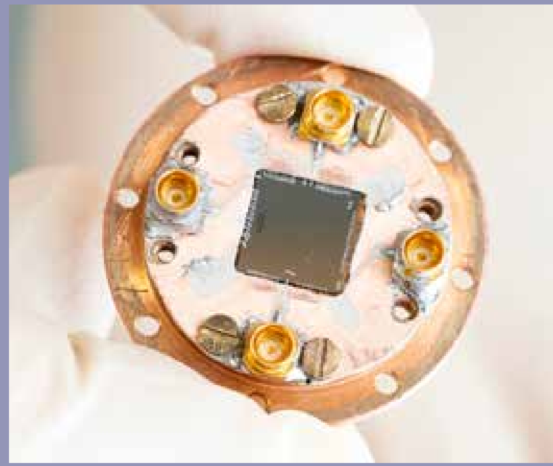
Dr. Gregor Oelsner, head of the Quantum Circuits Group in the Quantum Systems Research Department and subproject leader of QSolid at Leibniz IPHT, prepares the cryostat for ultra-low temperatures for the research on new superconducting circuits for the quantum computer of the future. © Sven Döring

Innovation Leap with Modern Quantum Technologies

Towards Advanced and Even More Powerful Supercomputers

Whether ultra-fast data processing or more precise medical diagnostics – quantum technologies are considered one of the greatest achievements of physics of the 20th century and enable new applications in many areas of life. At Leibniz IPHT, research into quantum systems focuses primarily on biomedical applications. In the coming years, the topic of quantum biophotonics is to be enhanced and anchored in the research profile of the institute. Leibniz IPHT is currently participating in several national collaborative projects.

In order to exceed the computing power of today's computers and solve mathematical tasks significantly faster, 25 leading German companies and research institutions are working on the first quantum computer from Germany in the five-year cooperative project **QSolid** (Quantum Computer in the Solid State). Equipped with several quantum processors based on superconducting circuits, the new supercomputer is expected to be far superior to previous computers for specific tasks. Leibniz IPHT contributes its many years of experience in the design, manufacture and characterization of superconducting circuits to the project. By developing new production methods and characterization processes for implementing high-quality superconducting circuits, the underlying key and circuit components as well as new material systems, the team from the Quantum Systems Research Department, together with its partners, contributes to the realization of the next-generation supercomputer.



Chips with the novel quantum circuits manufactured by the Competence Center for Micro- and Nanotechnologies are mounted on special sample carriers and provided with the necessary connections before they are used in the cryostat for measurements near absolute temperature zero. © Sven Döring

The development of reliable key technologies for high-performance quantum computers, but also for extremely sensitive quantum sensors for exploration and navigation systems or precise diagnostic procedures, is part of the **SuperLSI** project (Highly Integrated Superconducting Nanostructures for Quantum Technologies). Five German partners from research and industry are working on the building blocks of superconducting quantum systems in the three-year project. By researching and developing novel, precise and standardized fabrication processes for highly efficient superconducting circuits, Leibniz IPHT brings its extensive expertise in quantum technologies to the project while expanding its competencies in this field. In addition to new coating and structuring processes, the researchers are working on DUV laser lithography as well as superconducting material concepts for the realization of highly integrated, robust quantum circuits of high quality.

The German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) is funding the two cooperative projects QSolid and SuperLSI with a total of 81.9 million Euros.

JeDis summer school

© Leibniz IPHT

Cosmopolitan

Vibrant Research Community Thanks to Global Networking

Environmental pollution, infectious diseases, or cancer are challenges that affect people all over the world. In transnational collaborations, research and industry partners work together on ideas and technological solutions in response to global issues. In this way, important findings and progress can be achieved for better healthcare or sustainable nature protection, from which all people can benefit.

Science thrives on an intensive and interdisciplinary exchange that links revolutionary findings, new knowledge, different perspectives as well as complementary experience of different actors, and mobilizes valuable research forces. This stimulating dialogue finds its expression in international collaborations and networks as well as in projects and alliances in which partners work closely together, and jointly use technological resources, and develop synergies for the creation of cutting-edge research results. In this way, fundamental successes can be achieved in solving global issues – whether for health research or environmental analytics.

Beyond national borders: Internationalization at Leibniz IPHT

Internationalization is an essential cornerstone of the overall strategic orientation of Leibniz IPHT. For this purpose, the institute is integrated into a close network of collaborations, clusters, collaborative research centers as well as scientific projects, and maintains relationships with universities, renowned research institutions, and partners all over the world. The scientific exchange with international specialists, and the resulting synergies are the driving force for innovations, in order to explore flagship solutions for pressing societal problems with the help of light.

Examples of such global networks, in which Leibniz IPHT is involved, are the EU project CRIMSON (pages 40-41), the Marie Skłodowska-Curie Innovative Training Network LogicLab (pages 44-45), the European initiative PhotonHub Europe® (page 49), and the European network IMAGE-IN (pages 50-51).

"The basis for this cutting-edge research are our colleagues. With their professional know-how, intercultural diversity and experience, they help shape scientific progress successfully," explains Gabriele Hamm, Internationalization Officer at Leibniz IPHT. "In recent years, we have seen a significant increase, especially in the number of researchers with international background. The proportion of employees coming to Leibniz IPHT from abroad in order to conduct research and work here is currently over 50 percent. This figure underlines the high international orientation, visibility, and good reputation of our institute as an attractive employer and outstanding research institution that attracts talents from all over the world."

To support this idea and to compete for the best specialists, worldwide recruiting is part of the internationalization strategy of Leibniz IPHT. Here, the workshop series "Women in Photonics" (page 52) ties in, in which the promotion of young scientists is closely linked to knowledge transfer and talent scouting.

The scientific education at Leibniz IPHT also has an international character: In order to gain intercultural experience at an early stage of their career, the institute offers its young researchers stays abroad for several months as well as active participation in international conferences and meetings. Multicultural competences can be acquired, which contributes to a cosmopolitan atmosphere at Leibniz IPHT. The experience gained enables students to continue their careers at renowned institutions abroad after completing their doctorates, which strengthens the institute's reputation as an excellent scientific institution and attractive research partner.

Leibniz IPHT regularly welcomes renowned international scientists in Jena, who work on research topics and projects together with the institute's staff in the context of guest stays and fellowships, such as the Humboldt Award winner Prof. Hassan Azzazy from the American University of Cairo in Egypt (page 48). Thus, close cooperation leads to top scientific achievements with global impact.

In addition, Leibniz IPHT researchers take on research and teaching activities at internationally renowned universities as visiting professors, which carries the institute's reputation as an excellent facility for top-class research beyond Jena into the world. These activities, as well as the attendance of conferences and participation in lecture programs at internationally important trade fairs, such as SPIE Photonics West in San Francisco, USA, lay the foundations for establishing worldwide contacts.

© Leibniz IPHT

> “Internationality and diversity are the driving forces for conducting excellent research at the highest level, and thus securing Leibniz IPHT a top position in the German and international research landscape.”

Gabriele Hamm is internationalization officer and supports strategic international partnerships and projects at Leibniz IPHT.

JeDis project meeting at UC Davis in California on the occasion of the fifth anniversary of the transatlantic cooperation.
© Leibniz IPHT

Laboratory visit at the Jena University hospital in the context of the JeDis Summer School "Clinical Biophotonics".
© Leibniz IPHT

Jena-Davis Alliance of Excellence in Biophotonics

Transatlantic Partnership Celebrates Fifth Anniversary

For five years now, the Jena-Davis Alliance of Excellence in Biophotonics, a transatlantic cooperation between Leibniz IPHT and the University of California, Davis, USA, has been researching new light-based solutions for healthcare and life science applications. The five-year anniversary, and thus the end of the project period, provided the opportunity for a positive assessment and an outlook for further joint activities and projects.

The Jena-Davis Alliance of Excellence in Biophotonics (JeDis) is a transatlantic initiative started in 2018, in which Leibniz IPHT and the University of California, Davis (UC Davis), work closely together in biophotonics research and teaching. One of the goals of JeDis is to intensify communication between (young) researchers, multipliers and young leaders in order to strengthen long-term relationships as well as to promote multidisciplinary scientific and intercultural exchange across continents.

On the occasion of the anniversary, a delegation from Jena visited their American colleagues in Davis in September 2022 to celebrate the joint work of the past years, and to look back on the research results achieved, and to agree on future goals of a continued close partnership.

Successful German-American cooperation

An essential pillar of the joint collaboration between Leibniz IPHT and UC Davis within the JeDis initiative is the interdisciplinary networking of excellent scientists. Both institutions complement each other through their expertise: UC Davis, for example, has many years of experience in the field of fluorescence lifetime imaging. Leibniz IPHT contributes its expertise in the field of Raman spectroscopy and multimodal imaging to the partnership. By combining this expertise, research into new photonic solutions for the diagnosis and treatment of diseases, in particular cancer, has been further advanced over the past five years.

Several joint summer schools and conferences, such as the career workshop "Women in Photonics" (page 52), were held as part of JeDis. In addition, young scientists visited the respective partner institute for research stays of several months, and worked on joint projects. The success of the collaboration of the two institutions is reflected, among other things, in joint publications and a doctorate.

The JeDis project was funded by the German Program for Transatlantic Encounters with monies from the ERP Special Fund of the German Federal Ministry of Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz, BMWK), which goes back to the Marshall Plan (officially: European Recovery Program, ERP).

Continuing the transatlantic cooperation

Following the five-year funding phase at the end of 2022, the collaboration of Leibniz IPHT and UC Davis is to be further intensified. The form of cooperation and common objectives were also discussed during the visit of the Jena delegation to Davis. In the future, there will be opportunities for the exchange of scientists in order to jointly advance the translation of photonic solutions to clinical applications. For example, it is planned that Leibniz IPHT will contribute to the new National Center for Interventional Biophotonic Technologies (NCIBT) initiated by UC Davis, which aims to develop light-based technologies for life science applications.

"In terms of our internationalization strategy, the cooperation with UC Davis is of particular importance. On the one hand, our technological approaches complement each other. On the other hand, the NCIBT and the Medical Center at the clinic in neighboring Sacramento, which is part of the university in Davis, open up new opportunities for translation. I see this as a good basis for a successful ongoing partnership," concludes Prof. Dr. Jürgen Popp, scientific director at Leibniz IPHT and co-initiator of the JeDis initiative.

A first broadband CARS setup was realized at Leibniz IPHT in 2022, which will help characterize cellular components and molecularly decipher cancer. © Sven Döring

Faster Diagnostics

Molecular Imaging Reveals Cancer Cells

In the CRIMSON research project, a team of scientists from Italy, Germany, France and Great Britain is pursuing an ambitious goal that is extremely important for society as a whole: Thanks to innovative technologies, cancer diagnostics is to be elevated to a new level, and patients are to be given hope of significantly improved early detection. In this interview, Dr. Tobias Meyer-Zedler, head of the Molecular Imaging Group in the Spectroscopy and Imaging Research Department at Leibniz IPHT and subproject leader in CRIMSON, explains how novel research approaches can provide a promising future for the detection of cancer.

Cancer is considered one of the most widespread diseases of our time. Especially in the age group between 40 and 79, cancer with more than 30 percent is the most common cause of death.[1] Understanding the development of cancer at the cellular level and diagnosing the disease at an early stage, is therefore extremely important for the success of a therapy and the chances of recovery.

What diagnostic methods for detecting cancer cells do currently exist?

Current diagnostic procedures for cancer detection usually involve biopsies, in which tissue samples are taken from patients and subsequently evaluated histopathologically by pathologists. This examination can take up to several days until a reliable diagnostic finding is available. Therefore, it would be invaluable if a reliable assessment of cellular changes could be made during surgery, or if biopsies would not have to be performed at all, and the tissue could be examined non-invasively *in vivo*.

What is the research goal of the scientists in order to improve today's diagnostics?

In the four-year EU project CRIMSON (Coherent Raman Imaging for the Molecular Study of the Origin of Diseases), which started in 2020, a new biophotonic imaging instrument is to be developed that will bring cancer diagnostics a major step forward. On the one hand, the system to be developed can significantly accelerate the assessment of pathologically altered tissue and support early diagnosis. On the other hand, it can be used to investigate the causes of disease at the cellular level in order to generate new approaches for customized therapy based on these findings.

Scientist Dr. Tobias Meyer-Zedler is conducting research on broadband CARS microscopy as part of the CRIMSON project. © Sven Döring

What technological advances are expected to help achieve this goal?

It is planned to develop a microscopy technology based on coherent Raman microscopy, or more precisely molecular sensitive coherent anti-Stokes Raman scattering microscopy (CARS). The sample to be investigated is irradiated by two laser pulses, which coherently excite characteristic molecular vibrations in the sample, whose signals are detected by the microscope. For this purpose, new compact laser sources for the realization of innovative hyperspectral CARS detection methods in combination with spectral analysis routines based on artificial intelligence are investigated in CRIMSON. The aim is to develop a hyperspectral CARS microscope for rapid cell and tissue classification with unprecedented biochemical sensitivity.

