reflexion

LEIBNIZ INSTITUTE *of* PHOTONIC TECHNOLOGY // ANNUAL REPORT 2016

Leibniz ipht
LEIBNIZ INSTITUTE *of* PHOTONIC TECHNOLOGY

Leibniz Association

Research, development and selected events at Leibniz-IPHT are supported by:

Prof. Dr. Jürgen Popp //
Scientific Director

Frank Sondermann //
Administrative Director

Dear Reader,

» The current edition of reflexion is the 25th annual report published by our institute. Since its inception on January 1, 1992, the annual report has changed in more ways than just its appearance. In the past 25 years, the Institute has undergone an impressive development. As a member of the Leibniz Association, Leibniz IPHT is firmly anchored in the domestic research scene and is also part of a global network. The current issue is dedicated to the main topic of micro- and nanotechnology. The scientific findings and existing competencies in this field are central components in the study of photonic solutions to problems in the fields of medicine, health, environment, and security, thus shaping the Institute's scientific profile. As always, our scientists report on their current research findings through their expert articles. You can access the articles through our app for Android tablets and iPads, along with the contents of the current issue as well as a comprehensive data sheet and supplementary material.

Here we would like to take a moment to extend our heartfelt gratitude to our colleagues for their ongoing daily work and exceptional commitment. We would also like to thank the Free State of Thuringia and the federal government as well as all our sponsors and partners in the areas of politics, science, and industry for a long-standing close and trusting mutual cooperation. We look forward to further successful collaboration.

Wishing you an enjoyable read,

Jürgen Popp
Scientific Director

Frank Sondermann
Administrative Director

Content

Year in Review 2016

» Leibniz IPHT has expanded its international visibility in the past year through a number of cooperative scientific efforts. Among these are collaborative efforts within Europe-wide research associations as well as cooperation agreements with partners from Brazil, Indonesia, and Australia. At the national level, the Institute solidified its collaboration with universities, research facilities, and industry partners in the field of biophotonics. Below is a selection of events from the review:

» In August 2016 in Fortaleza, Brazil, on Leibniz IPHT's initiative, a joint statement on closer cooperation between Brazilian and German research organizations was formally presented and signed by the representatives of seven participating institutions. With this bilateral partnership, the participants hope to intensify scientific relations between the two countries. In line with its international strategy, Leibniz IPHT has strengthened and further expanded its international collaborative network through arrangements with the Centre for Nanoscale BioPhotonics in Adelaide, Australia, the University of California, and the Institut Teknologi Sepuluh Nopember (ITS) in Surabaya, Indonesia.

» In August, a total of 14 scientists from Leibniz IPHT and the Friedrich Schiller University Jena attended the 25th International Conference on Raman Spectroscopy (ICORS) in Brazil. The Institute was represented by its own stand at the accompanying industrial exhibition. At the conference, Leibniz IPHT hosted a workshop in cooperation with the German House of Science and Innovation – São Paulo (DWIH-SP), the Leibniz Association, Leibniz Health Technologies, and the German Research Foundation (DFG), with the aim of identifying potential future research projects.

» As a partner in several projects successfully launched by the European Horizon 2020 program, Leibniz IPHT made valuable scientific contacts this past year with associates from research and industry. Topics for research projects range from multimodal imaging (MOON) and point-of-care diagnostics (MIB) to artificial glass fiber nervous systems (FINESSE).

» To improve the optical analysis of biological samples, the Jena Biophotonic and Imaging Laboratory (www.bil-jena.de) was established on July 1, 2016, giving scientists unparalleled access to multidisciplinary, multimodal imaging methods. In addition to Leibniz IPHT, the center's associates include the Friedrich Schiller University Jena and the Jena University Hospital. The DFG-funded center is available to research institutes, companies, and universities for questions relating to biophotonic analysis.

» Since April, Prof. Ute Neugebauer has been bolstering research on the subject of spectroscopic diagnosis of infections and sepsis. Prof. Neugebauer was appointed by both the Friedrich-Schiller-University (FSU) and Leibniz IPHT to FSU's Faculty of Chemistry and Earth Sciences as Professor of Physical Chemistry with an emphasis on spectroscopic diagnosis. The chair is tied to the directorship of the research group of the same name at Leibniz IPHT and Jena University Hospital's Center for Sepsis Control and Care (CSCC). Through close cooperation, Prof. Neugebauer has been successful in expediting the transfer of the research findings to medicine.

Congressional evening for the Leibniz Association in collaboration with Leibniz Health Technologies on the topic of diagnosing infection

Formal signing of the joint statement on closer cooperation between Brazilian and German partners

The Bild der Wissenschaft gives a detailed account on the research activities of Leibniz IPHT and Leibniz Health Technologies in the field of sepsis

» As a coordinator for Leibniz Health Technologies, Leibniz IPHT gave the topic of sepsis a prominent place in the Summer 2016 edition of the magazine Bild der Wissenschaft. In a series of articles, the current work on the diagnosis and treatment of infections at both the Institute and the research alliance was reported on in detail and through that made accessible to a broad audience. The magazine has the widest circulation among German-language scientific magazines and reaches approximately 450,000 readers on a monthly basis.

Information on the organizational structure and current key performance indicators can be found on pages 44 to 50.

Data sheets, including a list of specialist articles, are available through the app.

Prof. Volker Deckert, on receiving the Raman Award at the International Conference on Raman Spectroscopy in Fortaleza, Brazil

Outstanding Personnel

In the past year, many of the outstanding achievements of the scientists at Leibniz IPHT have been recognized with international and national prizes, including numerous poster awards for doctoral candidates. A sampling:

Volker Deckert // Raman Award for the most Innovative Technological Development (ICORS 2016)

Torsten Frosch // Bunsen-Kirchhoff Prize for Analytical Spectroscopy (GDCh, DAAS)

Alexej Grjasnow, Mario Kanka, Rainer Riesenberg // Thuringian Research Prize for Applied Research

Thomas Henkel, Ute Neugebauer, Jürgen Popp // Gold medal for iENA 2016 (68th International Trade Fair for Ideas, Nuremberg)

Sandro Heuke // 2016 VAA Foundation prize for outstanding research (VAA Foundation)

Matthias Jäger // Senior Member of the Optical Society of America (OSA)

Guobin Jia, Jonathan Plentz // Silver medal for iENA 2016 (68th International Trade Fair for Ideas, Nuremberg)

Jürgen Popp // Acceptance to the College of Fellows at the American Institute for Medical and Biological Engineering (AIMBE)

Jürgen Popp // Pittsburgh Spectroscopy Award (PITTCON 2016)

Volkmar Schultze // Gold medal for iENA 2016 (68th International Trade Fair for Ideas, Nuremberg)

IPHT – 25 Years

» In January, along with guests from the fields of science, business, and politics, the Leibniz Institute of Photonic Technology celebrated the Institute's 25th anniversary with a ceremony at the Volksbad Jena. Founded in 1992, initially under the name "Institute for Physical High Technology," the Institute is now firmly established on the national and international research scene as a member of the Leibniz Association under the name Leibniz Institute of Photonic Technology.

With its clearly defined research profile of "Photonics for Life" and the challenge of researching from basic principles to practical procedures and systems, Leibniz IPHT has taken on a central role in the research of photonic solutions for issues concerning health, medicine, the environment, and security. Examples of the Institute's scientific successes include high-sensitivity sensors that measure the surface temperature of Mars, the establishment of spectroscopic methods for rapid on-site diagnosis of infection, lensless microscopy, THz imaging as an alternative to controversial naked body scanners, and methods for the production of special fibers for high-performance lasers.

Prof. Jürgen Popp, who has headed the Institute since 2006, confirms this with the following statement: "Our success is due to both our outstanding technological equipment, in particular, the modern fiber technology and micro- / nanotechnology, as well as to the scientific expertise of the Institute's staff. Their motivation and commitment will turn IPHT into a place where ideas are born." Three hundred guests attended the anniversary party at the Volksbad, among them numerous representatives from research, business, and politics, such as Thuringia's Prime Minister Bodo Ramelow; the president of the Leibniz Association, Prof. Matthias Kleiner; and Jena's mayor, Dr. Albrecht Schröter. The anniversary edition 25 Years at the Leibniz Institute of Photonic Technology provides a comprehensive overview of the Institute's research activities over the past 25 years.


Guests from politics and research

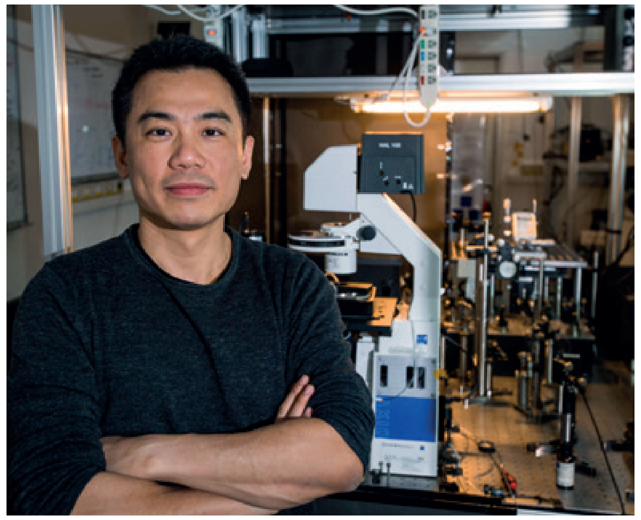
Opening words by Bodo Ramelow


The band JazzFriends

Nanooptics Research Group

Targeted interaction of molecules with light

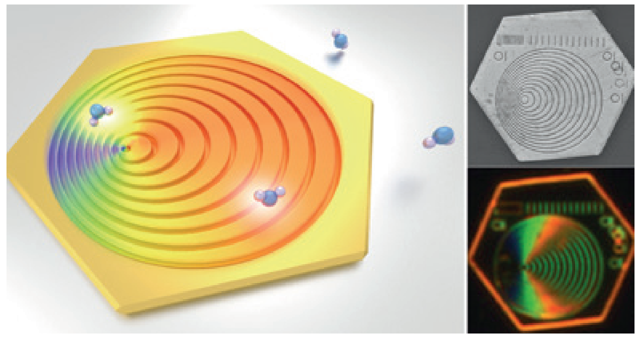
» Dr. Jer-Shing Huang possesses a tool that measures no more than a few nanometers: nanoantennae. At the tiny antennae, made of metal or semiconductor material, he focuses irradiated light into an area whose dimensions are below the Abbe limit, the resolution limit of approximately half the wavelength of the light. In this way, he can intensify interactions of light with molecules that would be impossible or very weak without the nanoantennae. Since November 1, 2016, Dr. Huang has been in charge of the new nano-optics research group, which operates at the interface between chemistry, physics, optics, and micro/nanotechnology.

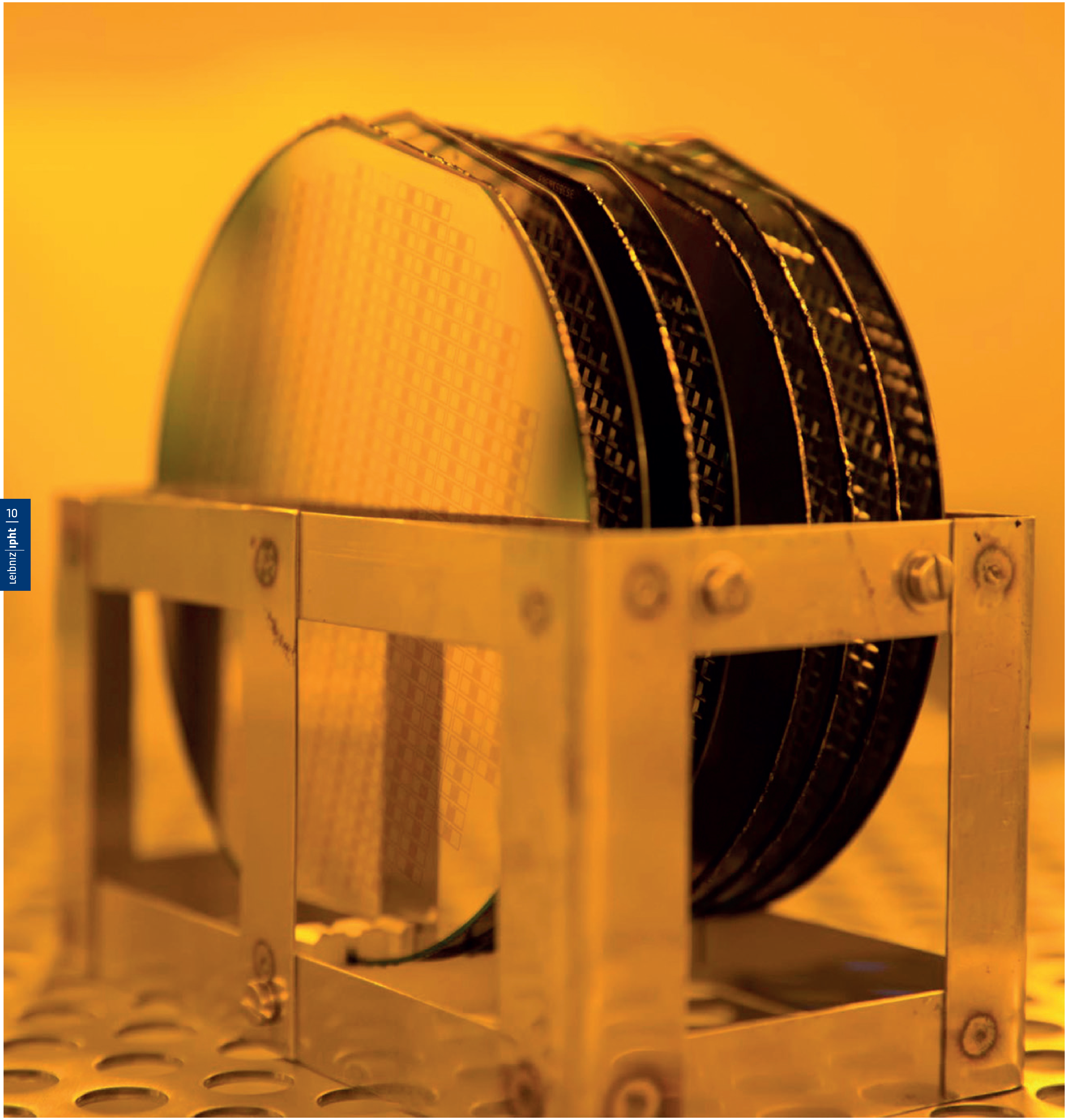

Dr. Jer-Shing Huang in the laboratory in Taiwan

Huang's group examines and controls fundamental processes involved in the interaction of light with matter at the nanoscale. Through the design of the antenna structures, he can influence the intensity, resonance frequency, spatial distribution, and polarization of the light field. To do this, Jer-Shing Huang relies on theoretical modelings with which he can calculate the properties of the field in advance. To produce the complex nanoscale antennae, the research group falls back on established processes of micro- and nanotechnology at Leibniz IPHT.