What advantages will patients be able to benefit from in the future?

In the long term, the novel microscopic technology should be able to provide labelfree molecular images of subcellular compartments in living cells or organoids as well as tissues with biomolecular sensitivity. As cells evolve into malignant tissue, their unique molecular fingerprint changes. In some types of cancer, there is an increase in certain molecules. These changes can also be detected as molecular details in the CARS spectra. By providing an even more precise insight into cells, we are creating the technological prerequisites for an even better assessment of tumors and their aggressiveness.

Thanks to the high imaging speed that the microscope will offer, dynamic changes of and in cells will also become visible through time-lapse imaging. Such observable cell developments can give doctors indications of a possible cancer disease. An early targeted drug therapy could follow immediately.

The technological solution to be developed is intended both as a surgical microscope and as an endoscopic instrument. It offers the advantage, for example, of being able to detect conspicuous tissue directly during an endoscopic examination and immediately initiate further steps. During surgical removal of tumors, surgeons would be able to assess within a few minutes, directly in the operating room, whether the morbid tissue has been completely removed and no tumor cells remained in the body.

The European Commission is funding the project with more than five million Euros.

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More information on the *CRIMSON* project:
www.crimson-project.eu

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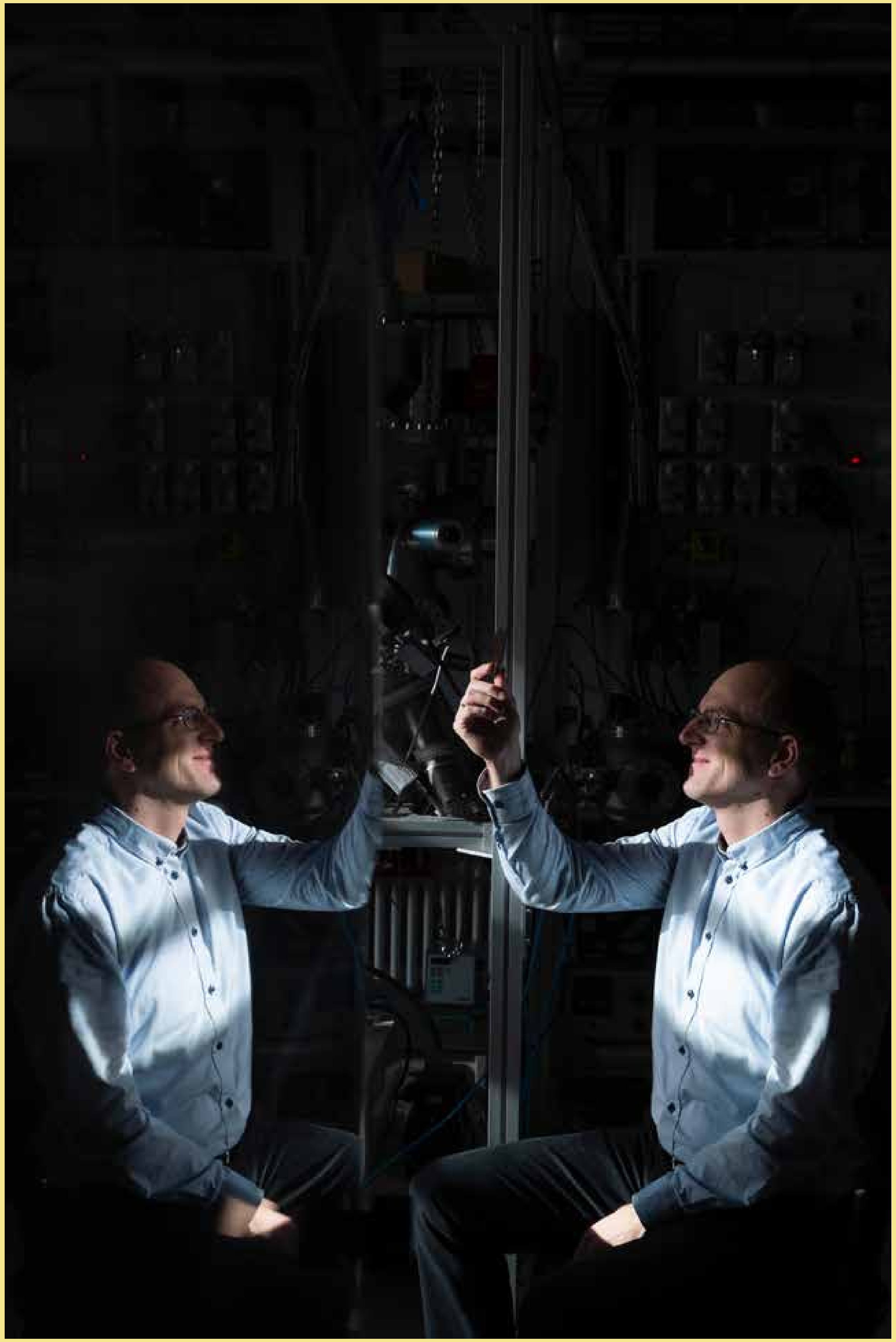
[1] Cf. Statistisches Bundesamt (Destatis): World Cancer Day: record low of in-patient cancer treatments in 2021, Press release of February 2, 2023, https://www.destatis.de/EN/Press/2023/02/PE23_N007_231.html [February 15, 2023]



Scientist Dr. Jonathan Plentz, head of the Photonic Thin Film Systems Group, in the coating laboratory at Leibniz IPHT, where smart fabrics are researched and various materials are applied as thin films to textile substrates. © Sven Döring

Intelligent Clothing

Smart Textiles Keep Batteries Charged

They count steps, monitor vital functions or are in charge of navigating to a destination – small, intelligent computer technologies such as smartwatches, fitness bracelets or pedometers offer many useful functionalities in the sports and wellness sector to make everyday life even more pleasant. In order to make these wearables available as constant technical companions at all times and to supply them with power, next-generation textiles offer unimagined potential by focusing on humans as a source of energy.

Mobile and miniaturized electronic devices worn close to the body should be even easier to supply with energy in the future, even when no external power supply is available. Researchers at Leibniz IPHT, together with ITP GmbH – Gesellschaft für Intelligente Textile Produkte of Weimar, Germany, and textile manufacturer E. CIMA of Barcelona, Spain, have developed an intelligent textile-based solution that makes energy generation self-sufficient: Novel materials can convert the emitted human body heat into electricity using thermoelectric effects.

For this purpose, thin-film coatings of less than one thousandth of a millimeter in the form of aluminum-doped zinc oxide are applied to textile fabrics as a thermoelectrically active functional layer. Integrated into high-tech clothing, these thermoelectric generators can produce energy basing on the temperature differences between the user's skin surface and the ambient temperature. This energy can then be stored in a rechargeable battery and can cover the power requirements of electronic devices for health or sports at any time.

Clever fabric: 3D spacer fabrics made of polyester, thermoelectrically coated as well as equipped with copper contacts, are the starting point for smart clothing suitable for energy generation and active cooling. © Sven Döring

The textile thermoelectric effect can also be used for cooling and temperature regulation by applying a voltage. These cooling properties make the innovative and clever materials particularly interesting for safety- and temperature-critical application scenarios in the industry, or for health and medicine. Therefore, intelligent clothing and thermoelectric textile solutions could, for example, help to better regulate body temperature, or reduce fever.

The development was funded by the German Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz, BMWK) as part of the Central Innovation Programme for small and medium-sized enterprises (Zentrales Innovationsprogramm Mittelstand, ZIM).

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Patents:

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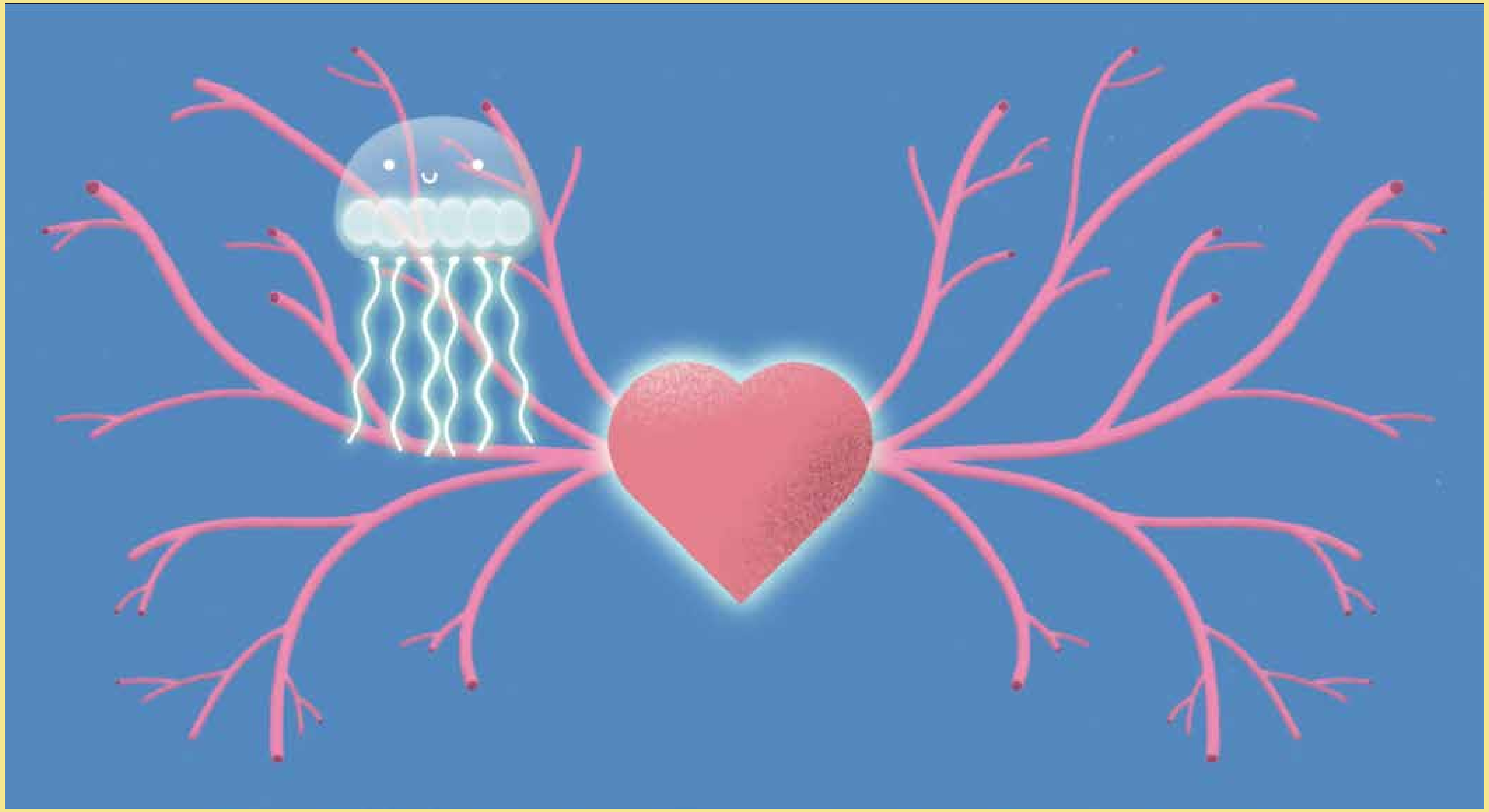

Using functionalized sensor molecules, researchers in the LogicLab science network are working to detect coronary disease at an early stage.

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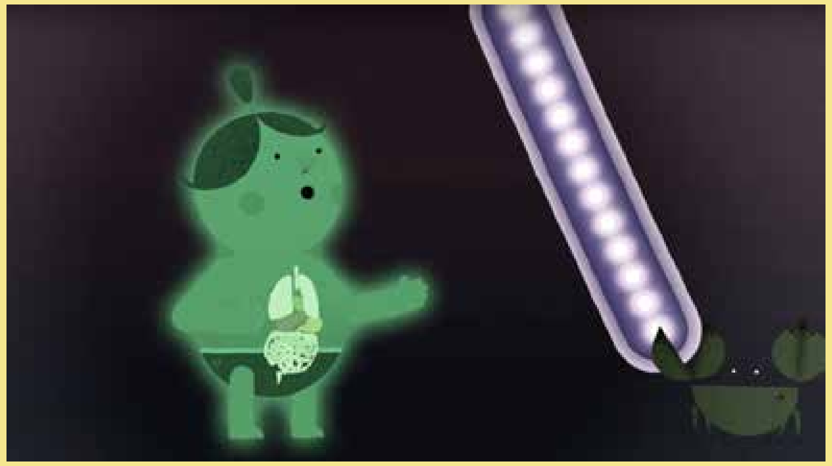

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Heart-healthy

With Smart Sensors Against Coronary Disease

With more than 30 percent, cardiovascular diseases such as heart attacks were the most common cause of death in Germany in 2021.[1] Deposits in the inner walls of the arteries are usually responsible for myocardial infarctions, which can lead to narrowings in the blood vessels, and to impaired blood flow in the heart muscle, and even to occlusion of the coronary arteries. In order to advance the diagnosis of coronary diseases and thus reduce the risk of heart attacks, the European network LogicLab is working with sophisticated sensors at a turning point.