The research and development of new structuring techniques is also a focus of the work. To characterize the structure-function relationships as well as the interaction processes, the research team uses both a wide range of Leibniz IPHT's spectroscopic techniques and their own methods, such as circular dichroism spectroscopy or fluorescence lifetime spectroscopy. Examples of applications for nanoantennae include the highly sensitive detection of molecular chirality, which determines the biological and therapeutic activity of pharmaceuticals. In the future, computer chips could contain nanoantennae as a new generation of photonic integrated circuits, making them even faster. In addition, nanostructures represent a new kind of tool for surface plasmon resonance spectroscopy or for the manipulation of objects by means of light.

Before Jer-Shing Huang came to Leibniz IPHT, he researched and taught in the area of nanoscale light-matter interaction in the Department of Chemistry at the renowned National Tsing Hua University (NTHU) in Taiwan. Among other honors, he received the university's prize for excellence in teaching and research as well as the prestigious Gold-Jade Fellowship, a distinction awarded to young scientists in Taiwan for outstanding foundational research. In the summer of 2016, as a visiting professor at the Abbe School of Photonics at the Friedrich Schiller University Jena, Huang already had the chance to convince himself of the research site's advantages. "I was very happy to accept the offer for the position in Jena," stresses Huang, who had turned down another offer in favor of Leibniz IPHT. "On the one hand, I feel a very strong connection to Germany through my family. On the other, I find the working conditions here to be outstanding for my research. Jena is a world-class research center with a long history in the field of optics, and I am proud to be a part of it in the future."


Plasmonic Doppler structure



Cleanroom Micro- and Nanotechnology

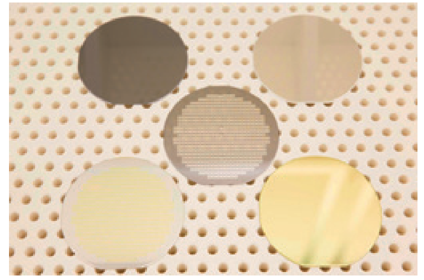
*» **Leibniz IPHT's modern micro- and nanotechnological procedures and processes provide the technological basis for realizing the globally exceptional optical materials, sensors, and components at the Institute.***

The Institute's comprehensive technology chain extends from various structuring techniques, thin-film technologies, and self-organization processes to microsystem technology. The following articles give an overview of how micro- and nanotechnologies can be used to produce, for example, thermosensors, high-performance optical glass fiber sensors, and gold, silver, or silicon nanoparticles as well as microfluidic components for a wide range of applications.

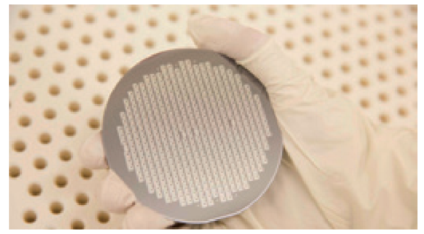
Cleanroom Micro- and Nanotechnology

» State-of-the-art lithography technology and self-organization methods are used in the research and production of complex functional micro- and nanostructures for detectors, plasmonic structures, microfluidic lab-on-a-chip systems, micro- and nano-optical components, and photonic systems. The cleanroom is a special place at Leibniz IPHT. Of its 1500 square meters, 730 are white space area. Here, in the technological heart of the Institute, a combination of thin film technology, nanolithography, and microsystem technology is used to create innovative structural and functional elements for biophotonic and photonic applications from virtually all departments.

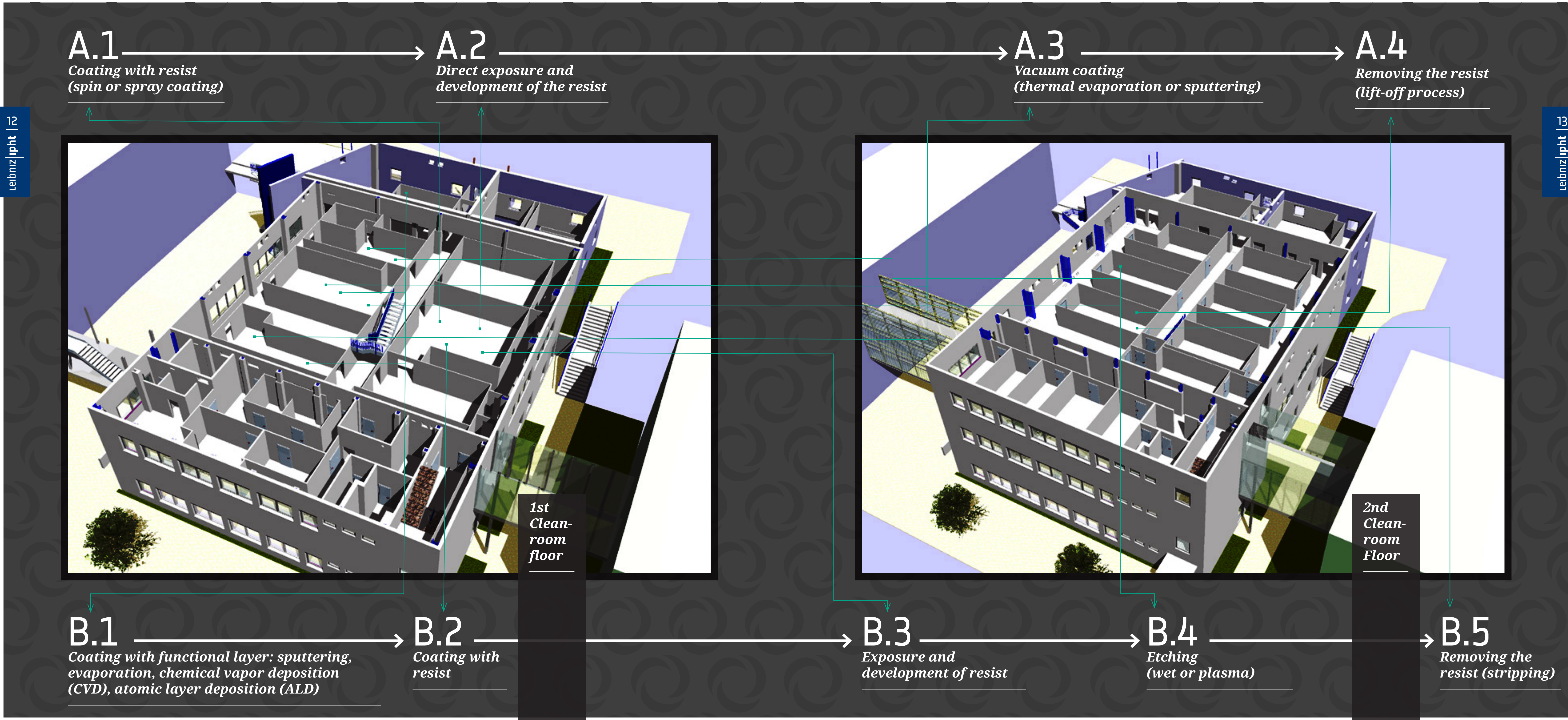
Resist coating in the photolithography



From silicon substrate to a structured wafer



Membrane wafer



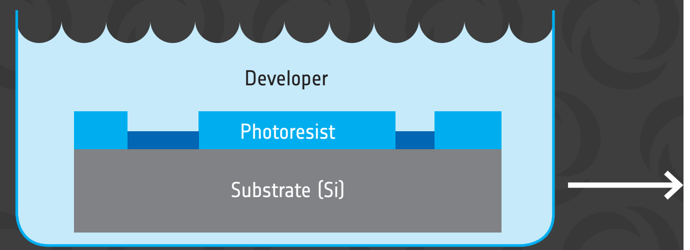
From Substrate to Functional Structure

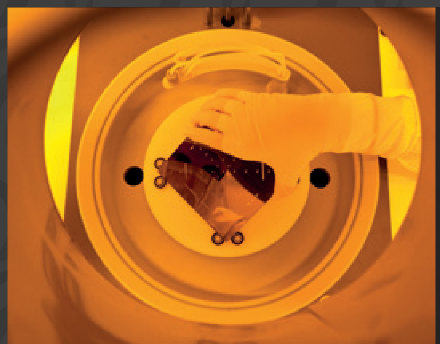
Different photoresists

A.1 Coating with resist (spin or spray coating)

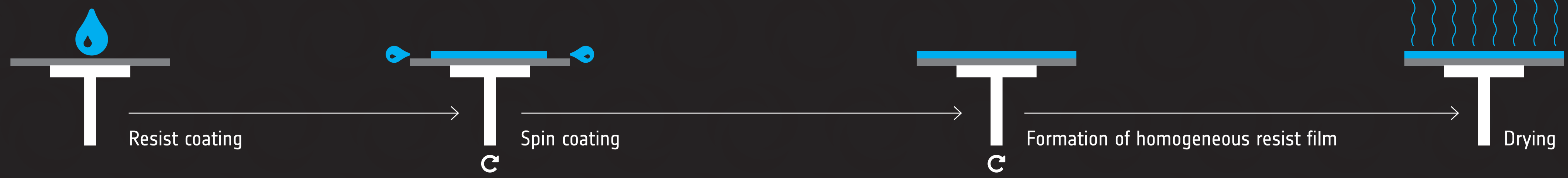
A.2 Direct exposure and development of resist

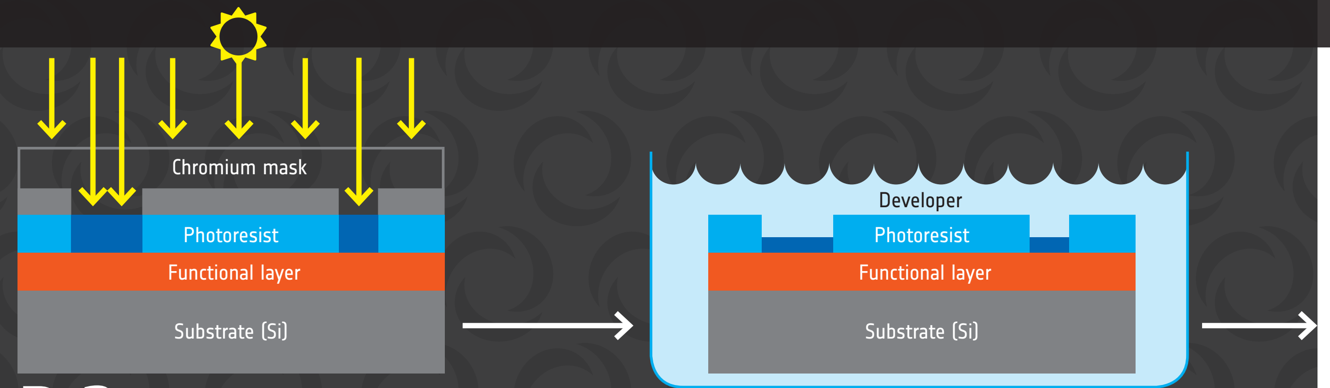
using laser lithography or electron-beam lithography (structure dimensions up to 0.8 µm or 0.03 µm)





Substrate / Mask cleaning





B.1 Coating with functional layer: sputtering, evaporation, chemical vapor deposition (CVD), atomic layer deposition (ALD)

ALD system

B.2 Coating with resist

B.3 Exposure and development of resist

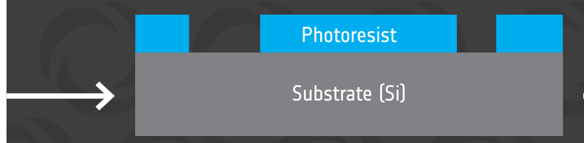
with mask (mask aligner) or wafer stepper (step and repeat), structure dimensions up to 2 µm or 0.8 µm

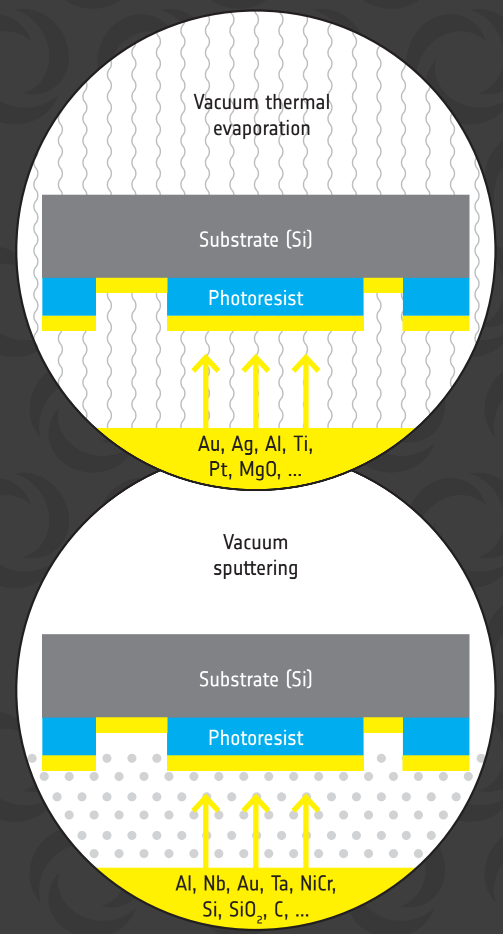
Mask aligner

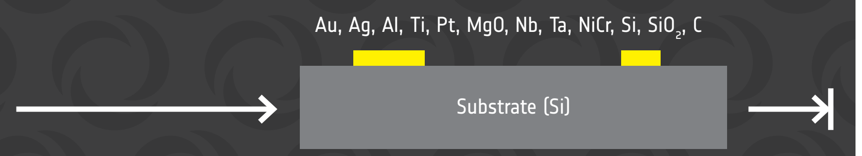
From Substrate to Functional Structure

A.3 vacuum coating (thermal evaporation or sputtering)

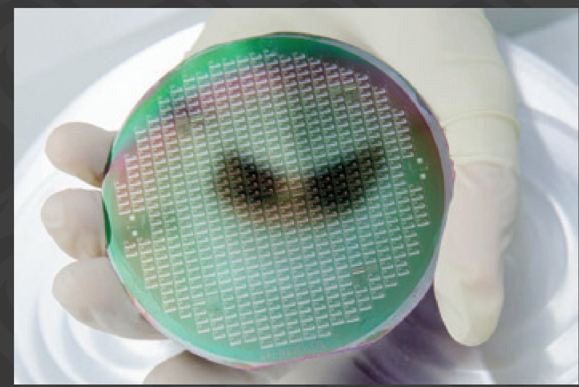
A.4 Removing the resist (lift-off process)

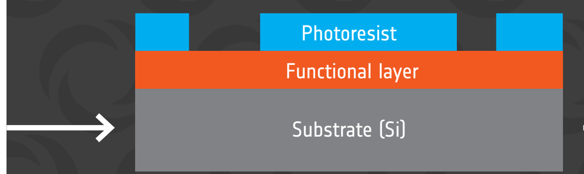


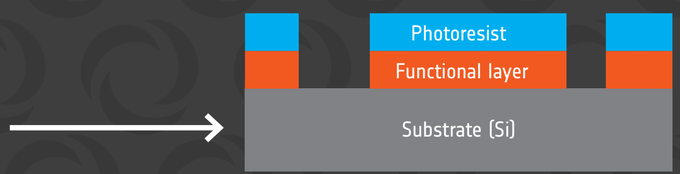





Visual inspection after lift-off


Visual inspection of an etched 100-mm wafer





B.4 Etching (wet or plasma)

B.5 Removing the resist (stripping)

Wafer-Level Nanolithography

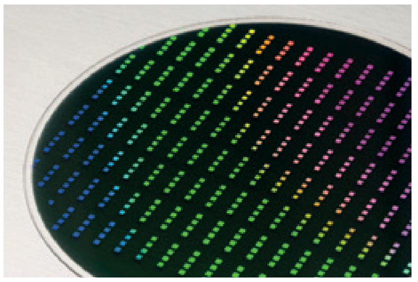
Electron-Beam Character Projection

» Chip-based plasmonically active surfaces for bio- and chemosensory applications are composed of artificial, usually periodic metal structures. The size of the structures lies far below the wavelength of visible light. They are often smaller than 100 nanometers and have lattice periods as low as 100 nanometers.

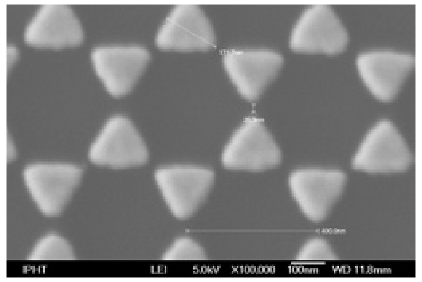
Electron-beam lithography enables the production of small structures on a wafer surface, but the technique reaches its limit with the exposure of large surfaces. Bio- and chemosensorics using surface-enhanced Raman spectroscopy (SERS) require regular plasmonic nanostructures on a square-millimeter surface area. Conventional electron-beam lithography facilities equipped with a narrow Gaussian electron beam need days or weeks to produce the structures. Faster than exposure with a single beam is electron-beam lithography with a variable-shape beam that can, for instance, expose a small rectangle with a single “shot.” Complex structures with non-parallel axes have to be approximated by rectangular decomposition and also require long exposure times with this technique.

The Vistec SB 350 OS electron-beam exposure system operates according to the principle of the “variable shape beam.” It is available on the Beutenberg Campus and is used by the Fraunhofer Institute (IOF) (the facility’s location), the Institute for Applied Physics (IAP) at FSU Jena, and the Leibniz Institute of Photonic Technology (IPHT). As a technology that augments character projection, it is also virtually unique on the research scene. It drastically reduces the previously large amount of time required for the exposure of complex geometric structures. Stencil masks produced through microtechnology are inserted into the beam path of the exposure ray like a aperture. A mask scans a wafer area of 2.5 x 2.5 micrometers per exposure, which allows for the parallel exposure of many structures. The apertures exist in more than 500 different geometric structures, or characters. Combining the characters with each other or with beam shaping allows for a large variety of complex patterns to be reproduced on the surface of the wafer. With character projection technology, the exposure time for a complete wafer with chips consisting of 250 nanometer-sized 2D gratings is reduced from 60 hours to 3 hours. The short writing time reduces time-dependent interferences, resulting in improved quality and homogeneity of the structures produced.

For more on food analysis via Raman spectroscopy, see the article on our app, “Development of food analysis applications based on surface-enhanced Raman spectroscopy.”

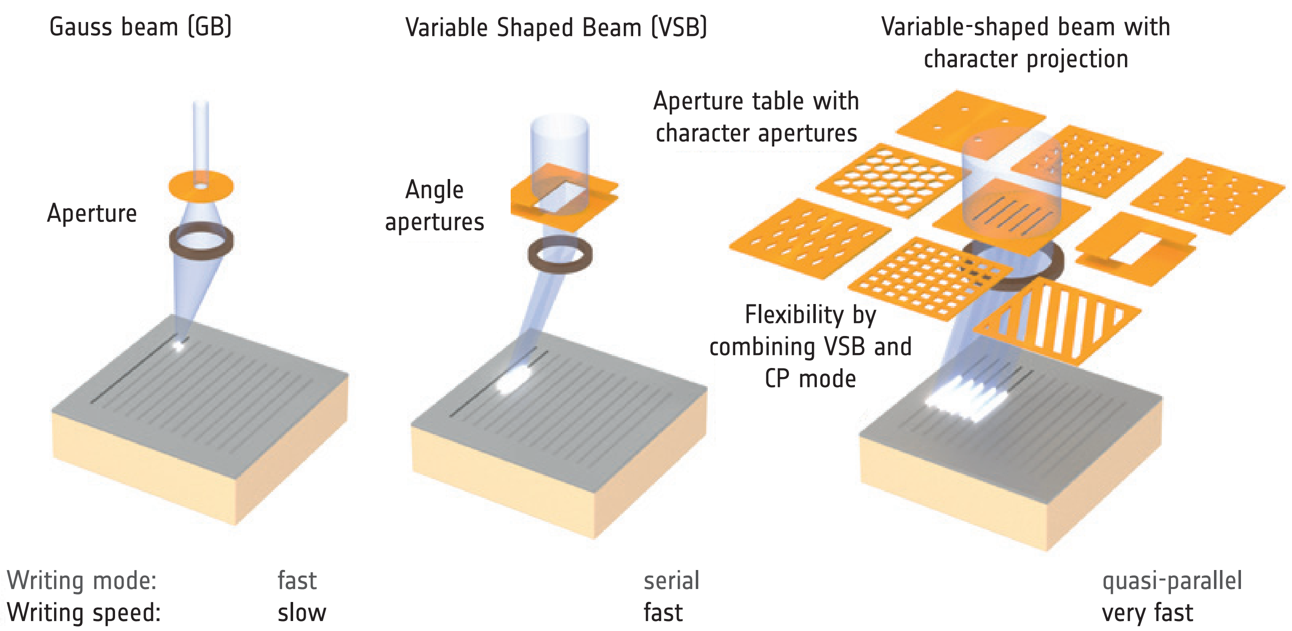


100-mm wafer with SERS structures (grating area 550 square mm, period 250 nm)

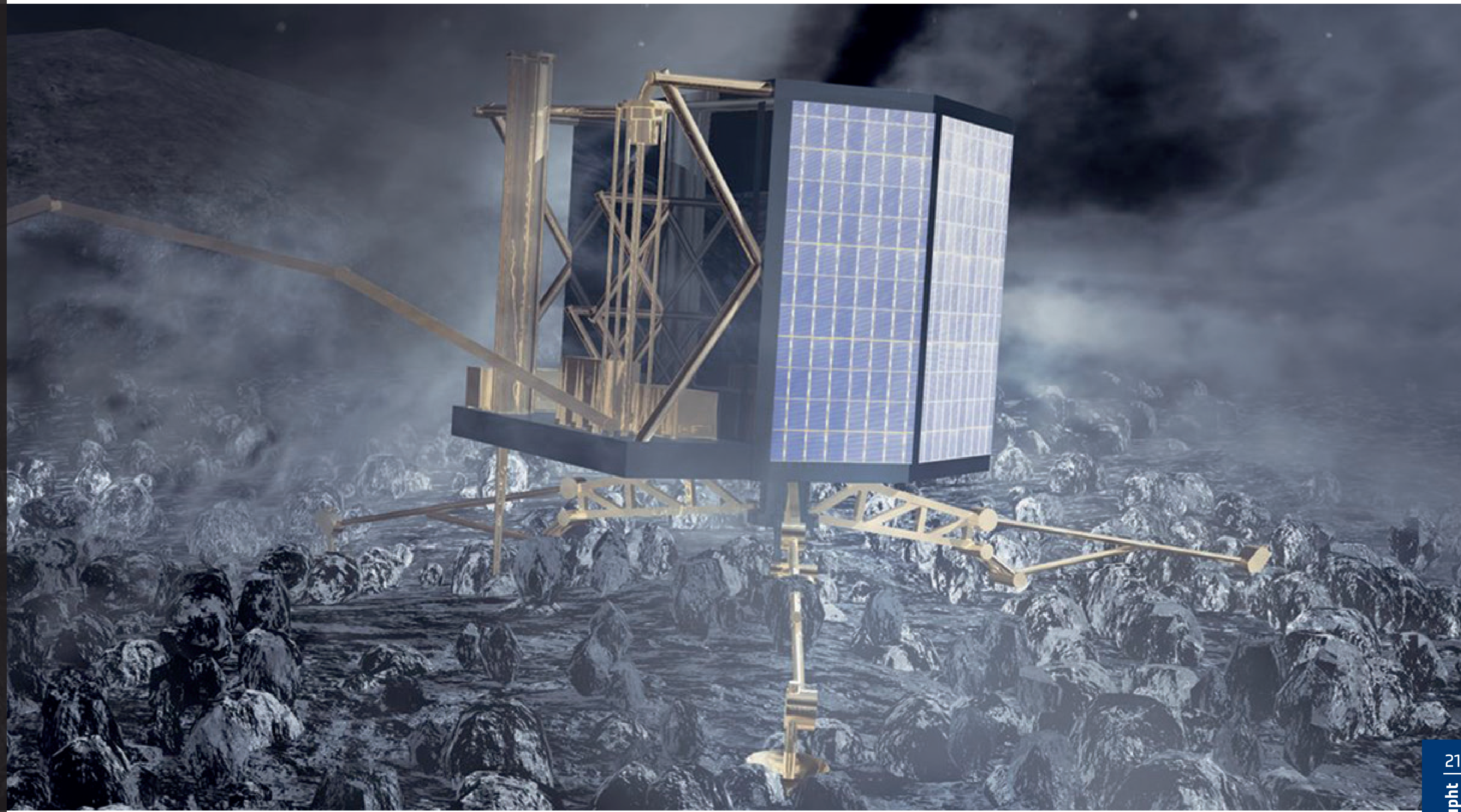


Gold bowties on Si as templates for *TopUp*-SERS, period 400 nm.