To this end, scientists from the Marie Skłodowska-Curie Innovative Training Network LogicLab (Molecular logic lab-on-a-vesicle for intracellular diagnostics) have been researching innovative molecular logic sensors for early detection since 2018. "These molecules have the special property of responding to stimulation, for example of a chemical nature, to other molecules or light, with a targeted interaction behavior. They could, for example, provide information about certain disease parameters by excitation with light. By functionalizing these molecules, we can furnish them with tailored properties that can provide answers in the context of diagnostic clarification," explains Prof. Dr. Benjamin Dietzek-Ivanšić, head of the Functional Interfaces Research Department at Leibniz IPHT and scientific coordinator of LogicLab.

The knowledge gained should help to diagnose endothelial dysfunction by identifying certain messenger substances. This disorder of the cell layer lining the blood vessels is one of the causes of arteriosclerosis. Its early diagnosis and immediate treatment can reduce the risk of dangerous narrowing of the blood vessels, which can lead to a heart attack.

First-class training program for young scientists

15 partner organizations from Germany, Ireland, the Netherlands, Poland and Slovakia contribute their expertise to the science network, coordinated by Leibniz IPHT. Together, they enable the 14 young researchers, who receive a unique training program as part of LogicLab, to lay the foundations for their scientific careers with guest stays, advanced scientific training, and opportunities for networking and professional exchange.

The five-year LogicLab project is funded by the European Union with more than 3.5 million Euros.

Good to know: When arteries calcify

Calcification of the arteries is also known as arteriosclerosis. Calcium, connective tissue and fat are deposited in the inner walls of the blood vessels. These deposits, known as plaques, lead to a narrowing of the arteries, and thus to poorer blood circulation and insufficient supply of oxygen to the organs. If the heart is not supplied properly, the blood flow is disrupted or an occlusion develops, a heart attack may be impending. Endothelial dysfunction, a functional disorder of the endothelium, i. e. the vessel wall, can develop into arteriosclerosis.

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Publications:

Yang, Valavalkar, Romero-Arenas, Dasgupta, Then, Chettri, Eggeling, Ros, Pischel & Dietzek-Ivanšić, Chemistry Europe, 2022, https://doi.org/10.1002/chem.202203468

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Yang, Chettri, Radwan, Matuszyk, Baranska & Dietzek-Ivanšić, Chemical Communications, 57, 6392-6395, 2021, https://doi.org/10.1039/D1CC01907D

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Further information on *LogicLab*: **www.logiclab-itn.eu**

https://youtu.be/C3_uOcFwdUs

https://youtu.be/gOsnyUO21us

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[1] Cf. Statistisches Bundesamt (Destatis): Causes of death statistics 2021: 7 % of all deaths directly due to Covid-19, Press release of 16 December 2022, https://www.destatis.de/EN/Press/2022/12/PE22_544_23211.html [February 21, 2023]

The atoms are located in a special glass vapor cell that tracks signals from the exotic matter in a magnetically very well-shielded setup. © Sven Döring

Dark Secrets of the Universe

Optical Magnetometers Reveal Hidden Worlds

Since time immemorial, looking up at the night sky has sparked a magical fascination and longing. Today, modern space probes and satellites provide ever higher resolution images and information of celestial bodies and galaxies, constantly expanding our knowledge of the universe. Nevertheless, central questions about the origin and development of the universe are still unanswered, which researchers want to decipher using innovative technologies.

"Numerous astronomical observations and realistic models of the origin of the universe suggest that the directly observable part of the universe represents only a fraction of the entire cosmos, and that a large part consists of unknown, invisible, so-called dark matter," explains Dr. Theo Scholtes, head of the Quantum Magnetometry Group from the Quantum Systems Research Department at Leibniz IPHT. "While the existence of this dark matter is widely accepted in science, its nature remains unclear. Therefore, it is being searched for in numerous and very different experiments worldwide."

A physically well-motivated hypothesis is that dark matter particles are so-called axions, or axion-like particles, particles with very small masses that may be able to form structures, such as axion walls or stars, and interact with the spins of "conventional" atoms. With the "Global Network of Optical Magnetometers for the Search for Exotic Physics" (GNOME), researchers are currently searching for signatures of such exotic objects.

To detect dark matter particles, Dr. Theo Scholtes, head of the Quantum Magnetometry Group, is working on optical magnetometers. © Sven Döring

To this end, GNOME currently connects up to 17 stations around the globe with highly sensitive optical magnetometers. One of these stations is operated by Leibniz IPHT at the Moxa Geodynamic Observatory of the Friedrich Schiller University Jena. "I developed the first version of the setup as a postdoctoral researcher at the University of Fribourg (Switzerland) and was able to continue the work seamlessly when I returned to Leibniz IPHT. I am very grateful to both sides for this," says Dr. Theo Scholtes.

If the earth passes through a structure of exotic matter, it can interact with the atomic gas contained in the GNOME magnetometers. The changing optical properties of the atoms in the synchronized sensors are detected by laser light.

The search for correlations in the data from the stations allows the detection of cosmic events, and thus to draw conclusions about dark matter.

In first comprehensive long-term measurements, no exotic cosmic events could be observed yet, but free parameters of some dark matter models could already be constrained. The collaboration is currently working on making the magnetometers even more sensitive to exotic interactions. In this way, the search for dark matter will be further advanced in the future, and its nature clarified.

In addition to the search for dark matter, optically pumped magnetometers also support biomedical applications, and can detect the smallest magnetic signals, such as heart and brain activity.

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Publication:

Afach, Buchler, Budker, Dailey, Derevianko, Dumont, Figueroa, Gerhardt, Grujić, Guo, Hao, Hamilton, Hedges, Kimball, Kim, Khamis, Kornack, Lebedev, Lu, Masia-Roig, Monroy, Padniuk, Palm, Park, Paul, Penaflor, Peng, Pospelov, Preston, Pustelny, Scholtes, Segura, Semertzidis, Sheng, Shin, Smiga, Stalnaker, Sulai, Tandon, Wang, Weis, Wickenbrock, Wilson, Wu, Wurm, Xiao, Yang, Yu & Zhang, Nature Physics, 17, 2021, https://doi.org/10.1038/s41567-021-01393-y

Revealed

Reducing the Risk of Alzheimer's and Infectious Diseases

Prof. Hassan Azzazy from the American University in Cairo is working on developing mobile diagnostic solutions. © The American University in Cairo

Alzheimer's Disease International estimates that approximately 50 million people worldwide suffer from dementia.[1] One of the most common forms is Alzheimer's disease, where the brain is irreversibly damaged by the breakdown of nerve cells, resulting in cognitive and motor impairments. The presence of heavy metals in water may be a risk factor for Alzheimer's disease. Optical chemosensors could be used to make progress in monitoring water pollution, and thus preventing the neurodegenerative disease. These are being researched in the Nanobiophotonics Research Department at Leibniz IPHT together with the American University in Cairo, Egypt.

Mercury, lead, or arsenic are highly toxic heavy metals that pollute water – with dramatic health consequences. Regular monitoring in order to ensure water quality and possible contamination is therefore required. Optical chemosensors are suitable for checking the levels of toxic metals in water. They are extremely sensitive and capable of detecting low concentrations, even of several toxic metals, quickly and at low cost.

"Such sensors are conceivable, for example, in the form of nanoparticles that change their optical properties in the presence of heavy metals. By modifying their surface and attaching special capture molecules, it would be possible to determine in a short time whether a toxic metal is present in a water sample to be examined. In this case, the metal molecule binds to the capture molecule, resulting in a color change of the nanoparticles," explains Prof. Dr. Wolfgang Fritzsche, head of the Nanobiophotonics Research Department at Leibniz IPHT. Together with Hassan Azzazy, Professor of Chemistry at the American University in Cairo, who was honored with the Georg Forster Research Award of the Alexander von Humboldt Foundation for his achievements, and who is conducting research at Leibniz IPHT as part of a research stay, he investigates the topic of optical chemosensors.

Prof. Hassan Azzazy is also involved in nanotechnologies, and is working to develop affordable and rapidly deployable diagnostic solutions for his home country. In the Middle East and North Africa (MENA region), in particular, the number of people affected by Alzheimer's could increase by 400 percent by 2050.[2] Thanks to optical chemosensors, a valuable contribution can be made to reduce key factors in the development of Alzheimer's disease.

In collaboration with Prof. Hassan Azzazy, a portable system for on-site detection using a colorimetric assay was developed at Leibniz IPHT. This was successfully demonstrated by the researchers for the DNA-based detection of the bacterium *Legionella pneumophila*. Infection with this pathogen occurs via contaminated water and can escalate to pneumonia. The solution developed is also based on the use of noble metal nanoparticles, whose color change indicates the presence of the bacterial genome.

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Publication:

El-Sewify, Radwan, Elghazawy, Fritzsche & Azzazy, RSC Advances, 12, 32744-32755, 2022, https://doi.org/10.1039/D2RA05384E

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[1] Cf. Statista: Statistics on dementia worldwide, https://de.statista.com/themen/2032/demenzerkrankungen-weltweit/#topicOverview, 28.11.2022 [February 24, 2023]

[2] Cf. Deutsche Welle: Dementia is becoming an increasing challenge in the Middle East and North Africa, https://www.dw.com/de/demenz-wird-zu-immer-gr%C3%B6%C3%9Ferer-herausforderung-in-nahost-und-nordafrika/a-60717312, 11.02.2022 [February 24, 2023]

Functionalized Fibers Change the Color of Light

Functionalized Fibers © Jens Meyer, Jena University

An international research team with participation of Leibniz IPHT has succeeded in functionalizing optical fibers in such a way that they transform invisible infrared light into red light by means of 2D materials. The special fibers could be used as miniature light converters in the future. This concept was researched and developed by the Friedrich Schiller University Jena and Leibniz IPHT in cooperation with partners at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena, and the universities in Sydney and Adelaide, Australia.

The researchers specially designed and "upgraded" the optical fibers to include new functionalities. "With the functionalized fibers, we can realize optical frequency doubling, allowing light to halve its wavelength and change its color. For example, red is generated from infrared," explains Prof. Dr. Markus Schmidt, Head of the Fiber Photonics Research Department at Leibniz IPHT. This makes the researchers the first in the world to succeed in functionalizing optical fibers in such a way that they can be used in the future as nonlinear light converters based on 2D materials. The scientists published their research results in the renowned journal Nature Photonics.

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Publication:

Ngo, Najafidehaghani, Gan, Khazaee, Siems, George, Schartner, Nolte, Ebendorff-Heidepriem, Pertsch, Tuniz, Schmidt, Peschel, Turchanin & Eilenberger, Nature Photonics, 16, 769–776, 2022, https://doi.org/10.1038/s41566-022-01067-y

Photonics Research for European SMEs

In the European initiative PhotonHub Europe®, Leibniz IPHT and 52 other leading international photonics institutions support small and medium-sized enterprises in the development and introduction of light-based technologies. The major initiative, successor to the photonics program ACTPHAST, is funded with 19 million Euros under the European Union's Horizon 2020 program. PhotonHub Europe® provides guidance and support for implementation of photonic solutions in the form of education and training as well as a wide range of offers in areas such as investment and innovation along the entire value chain, from product concept to market launch.

Already under ACTPHAST, a fruitful cooperation started between the laser manufacturer Bloom SAS and the Optical Fiber Materials and Structures working group under Dr. Katrin Wondraczek. The successful collaboration will continue in spring 2023 with a follow-on project in the context of PhotonHub.

Since the start of the 2021 initiative, Dr. Francesco Reina, scientist in the Biophysical Imaging Research Department at Leibniz IPHT, has also been cooperating closely with Alessandro Rossetta, founder of the Italian start-up FLIM LABS, which specializes in microscopy and spectroscopy. Together, they are testing newly developed laser diodes at Leibniz IPHT that are used in imaging techniques for laser excitation. In the meantime, this has resulted in a prototype for performing lifetime-based fluorescence measurements, which will be validated in the laboratory and in field research in the near future.