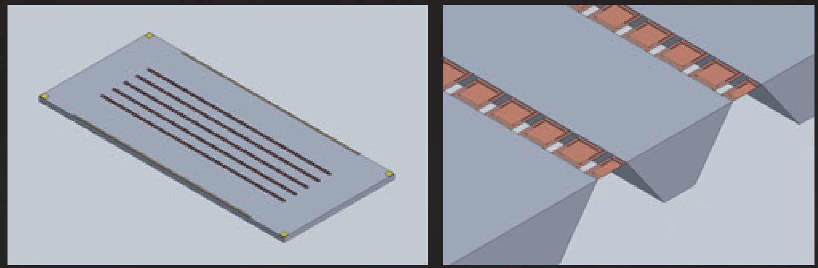
Tracking of prohibited substances in foodstuffs using SERS substrates



Electron-beam lithography: comparison of writing principles source: DLR; http://www.dlr.de



Ultra-thin self-supporting membranes – the core of the thermosensor



Schematic representation of self-supporting as well as structured silicon nitride membranes, extraction occurs through deep etching with leach

Exs. of TIMERS sensors:

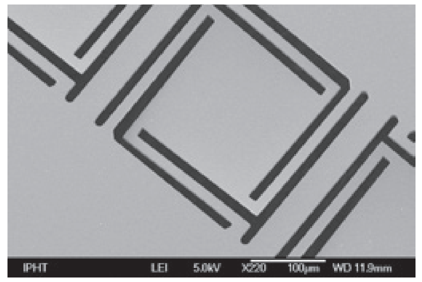
- Thermocouple material base: BiSb, Sb
- Detector format: 5 x 64 pixels, discretely readable
- Pixel size: 250 µm x 270 µm
- Absorber: broadband soot absorber (Ag)
- Operating temperature: 170–300 K (temperature range for proposed space mission; operating temperature on Earth up to 180 °C)
- Wavelength range: 8 to 200 µm (in space, with Ag / soot sensitiv between wavelengths of 0.4 and 20 [40] µm)
- Wafer: 100 mm silicon wafer
- Membrane-type stress-adjusted silicon nitride
- Chip dimensions width: 12.1 mm, length: 26.6 mm
- Receiving surface 190 x 190 µm²

Thermosensors – Emerging into New Realms

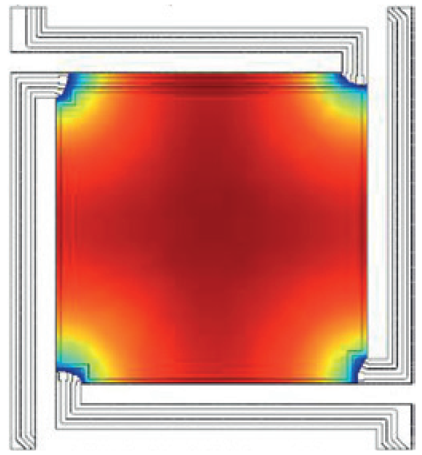
» For more than 50 years, our colleagues at Leibniz IPHT have been developing robust, miniaturized radiation sensors with high detectivity. In space missions, which represent technology drivers, thermopile sensors measure the surface temperature of comets and planets, among other things, without the need for contact. Space aside, future areas of application exist mainly on Earth. When integrated into small measuring instruments, the sensors could be used, for example, for gas analysis with cell phones or as portable accessories in our daily lives.

The thermosensors operate according to the thermoelectric principle. The sensors receive infrared radiation, or heat radiation, which they convert into a very low electrical voltage. Only by connecting many thermocouples to a so-called thermopile is a voltage signal produced that can be evaluated with standard electronics. The sensor design is first optimized through thermal and mechanical simulation calculations. After subsequent layout processing, the miniaturized thermopiles are formed in the clean room on silicon substrates using classical microtechnology. To meet future demand for miniaturized gas detectors, for instance, scientists are researching new production methods for the sensors. Using surface micromachining (SMM), in contrast to conventional depth etching (bulk micromachining), free-standing filigree receiver structures are generated on the surface of the silicon carrier using selective coating and etching processes.

Areas of application to be addressed in the future, such as mobile gas analysis, require powerful, miniaturized infrared sources in addition to high sensor detectivity. The two components form a gas measurement cell that detects which and how much gas is found between the light source and the sensor. For evaluation, a smartphone app compares the measurements with spectra from an online database. These devices or modules, to be developed in cooperation with regional, medium-sized industrial partners, form the basis for portable, high-sensitivity gas analysis systems.



Self-supporting silicon nitride membrane in the form of an etched spiral structure (SEM)



Simulated temperature distribution within the receiving surface of the spiral structure (temperature difference approx. 0.11 K)

Sample handling in a pure nitrogen atmosphere in IPHT's cleanroom at the ALD coating facility

Atomic Layer Deposition

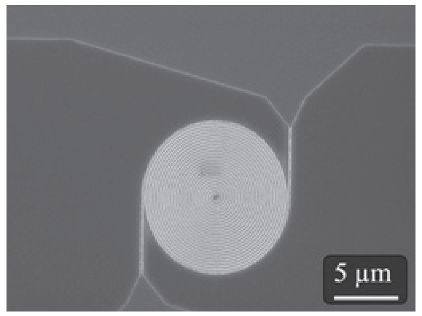
Layer by layer to function

» They are an integral part of high-sensitivity temperature sensors and new ultrafast single-photon detectors. Alternatively, they serve as a protective coating for nanostructures: just a few nanometers thin layers of aluminum nitride, niobium nitride, aluminum oxide, titanium dioxide, or silicon dioxide. With atomic layer deposition (ALD), these ultra-thin layers can be deposited on surfaces evenly and virtually without defect.

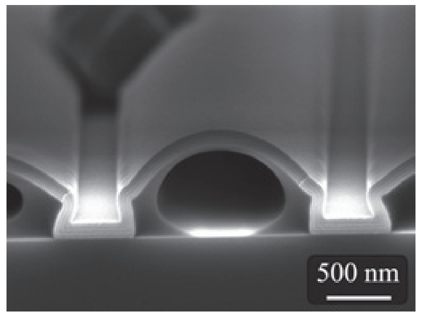
At Leibniz IPHT, the ALD process is a key technology for realizing new applications. For the first time, it was possible to produce high-resolution superconducting single-photon counters for low-temperature sensory application with an approximately 5 nanometer-thin polycrystalline niobium nitride film. In addition, thin layers of silicon dioxide and titanium dioxide are being studied as dielectric functional layers for metamaterials or as a protective coating for plasmonic nanoparticles. Similar to chemical vapor deposition (CVD), chemical compounds are deposited on the surface of a substrate during atomic layer deposition in a reactor. The necessary reactants, also known as precursors, are successively introduced into the reactor in alternating order, in contrast to CVD. This results in a cyclic process that usually consists of four or more individual steps: the first precursor reacts in a self-limiting process with the reactive surface of the substrate to form the first molecular layer. The functional groups of the precursor are designed in such a way that the precursor does not react with itself or with the products resulting from the reaction. Non-binding residues from the first precursor can be removed by flushing the reactor with inert gases. With the elimination of the functional groups of the previously bound monolayer, the subsequently introduced second precursor reacts to the second segment of the intended film composition. Finally, the reactor is again flushed with inert gases. Through the number of process cycles and the choice of precursors, it is possible to precisely and easily control the thickness and chemical composition of the thin films. In classic ALD, the substrate is activated by high substrate temperatures of up to about 500 degrees Celsius. Particularly with temperature-sensitive substrates, the progression to the plasma-assisted ALD process allows for the deposition of layers at temperatures well below 100 degrees Celsius. Compared to other deposition methods such as sputtering, ALD makes it possible to have a highly uniform coating over large substrates, without holes or larger defective areas.

Elevated or deep structures with high aspect ratios, which only allow for uneven coating with conventional methods, can retain their structural integrity with ALD because of its self-limiting precursor reactions. The separate introduction of precursors into the reactor provides an additional advantage in that it allows for the realization of complex layer compositions through multi-stage processes.

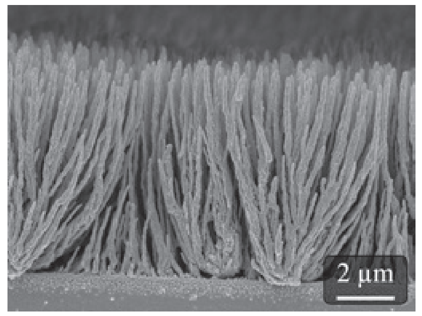
To discover how to use nanometer-thin niobium nitride layers for fast single-photon detection, please check our app for the article "Properties of nanometer-thin niobium nitride layers for ultrafast single-photon detection."



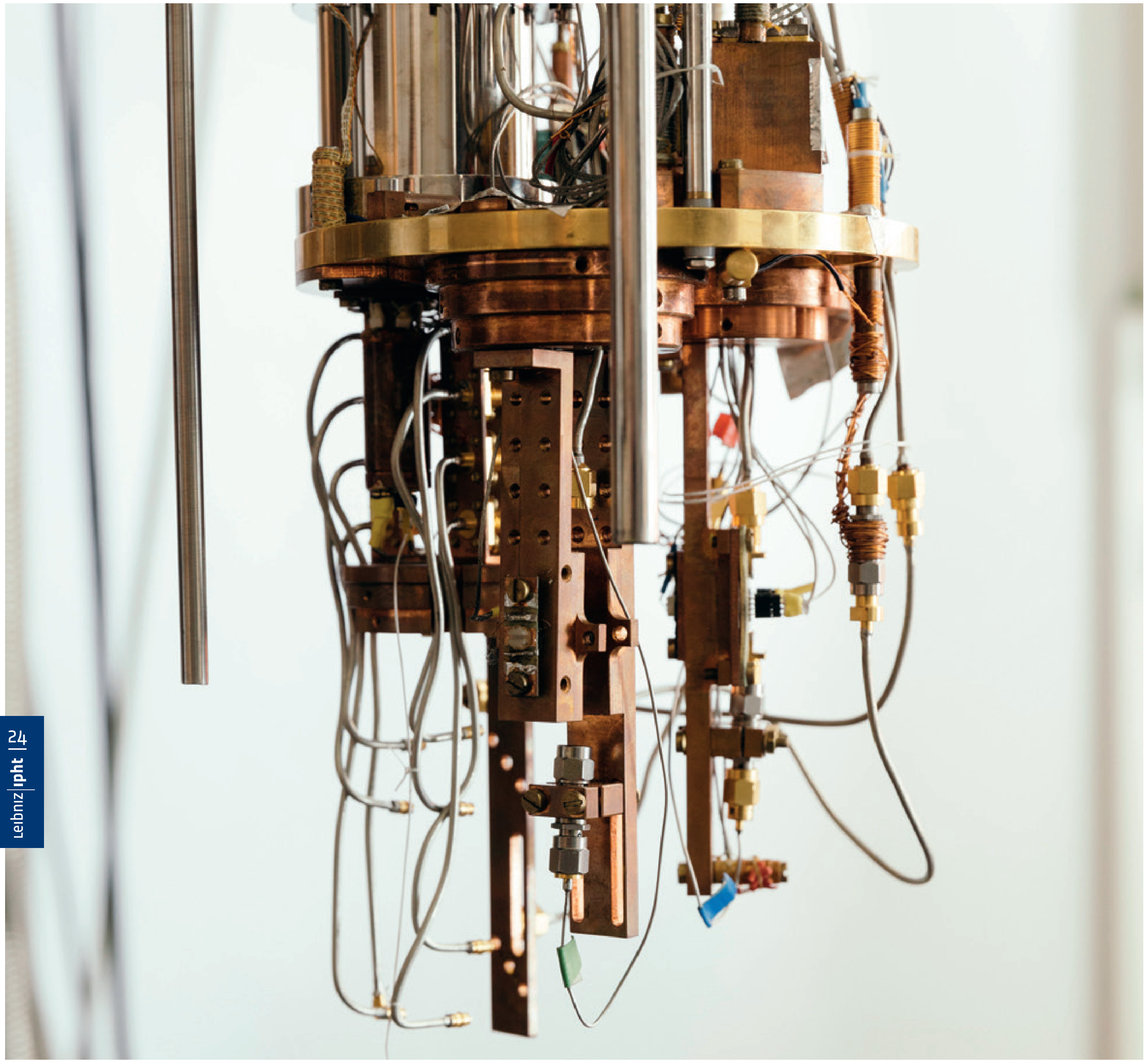
Superconducting niobium nitride coil generated through ALD / electron-beam lithography



Conformal ALD multilayers of Al_2O_3 and TiO_2



Silver-silica hybrid structure produced by metastable ALD



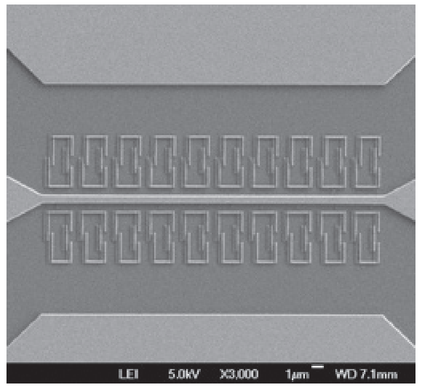
The cooling system's lowest temperature stage at which the effects of light-matter interaction in artificial atoms is measured

Superconducting Nanocircuits as Artificial Atoms

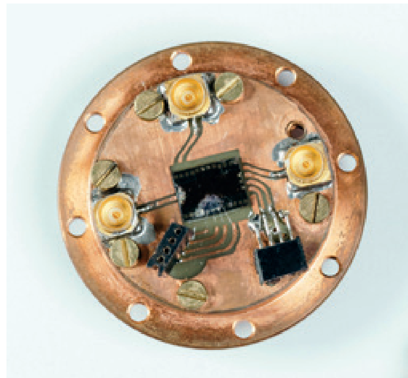
» With their particular physical properties, artificial atoms make excellent research objects for the investigation of basic quantum mechanical effects. The micro- and nano-technological methods established at IPHT enable the reproducible fabrication of artificial atoms, which serve as a basis for fundamental research in the fields of light-matter interaction, quantum optics, detection of individual photons in the microwave range, new metamaterials, and quantum computation. The basic findings from these areas are incorporated, for example, into new high-sensitivity optical detection methods at the Institute.