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More information about *PhotonHub Europe®*: **www.photonhub.eu**

Imaging Experts of Tomorrow

The European network IMAGE-IN (Marie Skłodowska Curie European Training Network for Imaging Infections: Integrated, multiscale visualization of infections and host response) trains the next generation of researchers who will advance imaging technologies for medical applications. The goal is to lay the foundation for new diagnostic and therapeutic approaches to better understand and target infections. The IMAGE-IN consortium consists of academic and industrial partners from Germany and Portugal who provide joint supervision and training for PhD students. The network is coordinated by Prof. Dr. Ute Neugebauer, head of the Clinical Spectroscopic Diagnostics Research Department at Leibniz IPHT. She is convinced of the quality of the program: "The doctoral students gain a comprehensive insight into spectroscopic techniques, and acquire the ability to deal with large, multidimensional data, and to analyze them precisely. The PhD students spend more than half of their time in a non-academic environment. This provides them with valuable experience for their careers in academic and industrial research, complemented by mentoring programs and career guidance."

The European Union is funding the project through Horizon 2020.

The IMAGE-IN Consortium

Participating partners in the IMAGE-IN training network are BMD Software Ltd., Jena University hospital, Friedrich Schiller University Jena, Chemometrix GmbH, Universidade de Aveiro, Universidade de Coimbra, University Hospital Bonn and Leibniz IPHT.

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The main goal of my project is to study infection- and sepsis-associated hematological and morphological changes in the heart and kidneys using MRI data. To this end, I am developing a segmentation method compatible with these data, and then focus on data analysis. I find it very interesting to have the opportunity to do research and work in an academic environment, such as Leibniz IPHT, and in a business, such as BMD Software in Aveiro, Portugal.

Mahyasadat Ebrahimi from Iran

© Leibniz IPHT

My project has two main objectives – to develop a collaborative platform to support digital pathology analysis, and to explore new algorithms for data analysis. We are using various web-based technologies and combine them with artificial intelligence techniques to develop methods for analyzing tissue samples. In fact, I chose the project and not the place, but now there are many things that I appreciate and love about Portugal, and especially about Jena, such as the history that connects the city with great names like Carl Zeiss, or the beautiful landscape, especially in the fall.

Rodrigo Escobar-Diaz-Guerrero from Mexico

© Leibniz IPHT

I am working on analyzing the interaction between host and pathogen using Raman spectroscopy data. For this, I conduct research on the characterization, localization and visualization of immune cells and pathogens. Research in the field of health sciences is very meaningful to me, and I am very motivated to contribute to progress in the medical field. I've come to really enjoy my stay in Jena, which is a great place for families. I am now preparing my secondment in Portugal with BMD, where I will gain further experience in industry.

Rustam Guliev, Azerbaijani from Russia

© Sven Döring

I am a PhD student in Computer Science, and I am focusing on spectroscopy, microscopy and imaging as part of my research topic. In this context, I am developing a web 3D visualizer with some important registration functions. I came to Jena and Aveiro to gain experience in a high-tech environment, and to learn from experienced researchers. I highly recommend Leibniz IPHT and the University of Jena if you want to learn more about the world of microscopy and imaging.

Yubraj Gupta from Nepal

© Leibniz IPHT

I am studying the localization of bacteria using marker-free imaging methods and marker-assisted techniques, as well as monitoring their host response in osteomyelitis (bone infections). I already have some experience in imaging and am very interested in how images are recorded. For this purpose, I measure on infected bone tissue to identify or localize bacteria using Raman spectroscopy. Jena as a city of optics and Leibniz IPHT as a leading optical institute focusing on biophotonics, are the ideal places for me to write my PhD thesis.

Shibarjun Mandal from India

© Leibniz IPHT

"Women in Photonics" Workshop Brings Top Female Scientists to Jena

With the career workshop "Women in Photonics", Leibniz IPHT has created an internationally significant event series for the promotion of young female scientists.

More than 100 participants from Europe, Asia, and North and South America had the chance to exchange ideas about their research at the "Women in Photonics" workshop at Leibniz IPHT which was held for the time now from May 22 to 25, 2022. During the three-day event, 40 female participants holding a doctorate degree, presented their scientific work. In addition, female professors, entrepreneurs and representatives of local and national companies such as Carl Zeiss, Jenoptik, Trumpf and Leica, reported on their research and presented their personal career paths.

After the lecture sessions, the participants had the opportunity to visit the information booths of the industry and research partners in order to talk about possibilities of future collaboration. Parallel to this, laboratory tours were offered within Leibniz IPHT, which were intensively used. The young female researchers were able to take a look at the clean room, the fiber drawing facilities, laboratories for CARS microscopy, or multimodal instrumentation, and talk to the researchers.

"Proud to be a part of an amazing group of intelligent women. Go #WomeninPhotonics!" tweeted Hannah O'Toole, UC Davis Biomedical Engineering PhD candidate and winner of the workshop poster award, directly from the evening event. The highlight of the networking dinner on the last evening was an inspiring talk by Prof. Anita Mahadevan-Jansen, President of the International Society for Optics and Photonics (SPIE), who spoke of her own career path, which was not always easy, and advised her young female colleagues not to let adverse conditions get them down, but to continue to realize their ideas with passion and ambition.

With the "Women in Photonics" workshop, Leibniz IPHT not only connects excellent young female scientists with each other and with executives from research institutions and companies. The event also helps to inspire and recruit talented female researchers for Leibniz IPHT, such as Dr. Maria Chernysheva, who came to Jena via the stations Moscow and Birmingham, and now heads the junior Research Group Ultrafast Fiber Lasers at the institute. Participant Dr. Hülya Yilmaz from Sabanci University in Istanbul, Turkey, has also found her way to Leibniz IPHT in the meantime, and does now research in the Spectroscopy / Imaging Research Department.

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More information on *Women in Photonics*:
www.leibniz-ipht.de/en/events/women-in-photonics-2023-2/

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Laser Technology Conference ESULaB Attracts International Audience

Leibniz IPHT brings together world-renowned laser experts from research and industry to discuss trends in laser technology in biophotonic applications.

The focus of this year's "European Symposium on Ultrafast Laser driven Biophotonics" (ESULaB) was the use of modern ultrafast laser technologies for the investigation of complex biomedical samples of organs, tissue, cells, proteins, or DNA.

Nearly 200 participants from 23 countries came to Jena from September 11-14 for the second ESULaB 2022, organized by Leibniz IPHT in collaboration with laser manufacturer Coherent. After several years of renovation works at the Volkshaus Jena, that was the first official event to be held in the newly designed meeting and conference center. The highlight of the first day of the conference was the presentation by Prof. Gérard Mourou, pioneer of ultrafast laser physics and nonlinear optics from the École Polytechnique in Paris. Mourou was awarded the 2018 Nobel Prize in Physics for his research on Chirped Pulse Amplification (CPA). Mourou's research made it possible to develop the most intense laser pulse to date, on which many applications in medicine and industry are based today.

Prof. Dr. Jürgen Popp said he was satisfied: "The ESULaB is an important platform to present the core topics of Leibniz IPHT and to discuss urgent problems with international researchers and industry representatives." Peter Vogt, sales director at Coherent, confirmed that biophotonics is a very significant application field for laser manufacturers: "ESULaB provided a great opportunity to exchange ideas with users and potential laser users about the special requirements in this research field." Daniel Siegesmund, Head of Public Relations and Research Marketing at Leibniz IPHT, is also pleased with the successful event: "In addition to the scientific discourse as well as the opportunity to meet, conferences have another meaning for us: they are an important tool in terms of research marketing. We use these events to invite colleagues from all over the world to visit us in Jena, and to introduce them not only to the city and the location, but also, in particular, to our institute as a modern research institution and attractive employer. Jena has a lot to offer in terms of science, culture and economy, and is able to look back on a long tradition, especially in the field of optics and photonics."

The next ESULaB is planned for fall 2024.

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More information on current events of Leibniz IPHT:
www.leibniz-ipht.de/en/events/

Awards & Prizes in 2022

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Senior membership in Optica as well as 3rd place in the 2022 Women in Ultrafast Science Global Award

go to Dr. Maria Chernysheva in recognition of her scientific work on ultrafast fiber lasers, which opens up new possibilities for sensing and diagnostic applications.

© Christian Kuttke

Winner of the 2022 Digital Innovation Hub Photonics (DIHP) Pitch

is the openUC2 team led by Dr. Benedict Diederich and Dr. René Lachmann, for the successful further development of their microscope modular system openUC2, which can be used in order to design and implement powerful imaging instruments for a wide range of applications.

© Leibniz IPHT

Winner of the THeX Award, DIHP Pitch and Science4Life Venture Cup

is the start-up DeepEn for its spin-off project to advance brain research with hair-thin endoscopes: The team consisting of Dr. Sergey Turtaev, Dr. Hana Cizmarova, Patrick Westermann and Dr. Jiri Hofbrucker won second place at the Thuringia Start-up Award, and thus won the THeX Award in the category "Founding". The expert jury of the Digital Innovation Hub Photonics (DIHP) also awarded the DeepEn team a research budget. They were also among the winners of the Venture Cup of the Frankfurt-based start-up initiative Science4Life.

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Dissertation Award for Best Doctoral Thesis at Universities in Portugal

of the Portuguese Society for Research and Development in Optics and Photonics went to Dr. André Gomes, whose work laid the foundations for a new generation of highly sensitive fiber optic sensors.

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First place in the Optica Student Paper Competition

goes to Jisoo Kim for his research on how to make spectroscopy even faster and more reliable using novel 3D nano-printed hollow-core micro-gap waveguides.

© Falk Ronneberger, Friedrich Schiller University Jena

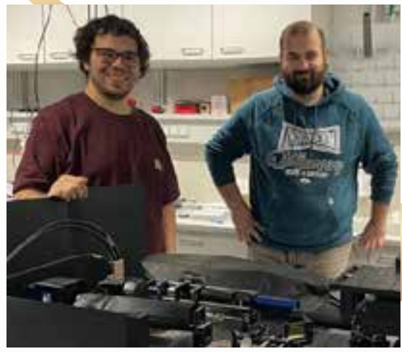
ZEISS Ph.D. Award 2022 in Advanced Optics

is awarded to Anindita Dasgupta for her dissertation project, which focuses on the technological advancement of super-resolution microscopy techniques.

© Fraunhofer IOF

Applied Photonics Award 2022

awarded to Felix Wechsler for the best master's thesis in which he shows how a commercially available microscope can be upgraded with a kaleidoscope to obtain high-resolution 3D images and further image information.



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napari Plugin Foundation Grant from the Chan Zuckerberg Initiative

awarded to Dr. Francesco Reina and Jacopo Abramo, who are developing a new plugin for the napari multidimensional image viewing software to bridge the gap between software, microscopy setups, and the devices used for image acquisition and imaging.

Putting Microcosm under the Microscope

Microscopy Expert Prof. Dr. Christian Eggeling Receives Recognition for Scientific and Academic Achievements

Awarded Prof. Dr. Christian Eggeling

© Sven Döring

High-resolution microscopy is needed to find out what holds the world together at its core, and to explore the tiniest building blocks of life. With its help, the micro and nano universe can be discovered in great detail and our understanding of the secrets of cell biology can be expanded. Imaging specialist Prof. Dr. Christian Eggeling, head of the Research Department of Biophysical Imaging at Leibniz IPHT, has been working on microscopy-based methods for more than 20 years, contributing to even better diagnosis and therapy of diseases. In 2022, the scientist was honored with two awards. In an interview, the physicist reveals why these awards are very special milestones for him.

Mr. Eggeling, you have been awarded the Royal Microscopy Society (RMS) Prize for Light Microscopy. Congratulations on this success. What did you receive this award for?

My research activities focus on super-resolved microscopy, which allows a deep and highly accurate view into the nanoworld and the interior of living cells. How molecules move freely, and how they interact with each other can be studied in great detail thanks to modern microscopy. Together with my team, I was able to combine, apply and further optimize super-resolved stimulated emission depletion microscopy (STED) with single-molecule fluorescence spectroscopy (FCS). By using this highly sensitive method, the diffusion and interaction dynamics of lipid and protein molecules in cellular membranes can be observed with high resolution, which was previously not possible in this way. Such processes are important to investigate as they are the basis for cellular signaling processes, such as extracellular communication or invasion of pathogens, such as viruses. Thanks to our techniques we can now observe these structures with very high precision. The Royal Microscopy Society award is one of the highest microscopy awards in the UK, and a wonderful recognition and great honor for me. This is in recognition of the work I have done so far in the field of super-resolution microscopy, where we have been able to make important advances in modern imaging and resolution of minute details.

You worked for many years alongside the 2014 Nobel Laureate in Chemistry, Prof. Dr. Stefan Hell, who broke new ground in microscopy. How did this time influence you?

I have a long and intensive history with Prof. Dr. Stefan Hell at the Max Planck Institute for Multidisciplinary Sciences (previously Max Planck Institute for Biophysical Chemistry) in Göttingen. During these almost ten years, I was able to actively participate in his group's pioneering work to overcome the resolution limit of 200 nanometers postulated by Ernst Abbe in the field of optical microscopy. In particular, we developed and optimized super-resolution STED microscopy. This time had a lasting impact on me because it showed me that it is worthwhile to persistently believe in an idea, despite all skepticism.