Although much larger than atoms, microstructured circuits made of superconducting materials obey the laws of quantum mechanics. Like their natural prototypes, the circuits, often referred to as artificial atoms, have discrete, individually addressable atomic energy levels and can therefore absorb light at a specific wavelength. A great advantage of artificial atoms is that scientists can use electric or magnetic fields to precisely control and vary the position of the atomic energy levels, their interactions, and their interaction with the radiated light. At the same time, macroscopic expansion leads to faster decay rates of atomic excitation. These are offset by a much larger dipole moment and consequently a faster light-atom interaction. Due to the small splitting of their energy levels, the superconducting circuits absorb microwave radiation, which is about six orders of magnitude longer than the optical transitions in atoms and molecules. To prevent a thermally excited transition between energies, experimental arrangements for single-photon detection must be cooled to temperatures close to absolute zero. For single-photon detection, an artificial atom is coupled to a superconducting cavity, for example. Through excitation within an electromagnetic field, a standing wave will form inside the cavity under resonance conditions. It is the same principle that produces sound in woodwind instruments. Unlike the audible sound of an instrument, the resonance wavelength of a superconducting cavity lies in the microwave frequency range. The absorption of a single photon in an artificial atom alters the transmission properties of the resonator. This effect is measurable and serves as proof of the absorbed photon. The physical properties of an artificial atom are based on the quantum mechanical effects of superconductivity and on the Josephson effect. The aluminum superconducting ring, which is interrupted by several submicron-sized aluminum oxide Josephson junctions, is applied to prefabricated chips by means of nano- and microtechnological coating processes. These contain previously microstructured feed and control lines. The number and arrangement of artificial atoms on a chip varies. For example, the design in the bottom left image demonstrates the collective interaction of 20 atoms with electromagnetic radiation. The geometrical arrangement of the atoms allows their interaction to be precisely controlled. These structures represent the first step towards new quantum metal materials. The chip is cooled in the cooling system, displayed on the far left, to temperatures a few millikelvin above absolute zero. At these temperatures, the quantum nature of microwave radiation becomes increasingly important. Only then can scientists examine the effects of the interaction of light with artificial atoms.

For more on single-photon detectors in the microwave frequency range, please see our app for the article "Single photon detectors in the microwave frequency range."



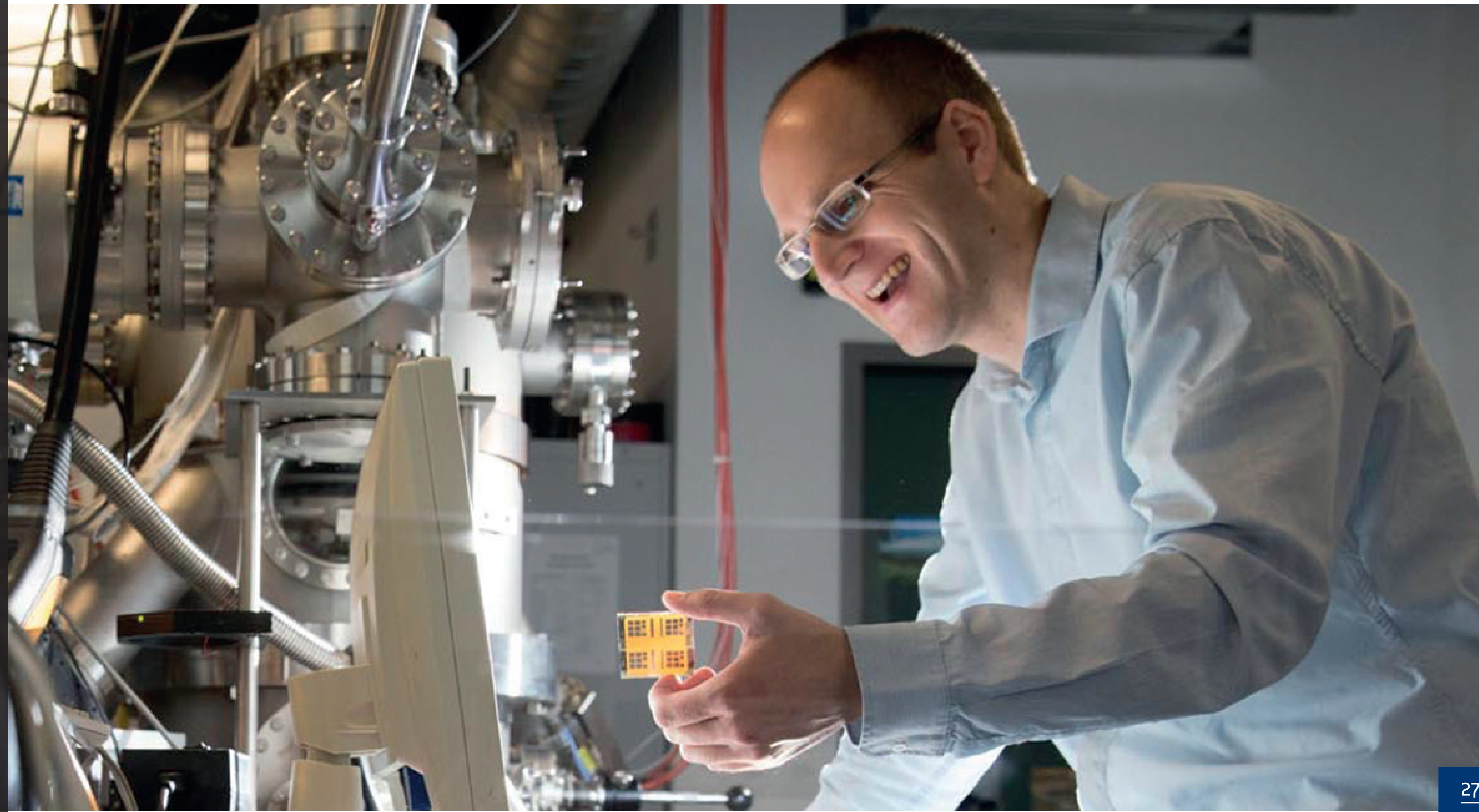
Twenty artificial atoms in the middle of a superconducting cavity



Contacted chip with artificial atoms

Silicon nanowires

Due to their structure and the resulting light scattering, nanowires made of silicon absorb significantly more light in comparison to silicon thin films, especially in the infrared wavelength range. At the same time, they possess outstanding antireflection properties. Dr. Guobin Jia and Dr. Jonathan Plentz use these advantages in a targeted manner to increase the efficiency of thin-film solar cells. The IPHT scientists in the Photovoltaic Systems team are investigating various *bottom-up* and *top-down* approaches that enable nanostructures to be produced on different substrates. Cost-effective carrier materials such as glass as well as scalable, large-scale, relevant manufacturing processes should make nanostructured solar cells a competitive alternative to wafer solar cells.



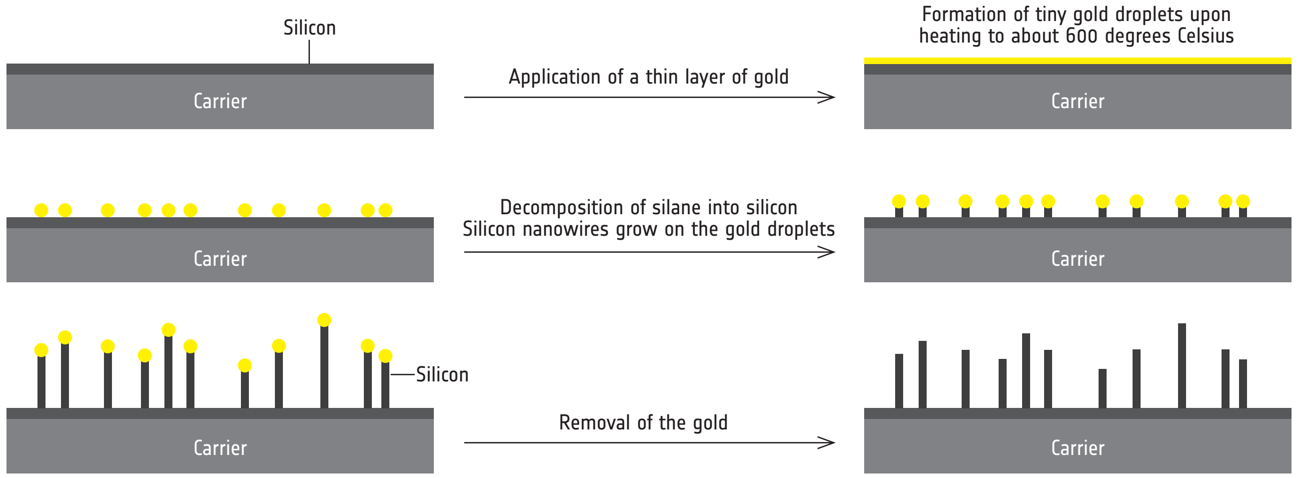
Top-down or Bottom-up:

Using nanotechnology to create silicon nanostructures

» Top-down and bottom-up processes enable the production of nanoscale silicon, whose chemical-physical properties differ from those of the macroscopic solid. Nanostructured silicon on glass substrates is the material basis for new low-cost, efficient thin-film solar cells, which could replace conventional silicon photovoltaics in the future. The technologies established at Leibniz IPHT for the production of silicon nanowires are resulting in the emergence of new applications beyond photovoltaics. The range of applications extends from biophotonic nanostructures for use in medicine and health technology to new sensor and detector materials for basic research. In one innovation project, scientists are performing interdisciplinary research on the antimicrobial potential of silicon nanofiber carpets. In relation to antibiotic-resistant pathogens, the structures could serve as a new form of antibacterial surface coating for implants or operating-room surfaces. Nanostructured silicon is finding uses in basic research as a material for high-sensitivity radiation sensors and particle detectors, as markers for intracellular multi-modal imaging, and in cancer theranostics. Modern nano- and microtechnology are available at Leibniz IPHT for the production of uniformly structured nanowire arrays, nanoparticles, and dense carpets made of monocrystalline silicon wires.

Bottom-up: VLS Method

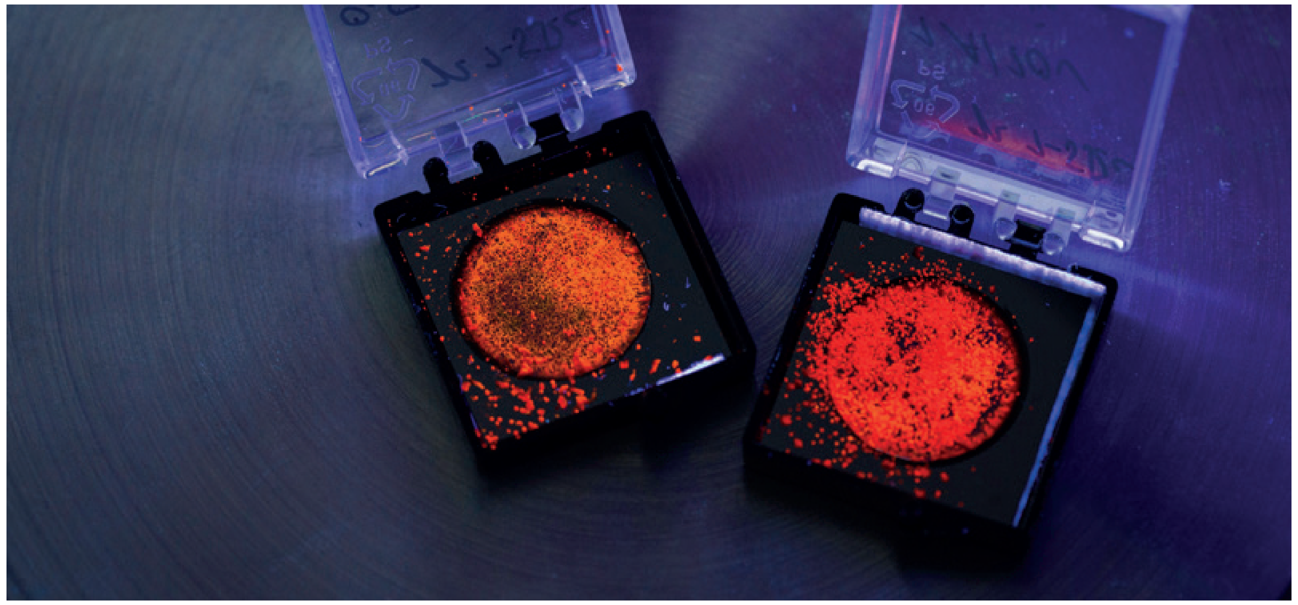
In the vapor-liquid-solid (VLS) process, a bottom-up process, monocrystalline silicon nanowires grow on a carrier substrate. To this end, a two-nanometer-thick gold layer is applied to a silicon-coated carrier through sputtering. Upon heating the carrier to about 600 degrees Celsius in a vapor deposition reactor, the gold melts and forms small droplets that form an alloy with the silicon from the subjacent layer. Silane, a gaseous silicon compound, is then introduced into the reactor, which adsorbs on the liquid gold droplets, themselves only a few nanometers thick. These accelerate the decomposition process of the silane into elementary silicon. As long as silane is available, crystalline silicon wires grow wherever there are gold droplets by the crystal nuclei in the silicon layer. This results in one-dimensional nanostructures whose diameter and position are determined by the specific metal catalyst, which is dissolved once the growth has reached completion.