To highlight the strengths of super-resolution microscopy methods, it is important to show their potential in cell biological applications. Therefore, I later accepted a professorship in Molecular Immunology and became the head of the Wolfson Imaging Centre Oxford at the Weatherall Institute of Molecular Medicine at the University of Oxford in the UK. This allowed me and my group to further apply and adapt microscopy methods to cell biological and especially immunological problems. In the interdisciplinary environment of the City of Jena, specialized in photonic and infection biology research, I now have the perfect environment to continue this work with my excellent team and the Microscopy Centre of the Jena Microverse Excellence Initiative Jena which I lead.

What is the motivation behind your passion for microscopy and the drive to further improve it?

Fundamental to all of our lives is health. However, infectious diseases and cancers are unfortunately ubiquitous in our society, and have also greatly affected me through the loss of very close family members. I am convinced that advanced microscopy, such as super-resolved microscopy, can help to better understand and detect cancers as well as infection of cells and uncover the underlying mechanisms. This will enable us to develop appropriate drugs. By optimizing existing imaging techniques, we can contribute to providing precise tools for medicine.

You also received another award this year, namely, for your commitment to teaching.

This summer, I received the teaching award from the medical student council for my teaching performance as a supervisor in the physics practical course for first-year medical students at the Friedrich Schiller University Jena. This award was a nice confirmation to impart joy, fun and curiosity in the field of natural sciences to young people. I think it is important to put oneself in the students' shoes, and to teach them physical basics as clearly as possible, such as how a microscope works and how it is constructed. Medical students and young researchers, in particular, will come into contact with microscopy again and again in their careers – so it is all the more important that they learn this elementary knowledge early on in their studies, and are motivated to discover more of it.

What would you like to pass on to young researchers and managers of tomorrow on their career path who still have their studies and first professional steps ahead of them?

Young people should do one thing above all: stay open-minded – open to new things. Don't let doubts throw you off your path, but always believe in yourselves and your ideas and beliefs – that's important.

Thank you very much for this interview, Mr. Eggeling.

Institute Highlights 2022

February 8, 2022
Funding from the European Research Council (ERC) for the WOKEGATE Project


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Prof. Dr. Tomáš Čižmár, Head of the Research Department Fiber Research and Technology at Leibniz IPHT, is awarded the prestigious ERC Grant with a prize money of two million Euros. With this grant, he will continue his research on minimally invasive endoscopic instruments for optical neuroscience diagnostics, enabling observations of neuronal cells in submicrometre detail and unprecedented depth. The development of new fiber types customized to application will further enhance experimental capabilities for *in vivo* neuroscience in deep brain regions, and bring the technology to a level of maturity that will allow its implementation by the start-up DeepEn.

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More information

May 2, 2022
New Junior Research Group Supported by Carl Zeiss Foundation Nexus Funding


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As head of the new Smart Photonics Research Group, physicist Dr. Mario Chemnitz, who has returned to Leibniz IPHT, is working on the photonic diagnostics of the future at the interface of biology, physics and data science. The Carl Zeiss Foundation grant of 1.5 million Euros will enable him to build a multidisciplinary team and a state-of-the-art laboratory to develop a fully fiber-integrated smart sensor and microscopy system.

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More information

August 31, 2022
Starting-up: openUC2 Successfully Spun Off


© Christian Kuttke

Dr. Benedict Diederich and Dr. René Lachmann spun off openUC2 GmbH from Leibniz IPHT in August 2022. They were supported by funding from the Leibniz Start-up Prize, which rewarded them for their business idea of a modular optical construction kit that enables powerful microscopes for a wide range of applications. Ten school research centers in Thuringia received the first optical kits as teaching materials for STEM subjects, sponsored by the Wilhelm and Else Heraeus Foundation and supported by the Foundation for Technology, Innovation and Research Thuringia (STIFT).

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More information

September 9, 2022
Maria Wächtler follows call to Rhineland-Palatinate Technical University Kaiserslautern-Landau


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With the start of the winter semester 2022/2023, Prof. Dr. Maria Wächtler has commenced her research work at the Rhineland-Palatinate Technical University Kaiserslautern-Landau (RPTU). In doing so, she links up with her accumulated expertise as head of the Quantum Confined Nanostructures Group in the Functional Interfaces Research Department at Leibniz IPHT. In the future, her focus will include investigation of semiconductor nanoparticle-based photoactive materials for photocatalytic applications. The subproject she supervises in the special research area CataLight will continue at the RPTU.

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More information

September 12, 2022
Ronny Stolz Appointed Honorary Professor at Ilmenau University of Technology


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With the appointment of Prof. Dr. Ronny Stolz to the Faculty of Electrical Engineering and Information Technology, the Technische Universität Ilmenau has been strengthening the field of quantum engineering since the winter semester 2022/2023. In the Research Department Quantum Systems at Leibniz IPHT, which he heads, the focus is on the development of quantum sensors based on superconducting and optically pumped magnetometers as well as on research into superconducting quantum circuits and material concepts. Currently, he and his team are working on long-term projects, including QSolid (quantum computing in the solid state) and QGrad (quantum gradiometers for geo-exploration and ordnance detection).

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More information

October 11, 2022
Mathias Micheel Elected Spokesperson of the yPC


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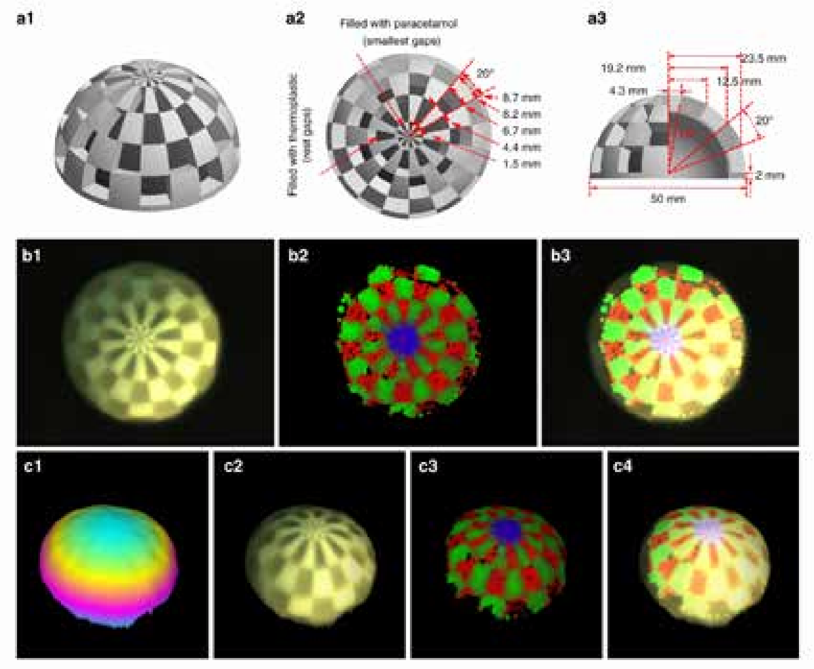
Dr. Mathias Micheel from the Functional Interfaces Research Department, together with Katharina Meyer from the University of Wisconsin-Madison, takes on the spokesperson position of the Young Physical Chemists of the Bunsen Society (yPC). In the future, their aim is to intensify contact with other young chemists' and physicists' organizations, and to interest more international doctoral students in the yPC and its events.

Publication Highlights 2022

Light: Science & Applications



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Real-time Molecular Imaging of Near-surface Tissue Using Raman Spectroscopy

Wei Yang, Florian Knorr, Ines Latka, Matthias Vogt, Gunther O Hofmann, Jürgen Popp & Iwan W Schie

Raman spectroscopy has shown great potential for clinical *in vivo* diagnostics by providing the molecular fingerprint of a sample without contact or destruction. However, current fiber optic probe-based Raman systems remain technologically limited. In a recent study published in Light Science & Application, a team of scientists led by Professor Dr. Iwan Schie in collaboration with Professor Dr. Gunther Hofmann from the Jena University hospital, Germany, developed a real-time molecular imaging system using Raman spectroscopy.

Their proposed system provides molecular-sensitive information to detect distinguish cancer from healthy tissues. The imaging platform combines molecular measurements, positional tracking, real-time data processing, and molecular virtual reality (MVR) images with a spatial resolution of 0.5 mm in the transverse plane and a topology resolution of 0.6 mm. The MVR images can be perceived as augmented chemical reality (AR) on the computer screen or directly mapped on the tissue, creating mixed reality (MR) information that can be seen in real-time.

The researchers also implemented a photometric stereo measuring system to map the molecular information on a 3D sample surface. This system allows for easy access to patients and provides biochemical distributions from the region of interest for disease tissue differentiation during surgical resection. Additionally, the proposed approach is universal and can be applied to non-medical applications such as manufacturing, quality control, or in conjunction with other optical and non-optical modalities.

The approach enables handheld imaging acquisition, real-time processing, and reconstruction of molecular information, and allows for a smart and intuitive visualization of the data using AR and MR. The solution offers new opportunities and can be a potential tool for real-time molecularly specific clinical diagnostics and molecular boundary demarcation.

This work outlines a new future direction for Raman-based applications and puts Leibniz IPHT at the frontier of technical developments in vibrational spectroscopy and clinical translation.

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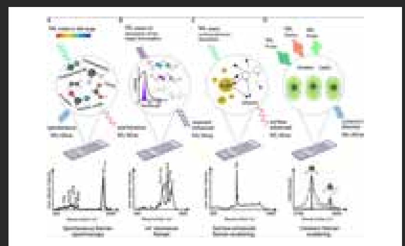
TrAC Trends in Analytical Chemistry



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Trends in Pharmaceutical Analysis and Quality Control by Modern Raman Spectroscopic Techniques

Anja Silge, Karina Weber, Dana Cialla-May, Lisa Müller-Bötticher, Dagmar Fischer & Jürgen Popp

This review paper discusses and explains new developments in Raman-based analytics that are especially important for modern pharmaceutical applications and procedures. The first section introduces Raman modalities that have a lot of potential for on-site applications in the pharmaceutical sector as well as in research and development. The second section offers an overview of innovative Raman spectroscopic instruments and the wide range of possibilities in terms of their analytical capabilities and identifying sample features. The third section will go into greater detail on photonic data science, which is a key factor in the development of Raman-based technology and helps to standardize Raman spectral analysis.

This review article was published in the Special Issue "On-site an *in vivo* Instrumentation and application of TrAC Trends in Analytical Chemistry". For a broad and application-oriented readership, important trends and novelties in Raman-based analytics with a focus on pharmaceutical applications are presented and explained. Thus, the interest in the three main topics of Leibniz IPHT, biophotonics, fiber optics and photonic detection, is promoted and a broad attention for optical health technologies is generated.

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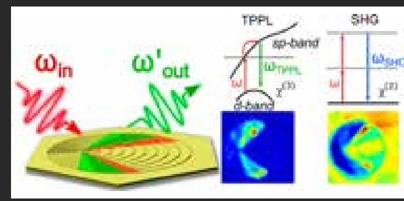
Nano Letters



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Nonlinear Optical Signal Generation Mediated by a Plasmonic Azimuthally Chirped Grating

Parijat Barman, Abhik Chakraborty, Denis A. Akimov, Ankit Kumar Singh, Tobias Meyer-Zedler, Xiaofei Wu, Carsten Ronning, Michael Schmitt, Jürgen Popp & Jer-Shing Huang

This publication presents an innovative approach to study the plasmonic enhancement effect in nonlinear signal generation (NSG) from gold gratings. Plasmon-enhanced NSG requires specially designed plasmonic nanostructures to optimally mediate the optical near and far fields such that maximum NSG efficiency can be achieved. In this context, plasmonic gratings are one effective type of nanostructures because they provide well-defined lattice momentum for photon-to-plasmon coupling. How to design a suitable plasmonic grating for nonlinear signal generation is, however, challenging because NSG processes can involve multiple frequencies coving a wide spectral range. To address this issue and find the optimal grating design, an azimuthally chirped grating (ACG) platform is particularly suited as it provides azimuthal angle-dependent grating periods and offers a spatially resolved plasmonic enhancement effect for NSG. This work studies the enhancement effect of plasmonic ACGs for surface-enhanced two-photon excited photoluminescence (TPPL) and second harmonic generation (SHG).

The capability of ACGs to serve as a spatially and spectrally resolved antenna that mediates the far and near optical fields of multiple input and output beams at different frequencies is demonstrated. The results show distinct spatial distributions of SHG and TPPL signals, revealing the difference in the underlying mechanisms. This information is valuable for the targeted design of effective plasmonic nanostructures for other nonlinear optical processes like, e. g., the molecule-sensitive coherent anti-Stokes Raman scattering (CARS). By understanding the complicated nonlinear enhancement effect of plasmonic nanostructures, the team aims further to design nanostructures for surface-enhanced CARS with sensitivity down to the single-molecule level.

This study is the result of a successful collaboration between the two Research Departments Spectroscopy and Imaging as well as Nanooptics. Here, the know-how of the Spectroscopy and Imaging Research Department in nonlinear spectroscopy and imaging with the competencies of the Research Department of Nanooptics in plasmonics complement each other in an ideal way. Furthermore, this study is also of major importance for the

Publication Highlights 2022

Collaborative Research Center CRC 1375 NOA where Leibniz IPHT is a central partner of.

The work was funded by the CRC 1375 NOA (Subprojects C1 and C5).

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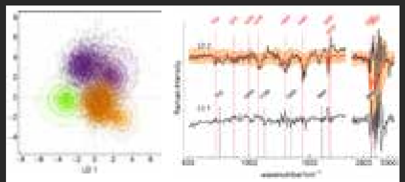
Analytical Chemistry



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Looking Inside Non-Destructively: Label-Free, Raman-Based Visualization of Intracellular *Coxiella burnetii*

Nancy Unger, Simone Eiserloh, Frauke Nowak, Sara Zuchantke, Elisabeth Liebler-Tenorio, Katharina Sobotta, Christiane Schnee, Christian Berens & Ute Neugebauer

Intracellular pathogens often exhibit a complex life cycle and can – protected inside of the host cell – cause persistent infections which are difficult to treat. Currently, the characterization of pathogenesis mechanisms requires labor-intensive methods, most of which involve destruction of the host cell. In this publication, we present a Raman-based, label-free, non-invasive and non-destructive method for localization, visualization and even quantification of intracellular bacteria in three dimensions within intact host cells. A *Coxiella burnetii* infection model was used to demonstrate the potential of the method. *C. burnetii* are obligate intracellular bacteria that cause the zoonotic disease Q fever in humans. Quantitative analysis at different time points after infection allowed the researchers to follow the infection cycle with the transition from the metabolically active large cell variant to the metabolically inactive, but infectious small cell variant around day six post infection. During the course of infection, a gradual change in lipid composition was observed.

The publication contributes to the achievement of the key objectives in the Biophotonics program area by presenting an innovative photonic method that can achieve highest specificity, sensitivity, and resolution for basic and applied research applications in the life sciences and medicine.

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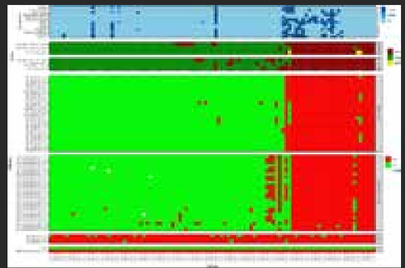
Scientific Reports



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Development of a New Antigen-based Microarray Platform for Screening and Detection of Human IgG Antibodies Against SARS-CoV-2

Sindy Burgold-Voigt, Elke Müller, David Zopf, Stefan Monecke, Sascha D. Braun, Katrin Frankenfeld, Michael Kiehntopf, Sebastian Weis, Thomas Schumacher, Mathias W. Pletz & Ralf Ehricht

Strategies to contain the current SARS-CoV-2 pandemic rely on molecular and serological testing in addition to vaccination. For any kind of serological test development, the search for the optimal antigen is essential.

The paper describes the verification of a new protein microarray with different commercially available preparations of important antigens of SARS-CoV-2. Antigens of other pathogens for which there are widely available vaccines were also included.

The optimized assay was used to determine the immune status of previously tested individuals and/or the vaccination status after COVID-19 vaccination. Microarray evaluation of the antibody profiles of COVID-19 convalescents and post-vaccination sera showed that the IgG response differs between these groups and that the choice of test antigen is critical for assay performance.

In addition, the results showed that the immune response is highly individual, depends on several factors (e.g., age or sex), and is not directly related to disease severity. The new protein microarray provides an ideal opportunity for parallel screening of many different antigens of vaccine-preventable diseases in a single sample and for reliable and meaningful diagnostic tests, as well as for the development of safe and specific vaccines.

The publication is about the development of a method for application in clinical diagnostics, specifically the use of biosensors by means of microarrays, a core topic at Leibniz IPHT. In this context, scientific results are translated into products, i.e. a real translation takes place. The publication has achieved a lot of resonance in the media on different channels

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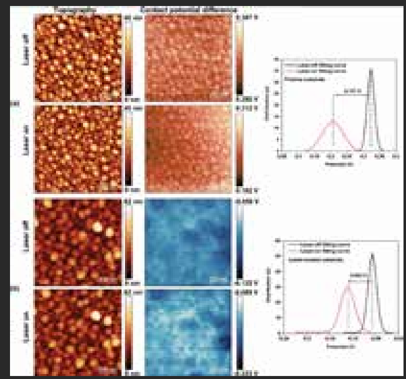

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Targeted Suppression of Peptide Degradation in Ag-Based Surface-Enhanced Raman Spectra by Depletion of Hot Carriers

Xiaobin Yao, Christiane Höppener, Henrik Schneidewind, Stephanie Hoeppener, Zian Tang, Axel Buchholz, Annika König, Selene Mogavero, Marco Diegel, Jan Dellith, Andrey Turchanin, Winfried Plass, Bernhard Hube & Volker Deckert

This paper introduces an efficient suppression method of peptide degradation using iodide demonstrated by a systematic surface-enhanced Raman spectroscopy (SERS) study of a small peptide in aqueous solution. Remarkably, a distinct charge separation-induced surface potential difference is observed for SERS substrates under laser irradiation using Kelvin probe force microscopy. This directly unveils the plasmon-induced catalytic effect of Ag-SERS substrates. Based on the presented results, it is proposed that plasmon-induced catalysis dominates peptide degradation in SERS experiments in liquid and the suppression of typical SERS sample degradation by iodide is discussed by means of the energy levels of the substrate under mild irradiation conditions.

Biophotonics is a key research field at Leibniz IPHT and SERS is an indispensable and critical technique for fast and reliable analysis. So far, sample degradation significantly limits the application of SERS in bio-applications. The surface potential motivated suppression of peptide degradation using iodide ions of the current study, consequently, is expected to have a major impact on SERS-studies at Leibniz IPHT and in general towards more reliable and reproducible SERS experiments of biomolecules under physiological conditions.

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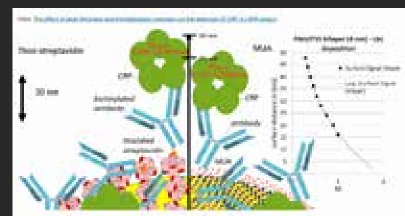
Scientific Reports



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The Effect of Layer Thickness and Immobilization Chemistry on the Detection of CRP in LSPR Assays

Stephan Kastner, Pia Pritzke, Andrea Csáki & Wolfgang Fritzsche

In this work, the potential of localized surface plasmon resonance (LSPR)-based sensing was demonstrated with respect to the detection of a clinically relevant inflammatory biomarker, a C-reactive protein (CRP). For the measurements, the shift of the LSPR peak in the visible wavelength range is monitored (Δλ in nm) and plotted against the time in a sensorgram. First, the nanoparticle-based sensors were investigated for their sensitivity to changes in the refractive index in the surrounding medium (bulk). In addition, the decay length of the particle sensors was determined to better estimate the sensitive range. Since the sensitivity of the particles decreases with increasing distance to the surface, it was systematically investigated how different immobilization approaches for capture molecules for specific analyte detection affect the signal strength and thus the detection limits.

The system presented in this publication can be used for different samples and can also be regenerated. Even with the rapid and direct thiol-streptavidin assisted immobilization of the CRP capture molecule, a detection limit of 300 ng/ml could be achieved, which is in the lower clinically relevant range. Due to the high temporal resolution of the sensorgram, additional, binding kinetic information about the capture-analyte interaction can be determined. Thus, the LSPR system tested here offers great potential, both for clinical studies in the laboratory and point-of-care applications, as well as

Publication Highlights 2022

for more complex studies of affinity and dissociation of interacting molecules in research laboratories or pharmaceutical development.
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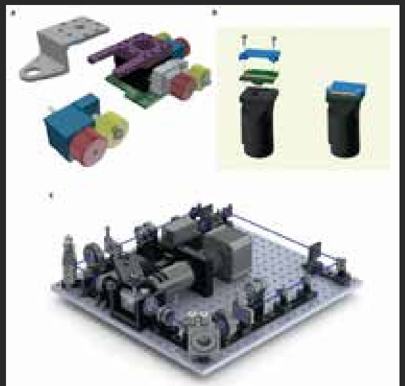
Nature Methods



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CAD We Share? Publishing Reproducible Microscope Hardware

Benedict Diederich, Caroline Müllenbroich, Nikita Vladimirov, Richard Bowman, Julian Stirling, Emmanuel G. Reynaud & Andrey Andreev

This article addresses how microscopes and related hardware designs can be made more reproducible through the use of computer-aided design (CAD) software and improved publication of design files. The introduction of suitable standards for publishing design files alongside the manuscript and that this is also part of the raw data of the scientific work are discussed. The article explains how CAD files can provide most of the information required to reproduce a design of a hardware part or system and can accelerate the dissemination of scientific knowledge, allow reproducibility at lower cost, permit a design's reuse and improvement, and promote innovation in the field of biological imaging. Finally, the article argues that requiring existing CAD files in their original, editable format, as well as exported formats that are easier to view or print, will increase the value to readers and allow greater reproducibility, improvement, and adaptability. Research – in large parts – is publicly funded, hence the results should also be shared with a wider community openly. In many studies this is not the case, which slows down developments and creates a certain exclusivity.

In the manuscript the researchers provide a good practice guide that will encourage the sharing of design files among the scientific community. With openUC2, a modular optical toolbox developed at Leibniz IPHT, new standards have been set in documentation and community building beyond the initial release. The result: More than 300 replications worldwide and an accelerated development in 3D printed photonics. In the scope of this paper the scientists emphasize the importance and advantages of sharing files openly, but also the implication on current business models – which is an important question also for Leibniz IPHT is discussed.
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Philosophical Transactions of the Royal Society a Math. Phys. Eng. Sci.

Polarized Illumination Coded Structured Illumination Microscopy (picoSIM): Experimental Results

Daniel Appelt, Elisabeth Ehler, Sapna Shukla Mukherjee, Rainer Heintzmann & Kai Wicker

Many microscopy methods achieve special capabilities by recording data, separated in time and subsequently processing this data. Confocal microscopy generates optical sections which look like the object having been cut by a sharp scalpel into slices which are only 1/100th as thick as a human hair. In a confocal microscope this is achieved by scanning a focused beam and a localized detection, needing a about 1 Million measured values separated in time. By using structured illumination, sections of similar quality can be obtained but needing only three subsequent exposures recorded by a camera. The images then need to be fused by a calculation to remove the out-of-focus light. In both methods one can think about the necessary sectioning information being encoded in time. At first, with only three exposures the minimum in the number of exposures seemed to have been reached.

In this publication a method is described which allows to obtain optical sections requiring only a single exposure. The aforementioned structured illumination method is used but the information is now not encoded in time but in the orientation of electric field of the light ("polarization"). The scientists used 2 cameras and 4 polarization filters combined with a special polarized illumination. Since the researchers modulate the direction of polarization spatially they can record images containing the necessary sectioning information simultaneously. These are then used to compute an optical section free of out-of-focus light.

In this publication the scientists describe the polarization coded structured illumination microscopy ("PicoSIM") method and show PicoSIM images of optically sectioned muscle fibers.

But nature cannot always be fooled at will. For the method to work well, the fluorescent molecules must be randomly oriented. This is the case for most samples, but not all.

The publication presents experiments performed at Leibniz IPHT by two PhD students (S. Shukla Mukherjee and Daniel Appelt). The PicoSIM method can be extended to other imaging modes (e. g. lightsheet microscopy, high resolution structured illumination, Raman microscopy) and can be made almost arbitrarily fast using femtosecond lasers. But the drawback of requiring non-oriented molecules remains as well as its reduced susceptibility to noise.
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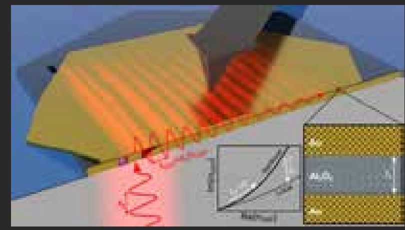
Nature Communications



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Extremely Confined Gap Plasmon Modes: When Nonlocality Matters

Sergejs Boroviks, Zhan-Hong Lin, Vladimir A. Zenin, Mario Ziegler, Andrea Dellith, P. A. D. Gonçalves, Christian Wolff, Sergey I. Bozhevolnyi, Jer-Shing Huang & N. Asger Mortensen

When light is "squeezed" into an ultrasmall gap between two metal plates (< 5 nm), quantum and nonclassical effects emerge due to the nonlocal response of the electron gas in metals. This can lead to the shift of plasmon resonances and introduce additional damping mechanisms, putting a fundamental constraint on the confinement of light. In particular, Landau damping, the energy loss due to relative motion between electron waves and individual electrons, is predicted to be extraordinarily enhanced due to the ultrahigh mode index in the gap. Such damping is typically neglected in classical electrodynamics but becomes significant in nanooptics. While the theoretical treatment of these phenomena is fairly well established, the experimental demonstrations and verifications are still missing.