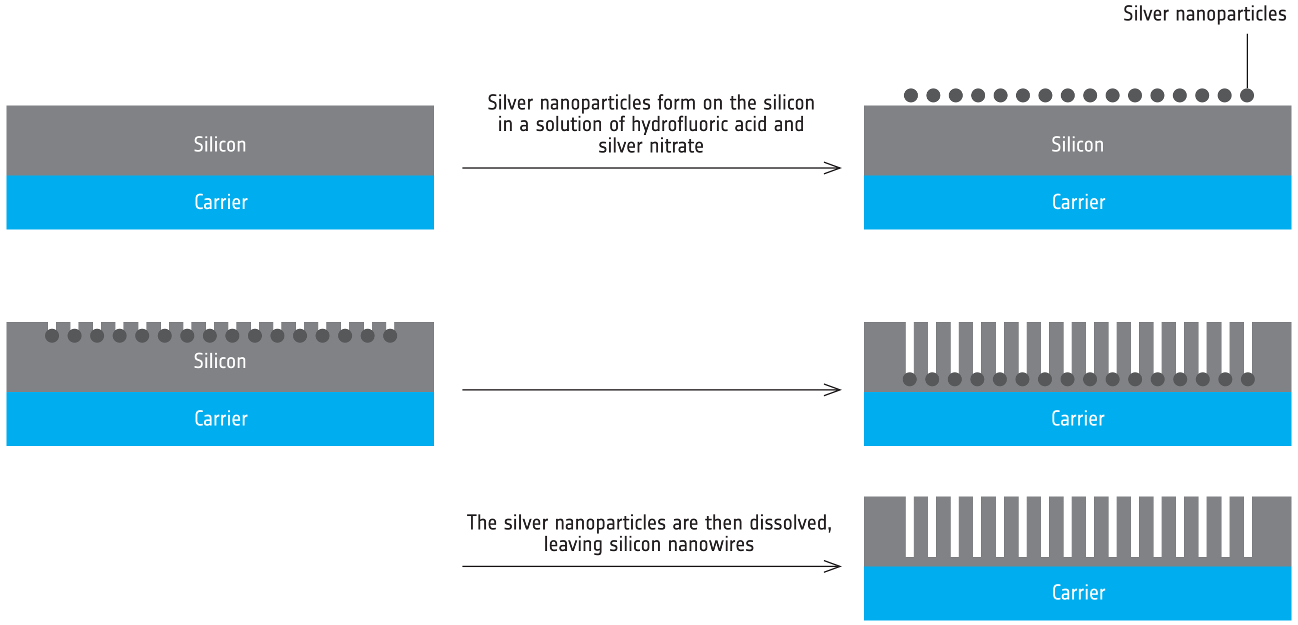
Top-down: Metal-assisted Wet Chemical Etching

In contrast to the *bottom-up* method, in the *top-down* method, the nanostructures are etched from a silicon layer. In addition to silicon wafers, the method mainly uses silicon thin films on glass slides. For nanostructuring, the layer is immersed in a solution of hydrofluoric acid and silver nitrate. If the silicon comes in contact with the solution, randomly distributed silver nanoparticles will form on the surface. At those sites where the nanoparticles are located, they catalyze the reaction of elemental silicon into silicon dioxide. The hydrofluoric acid in the solution etches the silicon dioxide out of the film. The simultaneous oxidation and etching processes produce the silicon wires, which measure several tens of micrometers in length.

These form dense, irregular carpets due to the random arrangement of silver nanoparticles on the surface. As part of the transnational "NanoPhoto" network under the coordination of Dr. Vladimir Sivakov, the process is used to produce photoluminescent silicon nanoparticles that have recently been studied for potential use in cancer theranostics. To produce the highly porous silicon nanoparticles in dimensions smaller than 100 nanometers, the silicon nanowires are comminuted by means of ultrasound after completing the etching process. Due to their large surface area and red-orange photoluminescence, silicon nanoparticles make suitable contrast agents and vehicles for various cancer therapeutics.

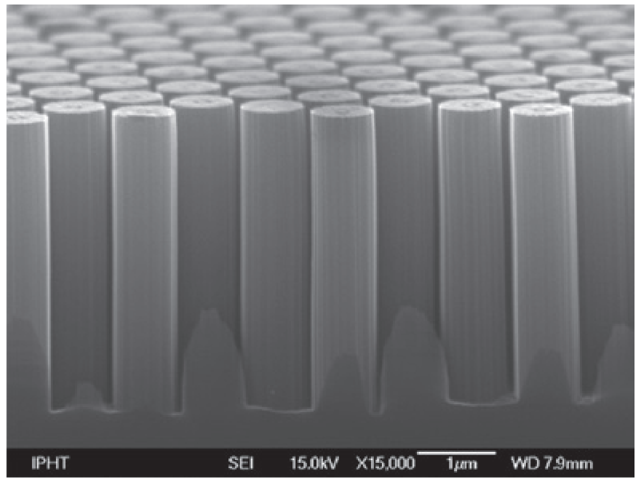


Silicon nanoparticles exhibit red luminescence under ultraviolet light



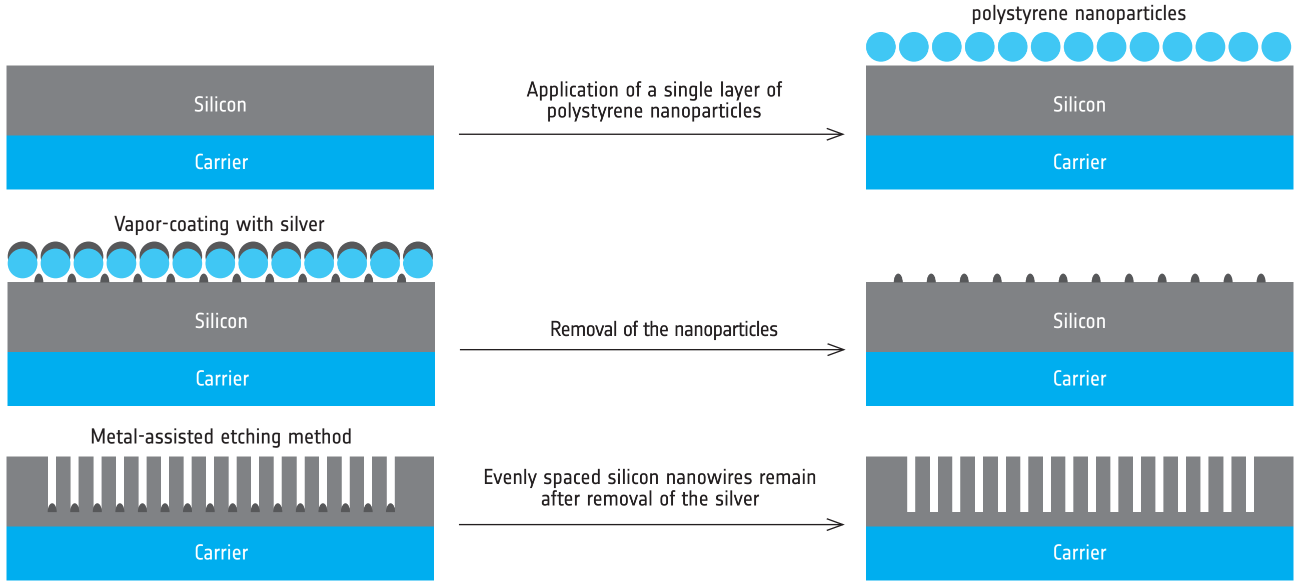
Well-ordered arrays: nanosphere lithography and wet etching

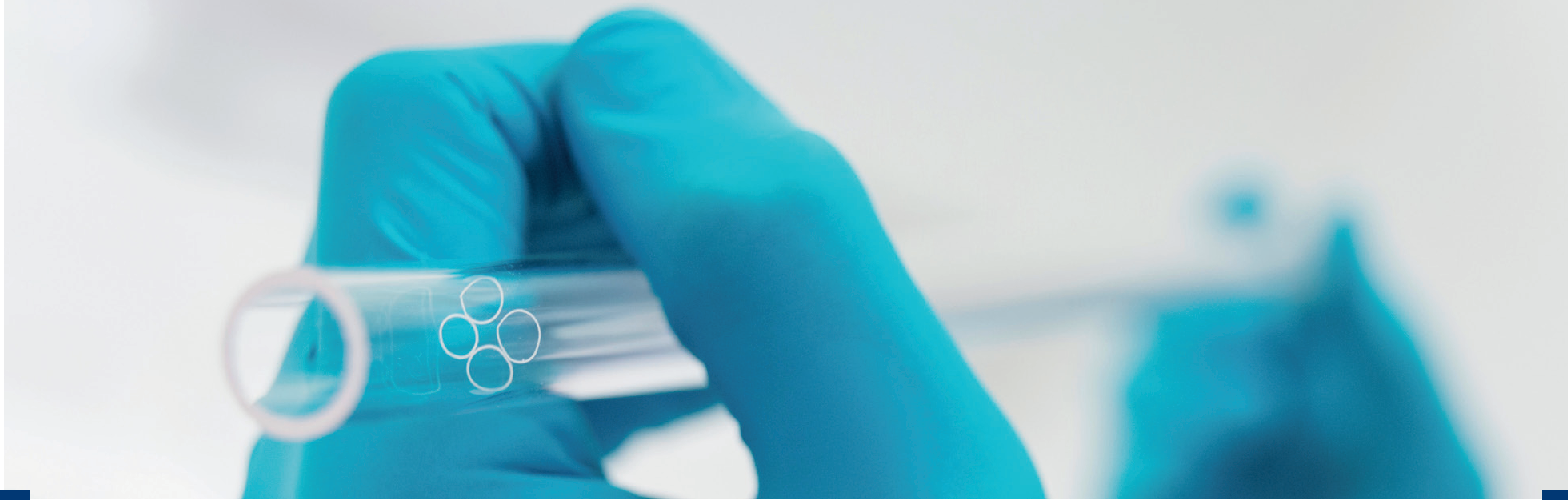
An expansion of the nanosphere lithography method can produce well-defined, ordered arrays of silicon wires. Precisely arranged polymer beads on the surface of the silicon serve as a mask through which the substrate is vapor-coated with silver. In the gaps between nanospheres, the isolated silver forms regular structures on the surface of the silicon layer. Once the polymer beads are removed, the silver becomes available as catalysts for the metal-assisted etching process. The distance and diameter of the silicon nanowires can be adjusted by means of spherical geometry. For both variants of the *top-down* method, the longer the duration of the etching process, the longer the resulting silicon nanowires. With the appropriate protocols, it is possible to produce nanostructures with aspect ratios greater than 100, as in, for example, arrays in which the distances between individual 26-µm-long silicon wires are only about 200 nm.



Uniform silicon wires produced through nanosphere lithography

Innovative high-performance image sensors are an example of one application of nanostructured silicon. To read more, see our app.



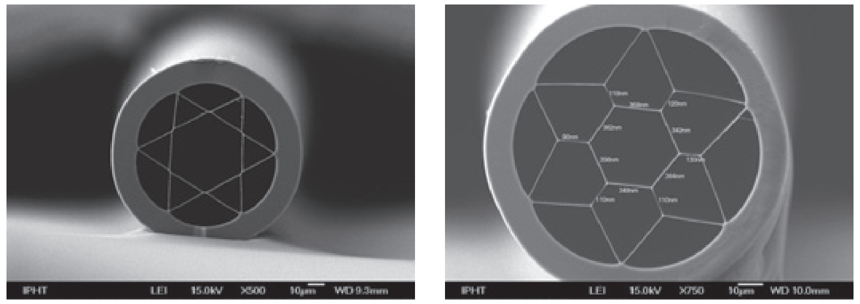


Microstructured Optical Fibers

» Due to their unique optical properties, microstructured glass fibers have great future potential for use in laser and amplifier applications as well as for sensor-based analytical tasks in the areas of biomedical and environmental technology. The complete technology chain at Leibniz IPHT is available to the optical fiber technology team for the production of the specialized optical fibers. In addition to various materials and material compositions that broaden the areas of application for optical fibers, the team researches different manufacturing technologies for producing fibers with specific structural and doping characteristics.