This work focuses on the experimental verification of nonlocal effects in propagating gap surface plasmon modes in metal-dielectric-metal (MIM) waveguides with an extremely small gap, which is an ubiquitous element of plasmonic devices. To study the effect, conventional material losses due to surface roughness have been maximally suppressed by the use of atomically flat monocrystalline gold flakes (root-mean-squared roughness < 0.5 nm) and ultrathin atomic-layer deposited aluminum oxide films to fabricate the MIM waveguide heterostructures. The complex propagation constant of the gap plasmons was characterized with a state-of-the-art near-field optical microscope. By comparing with the predictions of a hydrodynamic model for plasmonics, the extraordinarily enhanced damping due to the nonlocal effect is experimentally demonstrated. This work is the first experimental demonstration of nonlocal damping in propagating plasmons.

This work demonstrates a successful intra-institute collaboration between the Research Department and the Competence Center for Micro- and Nanotechnology at Leibniz IPHT and a strong international collaboration between the institute and the University of Southern Denmark (SDU). Moreover, this work marks an important step in the combination of Leibniz IPHT's expertise in photonic research with quantum nanooptics.
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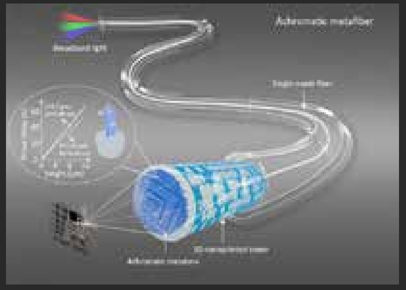
Publication Highlights 2022

Nature Communications



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An Achromatic Metafiber for Focusing and Imaging Across the Entire Telecommunication Range

Haoran Ren, Jaehyuck Jang, Chenhao Li, Andreas Aigner, Malte Plidschun, Jisoo Kim, Junsuk Rho, Markus A. Schmidt & Stefan A. Maier

Dispersion engineering is essential to the performance of most modern optical systems including fiber-optic devices. Even though the chromatic dispersion of a meter-scale single-mode fiber used for endoscopic applications is negligible, optical lenses located on the fiber end face for optical focusing and imaging suffer from strong chromatic aberration. Here we present the design and nanoprinting of a 3D achromatic diffractive metalens on the end face of a single-mode fiber, capable of performing achromatic and polarization-insensitive focusing across the entire near-infrared telecommunication wavelength band ranging from 1.25 to 1.65 µm. This represents the whole single-mode domain of commercially used fibers. The unlocked height degree of freedom in a 3D nanopillar meta-atom largely increases the upper bound of the time-bandwidth product of an achromatic metalens up to 21.34, leading to a wide group delay modulation range spanning from -8 to 14 fs. Furthermore, the researchers demonstrate the use of a compact and flexible achromatic metafiber for fiber-optic confocal imaging, capable of creating in-focus sharp images under broadband light illumination. These results may unleash the full potential of fiber meta-optics for widespread applications including hyperspectral endoscopic imaging, femtosecond laser-assisted treatment, deep tissue imaging, wavelength-multiplexing fiber-optic communications, fiber sensing, and fiber lasers.

In the publication, the scientists have shown that nano-printed metastructures on fibers enable light to be focused achromatically over a broad spectral range. The decisive factor here is the use of the nanoprinting process, which makes it possible to flexibly deposit nanostructures with a very high asbestos ratio on fibers. For Leibniz IPHT, this opens up a new possibility for tailoring the beam properties at the end of a fiber.
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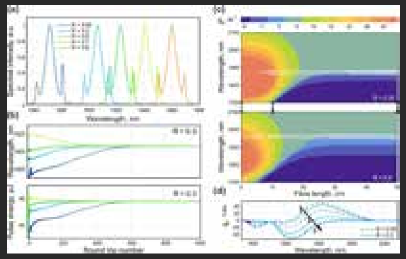
Communications Physics



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Gain-controlled Broadband Tuneability in Self-mode-locked Thulium-doped Fiber Laser

Dennis C. Kirsch, Anastasia Bednyakova, Petr Varak, Pavel Honzatko, Benoit Cadier, Thierry Robin, Andrei Fotiadi, Pavel Peterka & Maria Chernysheva

Involvement of a saturable absorber in ultrafast fiber lasers design presents one of the critical bottlenecks restraining their flexibility, energy endurance and performance scaling. There is a serious urge for improved saturable absorbers or finding new ultrafast modulation techniques. Self-mode-locking may remedy this as no additional components are required other than the rare-earth-doped fiber that is anyway required as an active laser medium. In the work, the researchers have presented an advanced concept of self-mode-locked Thulium-doped fiber laser without any saturable absorber or modulator, generating 350-fs solitons tuneable within 90 nm wavelength range around 1900 nm with 80 mW of average power at excellent long-term stability. This generation was entirely enabled by the unique design of Thulium-doped optical fibers with reinforced ion-pair concentration to ensure ultrashort pulse generation and to break the picosecond barrier. Furthermore, the unique level structure of the Thulium-doped fiber can be exploited in such a way that its absorption and emission wavelength spectrum is shifted by changing the degree of excited Thulium ions. By changing the intra-cavity power through a variable ratio of output coupling, the laser generation wavelength could be adjusted without a spectral filter. The ultrashort pulse generation was ensured within 90-nm wavelength range.

Overall, the researchers demonstrated that the single rare-earth-doped fiber can play three roles in ultrafast laser cavity: gain medium, saturable absorber and enable wavelength tuneability. Such laser design represents a very promising platform for reliable, compact easy-to-operate ultrafast instruments for a variety of applications. Furthermore, translation of the proposed concept to other rare-earth ions can also facilitate streamlined mid-IR laser research.
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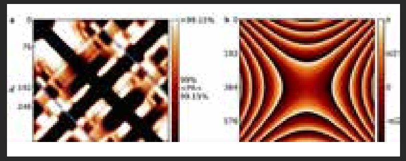
Optics Express



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Near Perfect Focusing Through Multimode Fibers

André D. Gomes, Sergey Turtaev, Yang Du & Tomáš Čižmár

Holographic multimode fiber-based endoscopes aspire to deliver high-quality *in vivo* imaging inside previously inaccessible structures of living organisms, amongst other insightful applications. At its core are holographically synthesized light fields which, after propagating through a multimode fiber, lead to diffraction-limited foci at desired positions at the fiber output.

Focussing behind multimode fibers results, however, in a high-intensity peak contaminated by a certain level of undesired speckle that extends across the complete field of view, while carrying a significant portion of optical power. The purity and sharpness of the achieved foci are determinant for the imaging performance, leading most of the times to the loss of contrast: a “showstopper” for applications requiring imaging with a high dynamic range. Therefore, amongst other activities, the researchers investigate all fundamental and technological limitations preventing from achieving a perfect focus, free from any undesired contamination. In this work, the scientists pursue the perfect diffraction-limited focus generated after propagation through a multimode fiber and explore its limitations. They demonstrate diffraction-limited foci containing in excess of 96 % of optical power delivered by the fiber, which represent, to the best of the teams knowledge, the highest value reported to date. Some of the key factors contributing to this result are the ability to simultaneously shape and control the amplitude, phase, and two orthogonal polarization states of the light field entering the multimode fiber.

In a nutshell, this work provides a guideline to consistently achieve high purity foci with reproducible performance and contains an extensive quantitative and qualitative study on the impact of various conditions of the experimental procedure. Such practical learnings are an essential step towards transferring ideas to instruments. The results have already shortened the path of the technology to the users in neuroscience within the framework of Leibniz IPHTs transfer endeavour “DeepEn”.
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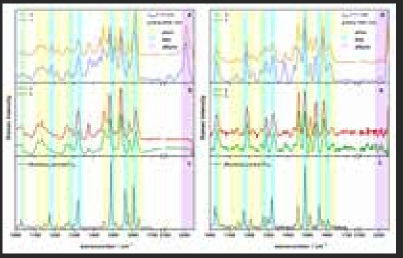
Publication Highlights 2022

Nature Communications



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Outpacing Conventional Nicotinamide Hydrogenation Catalysis by a Strongly Communicating Heterodinuclear Photocatalyst

Linda Zedler, Pascal Wintergerst, Alexander K. Mengele, Carolin Müller, Chunyu Li, Benjamin Dietzek-Ivanšić & Sven Rau

Photocatalysts are of fundamental importance both in large-scale chemical analyses and in metabolic processes in living organisms. Therefore, understanding how they work is of utmost importance not only to optimize photocatalytic processes but also to develop more stable, selective, and efficient photocatalytic systems. In this work, among other things, essential electron transfer processes of photocatalytical systems were understood by special spectroscopic investigations of three structurally similar photocatalysts that differ only in their bridging ligand. Contrary to the prevailing opinion in research so far, it could be shown that not the first electron transfer process, but the speed of the 2nd electron transfer correlates with the photocatalytic formation of NADH from NAD+. A second important finding is that the complex with the fastest photocatalysis is not the one with the fastest intramolecular electron transfer for the first electron. Various processes could be identified that limit the efficiency of the catalyst. This work thus lays the foundation for realizing more stable and efficient catalysts in the future.

In Prof. Dietzek-Ivanšić Research Department, the method of spectro-electrochemistry (SEC), i. e. UV-Vis-SEC, resonance Raman-SEC and transient absorption SEC, among others, was established and used to investigate the dynamics of light-induced charge transfer processes. The mastery of this elaborate, sensitive, and very informative transient absorption SEC, which is, however, experimentally challenging, is unique worldwide. Thus, this unique selling point has promoted the visibility of the institute and has contributed significantly to the successful establishment and defence of the TRR-SFB CataLight and other projects. The above work also builds a bridge to biophotonics as a core competence of the institute because the molecule NADH plays a crucial role in the energy metabolism of living systems. Thus, this work and the method are also highly relevant for basic biochemical research.

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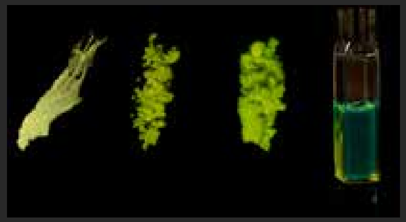
Angewandte Chemie



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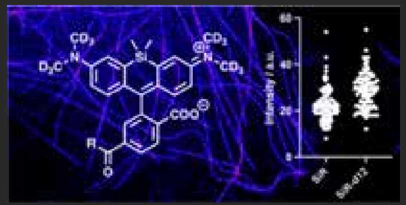
A Highly Fluorescent Dinuclear Aluminium Complex with Near-Unity Quantum Yield

Flavio L. Portwich, Yves Carstensen, Anindita Dasgupta, Stephan Kupfer, Ralf Wyrwa, Helmar Görls, Christian Eggeling, Benjamin Dietzek-Ivanšić, Stefanie Gräfe, Maria Wächtler & Robert Kretschmer

Chemical Science



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N-Methyl Deuterated Rhodamines for Protein Labelling in Sensitive Microscopy

Kilian Roßmann, Kerem C. Akkaya, Pascal Poc, Corentin Charbonnier, Jenny Eichhorst, Hannes Gonschior, Abha Valavalkar, Nicolas Wendler, Thorben Cordes, Benjamin Dietzek-Ivanšić, Ben Jones, Martin Lehmann & Johannes Broichhagen

The development of new molecular markers and fluorophores for the life sciences contributes to an even better investigation and understanding of structures and processes in cells and – perspectively – in tissues. The requirements for such molecular markers and fluorophores are manifold. They should be non-toxic, have characteristic optical properties and high fluorescence quantum yields, and ideally be capable of staining only certain cell types or cell components or of changing their optical properties depending on biologically relevant environmental parameters.

Leibniz IPHT contributes to the development of such innovative fluorophores and markers by characterizing the optical properties of such new molecules in cooperation with synthetic groups, e. g. the groups of Johannes Broichhagen at Leibniz Research Institute for Molecular Pharmacology and Robert Kretschmer at the Chemnitz University of Technology, and thus investigating the applicability of the systems. For example, new deuterated silicone rhodamines were shown to exhibit significantly improved fluorescence properties, in terms of brightness and emission lifetime, as well as reduced bleaching. The studies on novel aluminum-containing fluorophores have also shown that these systems exhibit a fluorescence quantum yield of 1, the highest value ever attainable, which has never been achieved before – for aluminum complexes. Together with fluorescence microscopic investigations, application scenarios of these fluorophores could be demonstrated not only in life sciences but also in materials sciences.