The basis for the customized optical properties of microstructured fibers are application-specific fiber designs that are conceived and developed with the aid of numerical simulations. The technological implementation of the predominantly complex fiber structures is achieved through a multi-stage process. First, a macro-structured preform is created. This contains the basic cross-sectional design for what will later be the fiber, although several hundred times larger in size. The pattern for the structure is fixed in an initial drawing step (cane) and then transferred to the microstructure fiber in the final drawing process.

For the first time, Leibniz IPHT was able to use this technology to produce microstructured fibers that guide UV light with a very short wavelength within a defined hollow core. Defined control of the fiber geometry by means of precise pressure control is the precondition for achieving a close simulation of the design parameters. Fibers of this sort constitute the basis for new fiber-optic sensors for bioanalytical and environmental-analytical problems. A precondition for light guidance are light-filled hollow cores, i.e., geometrically arranged perforated structures with a diameter of a few micrometers. These are formed by means of nanometer-thick glass bridges within the fiber. The nanoscale substructures in the fiber cross-section develop through first positioning extremely thin-walled, precisely manufactured glass capillaries in a glass jacket tube that corresponds to the fiber design for capillary packs. The subsequent drawing step transfers the loose capillary structure of the preform into a compact secondary preform, or cane, by means of local fusion. In this drawing process, negative pressure can be used to maintain control over whether the glass capillaries in the preform fuse selectively or extensively with one another and with the surrounding jacket tube. Since the resulting possible structural variations in the cane also affect the final fiber structure, the first drawing step is an added means for application-oriented fiber modification. The intended fiber microstructure ultimately arises when the cane is twisted to the fiber. A selection of pressure conditions during the drawing process enables further modification of the fiber structure. In the case of "passive" pressure control, the air expands when heated in the capillaries of the sealed cane. The resulting pressure within the capillaries ensures that the cavity is maintained during the drawing step. By contrast, in the case of the "active" fiber drawing variant, defined overpressure on the capillaries leads to the formation of the hollow core in the fiber. The production of fibers with customized micro- and nanostructures requires great technological know-how and many drawing tests.



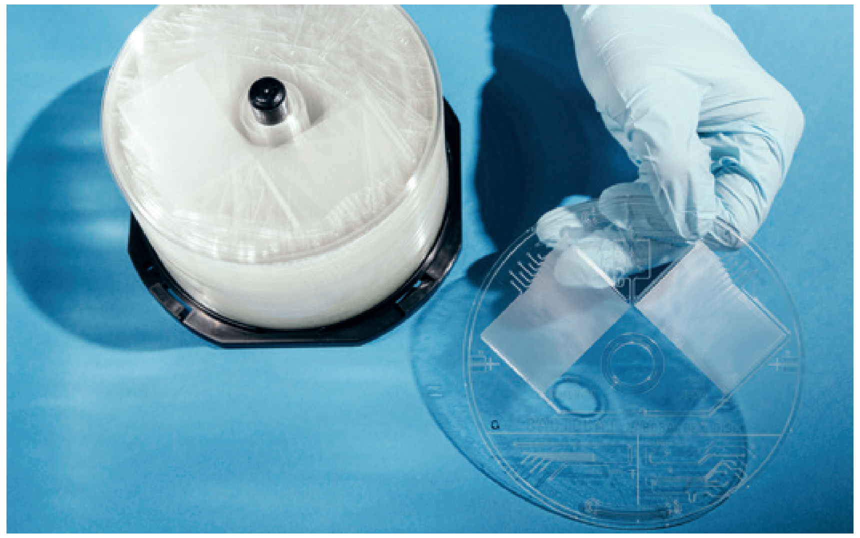
Adjustment of fiber microstructure through defined underpressure and overpressure regulation Electron microscopic image capture of cross sections of hollow core fibers drawn with both active (left) and passive pressure control (right)

To find out how we calculate light guidance in hollow-core fibers, please see our app for the article "Analytical formulas for modes in hollow core fibers."

Microfluidics

Laboratory of the future on a chip

***»** To further improve medical care for the populace, the laboratory of the future will be able to fit into your jacket pocket and deliver test results, such as for a blood test, within minutes. The new light-based detection methods are particularly suited to rapid on-site analysis and diagnosis. Microfluidics offers a wide range of technological solutions for combining modern spectroscopic and optical methods with a compact chip platform. Today, these microfluidic lab-on-a-chip systems (LOC) are already supplementing time-consuming, expensive routine laboratory procedures and ensuring on-site analysis and diagnosis independent of the need for a specific laboratory infrastructure.*



Microfluidic-Laboratory-Disc

The clean room at Leibniz IPHT provides ideal technological conditions for the production of microfluidic components using microsystem technology. Photolithography, wet and dry etching processes, and coating methods such as sputtering are used to structure chip substrates from glass, silicon, or quartz glass. However, the tiny channels and functional components of the microfluidic chips will only form with the exact connection of both the top and bottom of a micro- or nanostructured chip by means of anodic bonding. This results in a solid chemical bond between the two halves, ensuring a high degree of stability in the finished chip. The micro- and nanotechnological processes allow for variable channel heights ranging from approximately 0.1 to 300 microns in glass and up to 800 micrometers in a triple-layer glass/silicon/glass composite system. Channels of different heights can be realized through multi-stage etching processes, for instance, to produce droplets in an oil-water mixture. The fine structures of free-standing nanopore arrays for nanosieves are produced by means of electron beam lithography.

For preparation as one-way microfluidic systems made of polycarbonate, the production process incorporates the use of external service providers for DVD mass production. The format of the microfluidic laboratory disc derived from the DVD standard provides sufficient space for complex screening applications such as the parallel generation, processing, and examination of up to 5000 individual sample drops. The geometry masters for producing these discs with the necessary microstructures are created in IPHT's clean room and provide the master for the production of the half-discs through one of the world's leading service providers for DVD mass production. The subsequent aligned bonding of the two microstructured DVD half-discs into the final microfluidic system is again performed in IPHT's clean room. This reduces pure production costs to less than 100 euros per component for the one-way microfluidic systems.

For the successful implementation of ideas from research and industry, Leibniz IPHT bundles competencies in the areas of microsystem technology, microfluid mechanics, photonics, and automation. The researchers use an efficient design approach to deliver customized, highly integrated microfluidic systems for a variety of applications. Microfluidic functional elements with versatile combination potential are used In addition to standardized chip formats and fluid connection technology. This enables complex process sequences to run on a single chip that can be implemented in optical measurement systems. At the same time, the chip design benefits from the software-based modeling of these microfluidic networks. With in silico modeling, the interaction of the microfluidic functional elements in single-phase flow systems and drop-based systems can be analyzed and visualized even before the chip is produced. In this way, potential design errors are recognized prior to production, and the functionality required for the chip is often already achieved in the first development life cycle.

What is microfluidics?

Small amounts of fluid in a confined space obey a different set of physical laws than those that govern macrofluidic systems. A large surface-to-volume ratio, capillary forces, and a weak turbulent flow dominate the behavior of fluids in ducts a few micrometers in diameter.

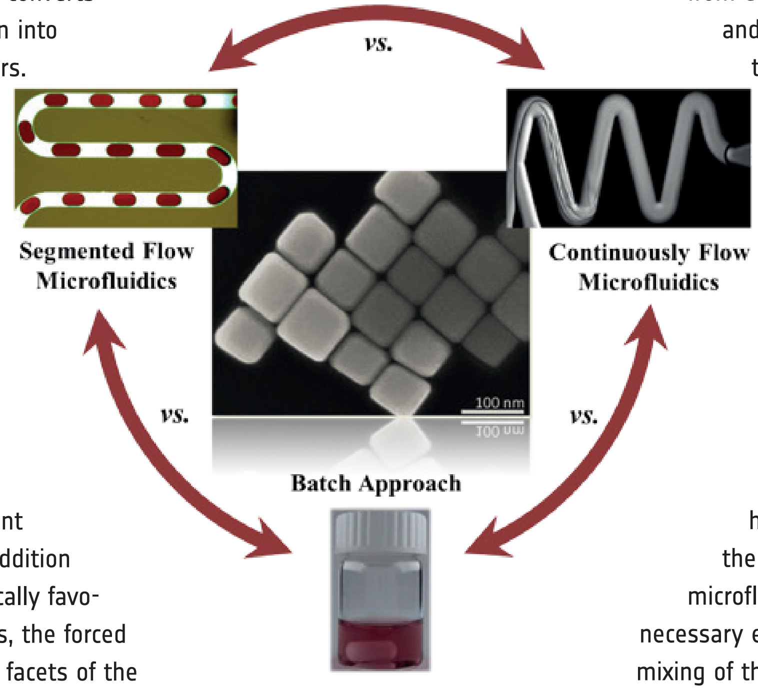
These effects are used in a targeted manner to completely mix two fluids in less than a millisecond. For other applications, cells are separated from a cell suspension and then sorted, rotated, and analyzed by optical spectroscopic methods through the targeted selection and fluidic interconnection of functional elements in the microchannels – all using only a few drops of a sample on a postcard-sized chip (16 x 12.5 mm²).

Nanoplasmonics

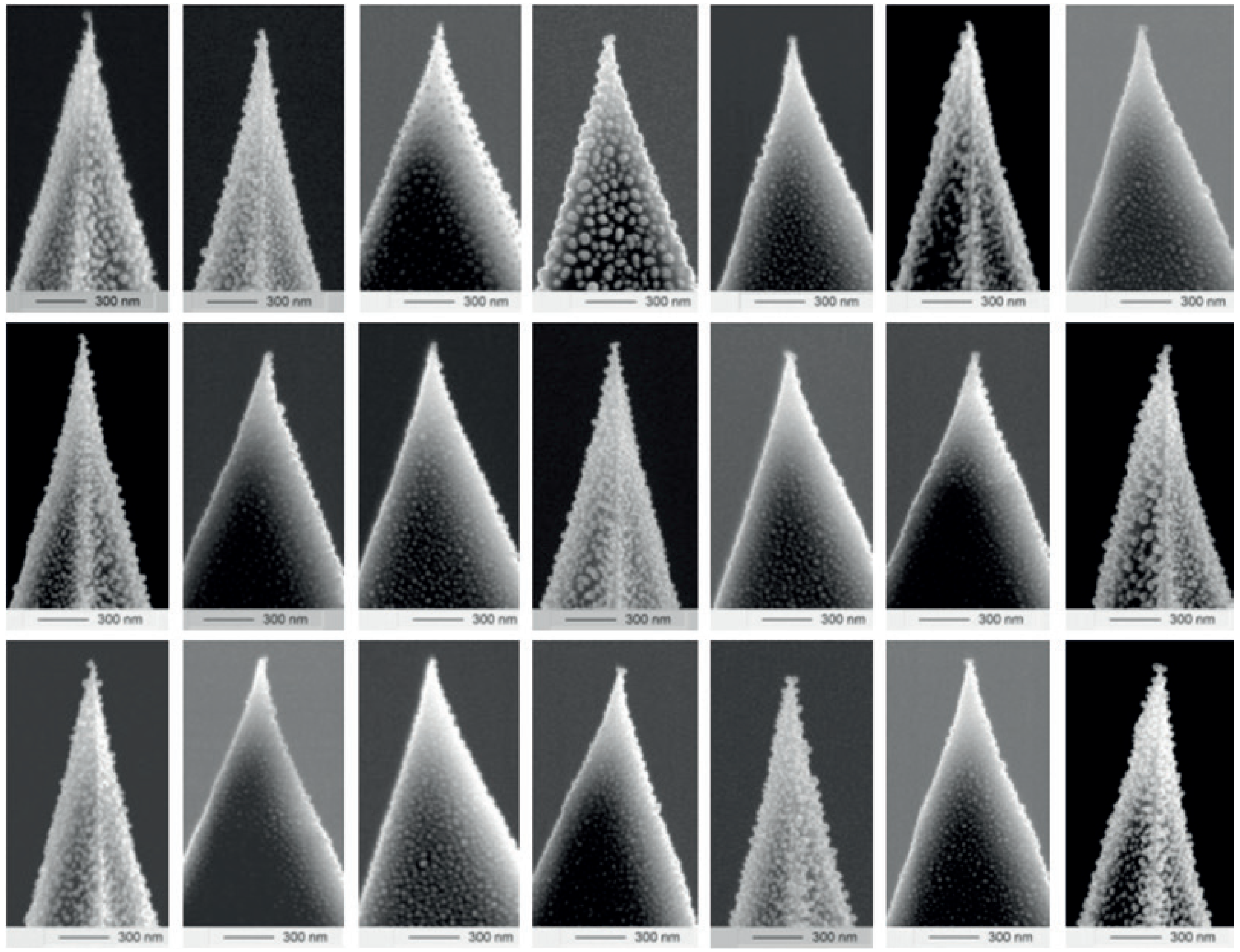
Metal nanoparticles of every shape and color

» In ancient times, people were already using gold nanoparticles to produce richly colored glass for drinking vessels and jewelry. The intense color is created through the interaction of the metallic nanostructures with incident light, which excites coherent vibrations in the conduction electrons in the metal. Since the resonance frequency of these plasmons is mostly within the visible spectral range, depending on their size, shape, material, and environment, the particles absorb and scatter different wavelengths of light and consequently have different colors. With customized metallic nanoparticles, scientists can now accurately control the position of localized surface plasmons and their interaction with light. As optical markers for biomolecules, signal transducers in sensor technology, or optical antennae, plasmonically active nanoparticles provide an outstanding means for the solution of bioanalytical questions.