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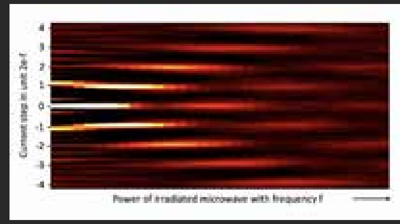
Nature



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Quantized Current Steps Due to the a.c. Coherent Quantum Phase-Slip Effect

R. S. Shaikhaidarov, K. H. Kim, J. W. Dunstan, I. V. Antonov, S. Linzen, M. Ziegler, D. S. Golubev, V. N. Antonov, E. V. Il'ichev & O. V. Astafiev

The quantum mechanical tunneling of paired electrons existing in superconductors through an insulating barrier leads to the Josephson effects which enable various applications ranging from medical diagnostics using magnetoencephalography over new airborne methods for the detection of raw material deposits to voltage standards in metrology.

The complementary quantum mechanical phenomena, the so-called coherent quantum phase slip, although being theoretically described, has so far lacked a clear experimental confirmation. In the frame of a collaboration with international partners, the researchers achieved a breakthrough by a first-time demonstration of pronounced current steps in the current-voltage characteristics under microwave irradiation in a few nanometers wide niobium nitride structure, a so-called superconducting nanowire. These steps occur equidistant at current values of exactly $I_n = 2e \cdot f \cdot n$, where 2e is the electric charge of an electron pair, f the frequency of the irradiated microwave in the Gigahertz range, and integer n denoting the step order. The current steps are caused by coherent tunneling of elementary magnetic flux quanta across the nanowire, resulting in a phase slip of the electron pairs' wave function by 2π along the wire. The measurement data clearly proves the so far controversially discussed coherent quantum phase slip effect and at the same time demonstrates the principle of a future quantum standard for electric current.

This convincing experiment was enabled by the research and development of novel superconducting nanolayers out of niobium nitride with unique properties based on an optimized atomic layer deposition process at Leibniz IPHT. Such ultra-thin, highly-disordered superconducting material lays the foundation for a new generation of quantum technologies exploiting phase slip as well as high kinetic inductance. Examples are the realization of quantum computers and the completion of the quantum metrological triangle. Leibniz IPHT has thereby created a unique technology to be exploited in future research on quantum circuits for an application range that could surpass the one of the Josephson effects.

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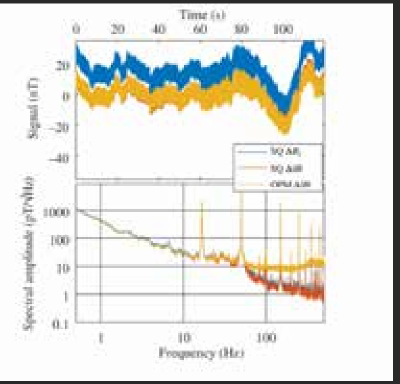
Publication Highlights 2022

Physical Review Applied



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Integrated Optically Pumped Magnetometer for Measurements within Earth's Magnetic Field

Gregor Oelsner, Robbert IJsselsteijn, Theo Scholtes, André Krüger, Volkmar Schultze, Gerrit Seyffert, Gerald Werner, Max Jäger, Andreas Chwala & Ronny Stolz

Ultrasensitive magnetic field detection is important in a wide range of research areas and applications. Important examples are within biomagnetism, where signals from the human brain or the human (fetal) heart support medical diagnostics, and within geophysics, where the precise characterization of anomalies in the Earth magnetic field is used for mineral exploration and archeology.

The article represents a systematic study of a novel photonic quantum sensor designed for targeted applications. The main challenge of ultrasensitive sensor operation within the geomagnetic field – many orders of magnitude stronger than the faint signals of interest – was addressed using a novel readout scheme, a sensor system design enabling portable and battery driven operation, and reducing noise contributions. In extensive studies and with the unique expertise of the project partners from Thuringian industry the scientists implemented a fully integrated demonstrator and evaluated its fundamental detection limits by theoretical analysis. On top, the researchers let the novel demonstrator compete with a state-of-the-art magnetic field detector based on superconducting circuits that is already used in applications. By measurements in a shielded environment, they identified the sources of noise and determined a magnetic field resolution of 140 fT / √Hz in a signal bandwidth of up to 250 Hz which allows detecting signal amplitudes of about eight orders of magnitude lower than the surrounding Earth's magnetic field. A final comparison of the signal quality between the established measurement system and the quantum sensor device demonstrated its performance in a real-world application. Finally, the researchers identified the tuning points for even further improvement in signal quality, bandwidth, and magnetic field resolution in a next-generation device, which is already under construction.

The work summarizes the path from the idea of a novel operational mode of atomic quantum sensors towards the demonstration of the device in real-world measurement scenarios. The article thus sketched the way from a basic of quantum technologies to application of quantum sensors in fields of environmental and life science.

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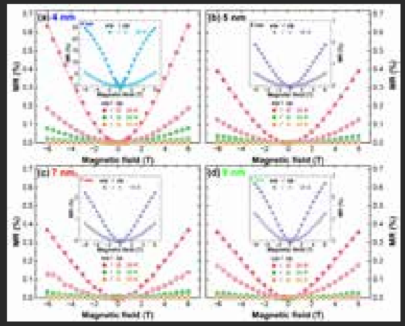
Magnetochemistry



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Analysis of Low-Temperature Magnetotransport Properties of NbN Thin Films Grown by Atomic Layer Deposition

S. V. Vegesna, S. V. Lanka, D. Bürger, Z. Li, S. Linzen & H. Schmidt.

During the last two decades, superconducting nanowire single photon detectors (SNPD) are structured from type-II superconducting thin films. However, there are still fundamental physics questions of how the "hot-spot" detection mechanism in SNSPDs after absorption of single photons works microscopically which are not answered so far. Instead, macroscopic models were applied for technological progress. Finding a microscopic model from the theory side is a challenging task due to the intertwined complexity of the various involved types of excitations in superconducting devices for IR single photon detection. Finally, the researchers wish to relate the "hot spot" formation with photon-induced and with magnetic-field-induced vortex-antivortex pair formation. The study focused on the analysis of interaction and localisation effects on electronic disorder in unstructured NbN in the normal state in temperatures that ranged from 50 K down to the superconducting transition temperature. By modelling the temperature and magnetic field dependence of the MR data, the scientists extracted the temperature-dependent Coulomb interaction constants, spin-orbit scattering energy, and valley degeneracy factor.

The operating region of the SNSPDs in present measuring systems is typically operated very close to critical current which introduces huge dark count. Magnetoconductivity study on NbN enables to broaden the operating regime of SNSPDs by choosing the operational parameters for a specific wavelength by tweaking the critical region of superconducting NbN with applied magnetic field and with applied current during the formation of "hot-spot". The researchers expect that vortices induced by an external magnetic field act as tunable additional players for the photon-induced vortex-antivortex pairs and their respective movement. This work brings the team a step further towards using the magnetic field as an additional "tuning parameter" to increase sensitivity of SNSPDs mainly for single photons with large wavelength.

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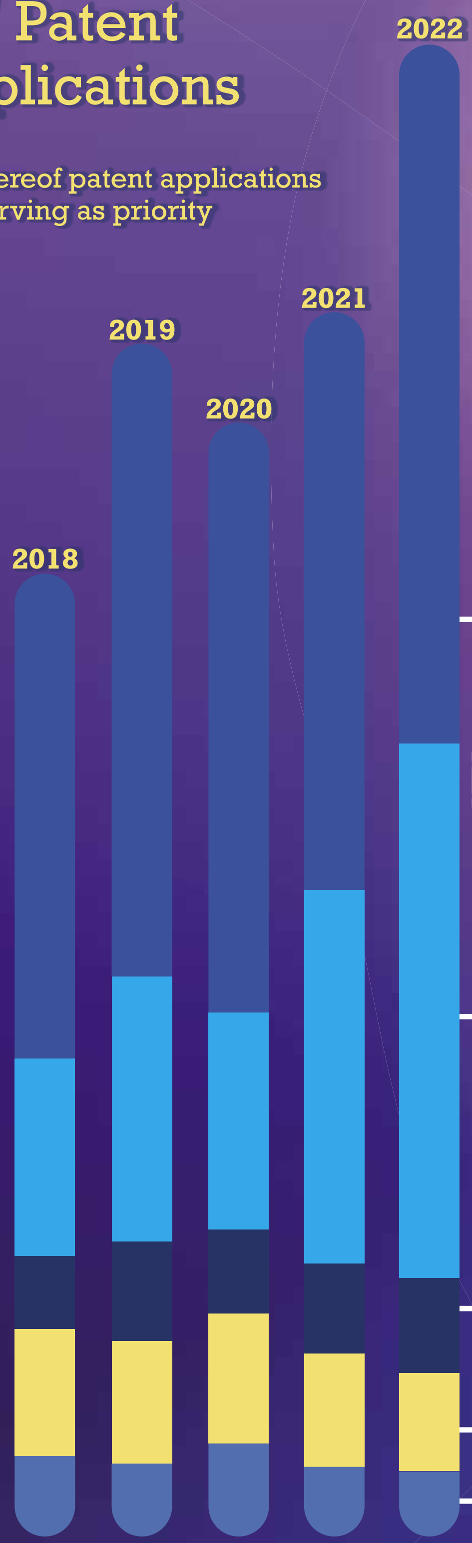
Key Figures of 2022

9 Patent applications

2 thereof patent applications serving as priority



21 Patents granted

8 thereof national

13 thereof international

18,254,784 €
Institutional funding

14,050,293 €
National projects, **5,285,804.95 €** thereof for Leibniz Center for Photonics in Infection Research (LPI)

2,404,155 €
DFG funding

2,627,424 €
Industrial projects

1,669,435 €
EU third-party funding, **124,382 €** thereof from ERA-Net / ERA-NetPlus, JPI etc.

39,006,091 €
Total budget
= 53.20 % Third-party funding

426
Employees

Employees from
35 countries

24 EU financed projects

6 of which coordinated by Leibniz IPHT

3 EU co-financed projects (ERA-Net, Eurostars etc.)

1 Trademark applications

1 thereof national

7 Trademark registrations

3 thereof IR / Community trademarks

51 %
Proportion of international researchers and doctoral students

150
Talks | Posters

40 thereof Invited Talks

13 thereof Keynotes

2 thereof Plenary Talks

95 thereof Contributed Talks

15 Doctorates

8 thereof women

223
Publications in peer-reviewed journals

112
PhD students

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Ultra Fast Fiber Lasers
Dr. Maria Chernysheva

Smart Photonics
Dr. Mario Chemnitz

Institute Personnel 2022

	Full-time Equivalents				
	Institutional Funding	**Third-Party Funding**	**Professors**	**Total**	**Persons**
Scientists	39.81	61.79	8.00	109.60	122
Visiting Scientists[2]	–	–	–	–	48
External Funded Scientists[1]	–	–	–	–	15
External Funded Employees[1]	–	–	–	–	2
External Funded Doctoral Students[1]	–	–	–	–	43
Doctoral Students	6.50	37.35	–	43.85	69
Technical Staff	36.46	36.45	–	72.91	78
Administration	20.48	2.00	–	22.48	24
Scientific Coordination	4.51	4.05	–	8.56	9
PR and Research Marketing	4.50	0.75	–	5.25	6
Executive Committee	1.00	–	0.50	1.50	2
Trainees	2.00	–	–	2.00	2
Total Personnel	**115.26**	**142.39**	**8.50**	**266.15**	**420**

[1] Employees, not financed from Leibniz IPHT payroll or employees, financed by another institution (e.g. University Jena), who have their main working place at Leibniz IPHT.

[2] Scientists, who worked in the legal year 2022 longer than one week at Leibniz IPHT and who are financed by another institution. Key date regulation December 31st, 2022 does not apply.

Budget of the Institute 2022

	spending in T Euro
Institutional Funding: Use	
Free State of Thuringia, Federal	18,254.8
Third-Party Funding	20,751.3
total	**39,006.1**

Institutional Funding: Use

Staff	9,038.1
Materials	4,248.7
Investments	4,968.0
total	**18,254.8**

Third-Party Funding

Federal Ministries of which 383.4 T€ for projects financed by the Leibniz Association of which 5,285.8 T€ for Leibniz Center for Photonics in Infection Research (LPI)	11,888.5
DFG Additionally Leibniz IPHT scientists at the University Jena used DFG-funds of 1,202.6 T€	2,404.2
Free State of Thuringia of which for restructuring in the frame of EFRE 1,075.8 T€	1,800.3
EU of which for EU-Initiatives such as ERA-Net / ERA-NetPlus, Joint Programming Initiatives and more: 124.4 T€	1,669.5
Assignments from Public Institutions	123.5
Other Contributions	361.4
Subcontracting in Joint Projects	22.8
R & D Contract incl. Scientific-Technical Activities	2,481.1
total	**20,751.3**

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from Ideas to Instruments

Leibniz Institute of Photonic Technology

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