Leibniz IPHT consequently uses a nanotechnological bottom-up approach to produce gold, silver, platinum, and palladium nanostructures. In this typically multi-stage process, a reducing agent initially converts metal ions in a solution into elemental metal clusters. These aggregate to produce crystal nuclei approximately three to four nanometers in size, known as seeds. In the subsequent step, the crystal nuclei grow in the presence of a weaker reducing agent and metal salt to form nanoparticles of different shapes and sizes. In addition to generating energetically favorable spherical particles, the forced growth of one or more facets of the crystal nucleus produces nanoscale prisms, cubes, rods, and stars. Their anisotropic shape enhances the plasmonic field at specific points on the surface of the particle. Without this field, the high-sensitivity detection of minute refractive differences, the basis for the most frequent sensory applications of plasmonic nanoparticles, would not be possible. The plasmonically active nanostructures are usually produced using a batch approach, in other words, in a reaction vessel. However, complex anisotropic structures such as large numbers of high-quality nanocubes and nanoprisms can be synthesized more efficiently in microfluidic reactors. These reactors allow for the precise manipulation of crystal nucleation and growth, which have very different reaction kinetics and should normally occur apart from each other both spatially and temporally. The ability to set optimal parameters for each reaction and to accurately control them allows for the production of reproducible particles with a highly uniform shape and size. Particularly in the critical step of crystal nucleation, the short diffusion lengths and accompanying high mixing rates within the small channels of the microfluidic reactor ensure the necessary efficient and homogeneous mixing of the chemical substances.



To learn more about the synthesis of plasmonic nanoparticles, see our app for the article "Micro meets nano: efficiency enhancement of the synthesis of anisotropic nanoparticles using microfluidic devices."



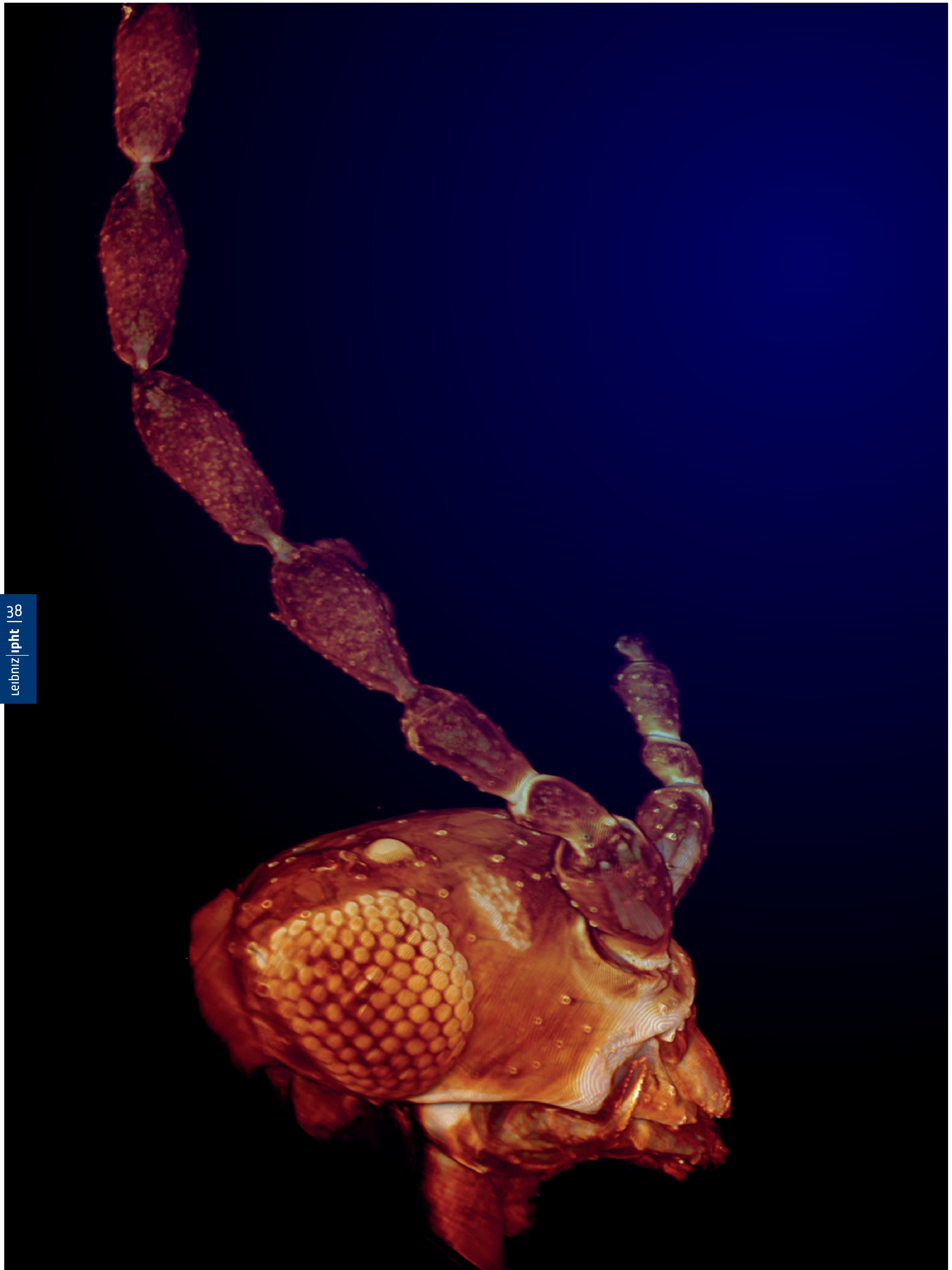
TERS tips coated with silver nanoparticles

TERS

Tip images from the nanoworld

» Individual viruses, proteins, DNA strands, and tiny explosive crystals: the research objects for Prof. Volker Deckert's team are just a few hundred thousandths of a millimeter in size. Classical microscopy hits its resolution limit when imaging such small structures. However, nanoscopy is still able to obtain structural and chemical information on nanoscale objects by combining high-resolution atomic force microscopy (AFM) with Raman spectroscopy. In tip-enhanced Raman spectroscopy (TERS), a laser focuses on a silver nanoparticle-coated AFM tip, which scans the sample. The AFM tip amplifies the Raman-scattered light from the sample, collects it with a microscope objective, and then images it. The method provides a spatial resolution of approximately one nanometer and possesses a sensitivity that allows for the characterization of individual molecules.

The reliable and reproducible production of the tips that scan the sample is of central importance for the TERS tests. The structure, size, and arrangement of the silver nanoparticles on the tip determine the local resolution and the degree to which the Raman signal of the sample is amplified. The researchers at IPHT use a so-called vapor deposition process to deposit minute silver particles onto the silicon AFM tip. Inside a vacuum chamber, a small amount of silver also vaporizes under the AFM tip. The silver vapor condenses on the cooler tip and forms particles with a diameter of 20 to 40 nanometers. In contrast to AFM tips with a uniform silver coating, the considerable roughness of nanoparticle-functionalized tips produces a better signal-to-noise ratio, with high detection sensitivity as a result. The small diameter of the silver nanoparticles provides one of the world's best lateral resolutions achievable with this method. Like the tips, the carriers for the samples affect the quality of the Raman spectra. For nanoscale objects and structures to be examined at all, it is necessary to avoid unintentional interactions between the carrier and the sample. Ideally, the carrier should also have an atomically smooth surface. Here, flat monocrystals of gold have proved to be a suitable carrier material. Using a wet process, scientists produce 20 to 30 nanometers of thin, transparent gold crystals with an atomically smooth surface that can be fixed to any conventional substrate, such as glass or silicon. When used, the gold crystals display amazing results: they simultaneously give added amplification to the Raman signal as well as improving the lateral resolution. Thanks to nanotechnology, Volker Deckert is obtaining increasingly detailed images of the world of atoms and molecules, allowing us to elucidate unexplored processes and phenomena on the nanometer scale.



Head of a ground louse: the image was taken with a light-sheet fluorescence microscope (Ulrich Leischner, in collaboration with Prof. Beutel)

Light Microscopy

Using light sheets and cat's eyes to create high-resolution multispectral images

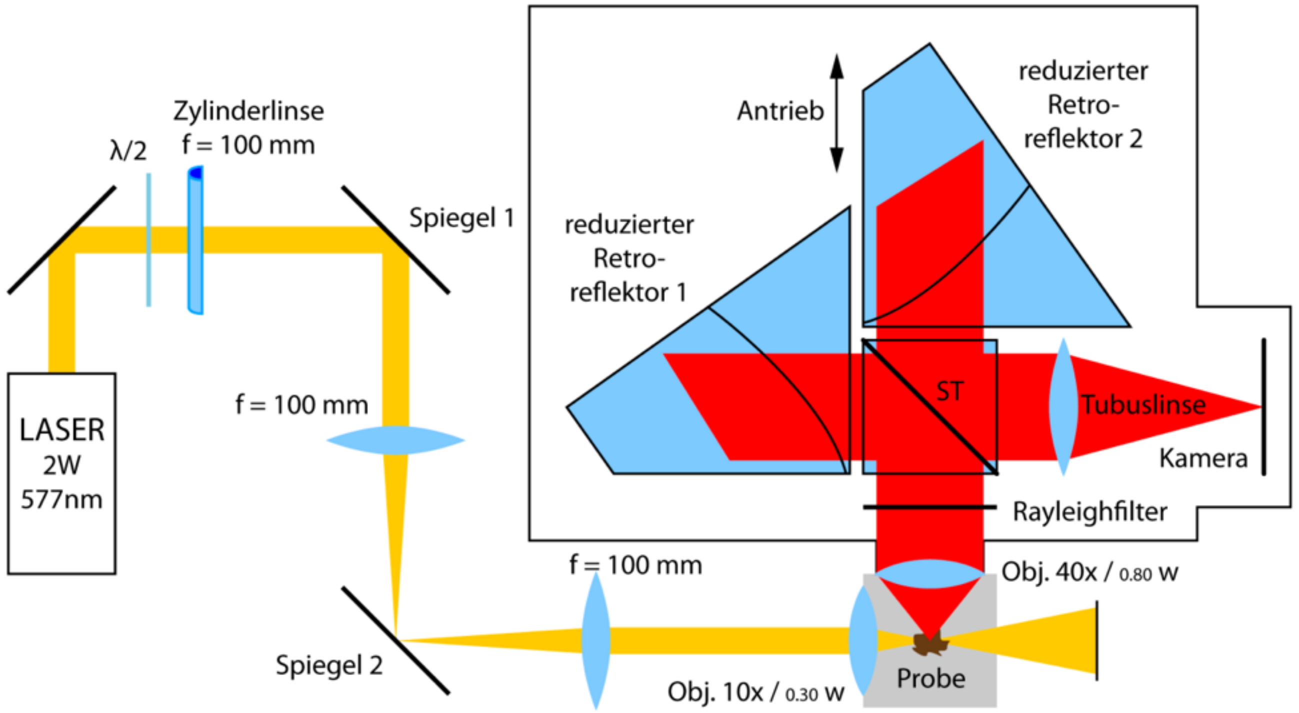
» An exact knowledge of the biochemical composition of organisms, tissue samples, and cells is an important prerequisite for medical diagnosis and basic research in the life sciences. Modern light-based and color-free methods like Raman spectroscopy use molecular vibrations to obtain information about the chemical composition of a sample. The multispectral analysis of the Raman-scattered light allows for high-resolution imaging of molecular compounds and consequently of the sample composition. The usual confocal Raman imaging methods only scan the sample point by point, which is too time-consuming for many applications. A radical new method of multispectral Raman imaging combines lateral light-sheet illumination with a novel cat's eye interferometric approach to obtain several million pixels of high-resolution spectral information at once. This method enables multispectral imaging with unprecedented speed.

The new imaging spectrometer uses the concept of light sheet microscopy, a known concept in fluorescence microscopy for a long time. Here, light is formed into a thin sheet, known as a light sheet. The light sheet selectively illuminates a single plane of a three-dimensional sample, which can then be analyzed spectrally. The challenge is to obtain a high-resolution image capture of the spectral information in each pixel in order to take a complete multispectral image in the illuminated plane, for example, of one million pixels. One known method that can be applied simultaneously to all pixels is interferometric imaging. Here, the Raman-scattered light is split into two parts by a beam splitter; it is then sent along two paths of different lengths and reunited at the detector. If the previously split light waves overlap again, this generates an interference signal from which the spectrum can then be calculated.

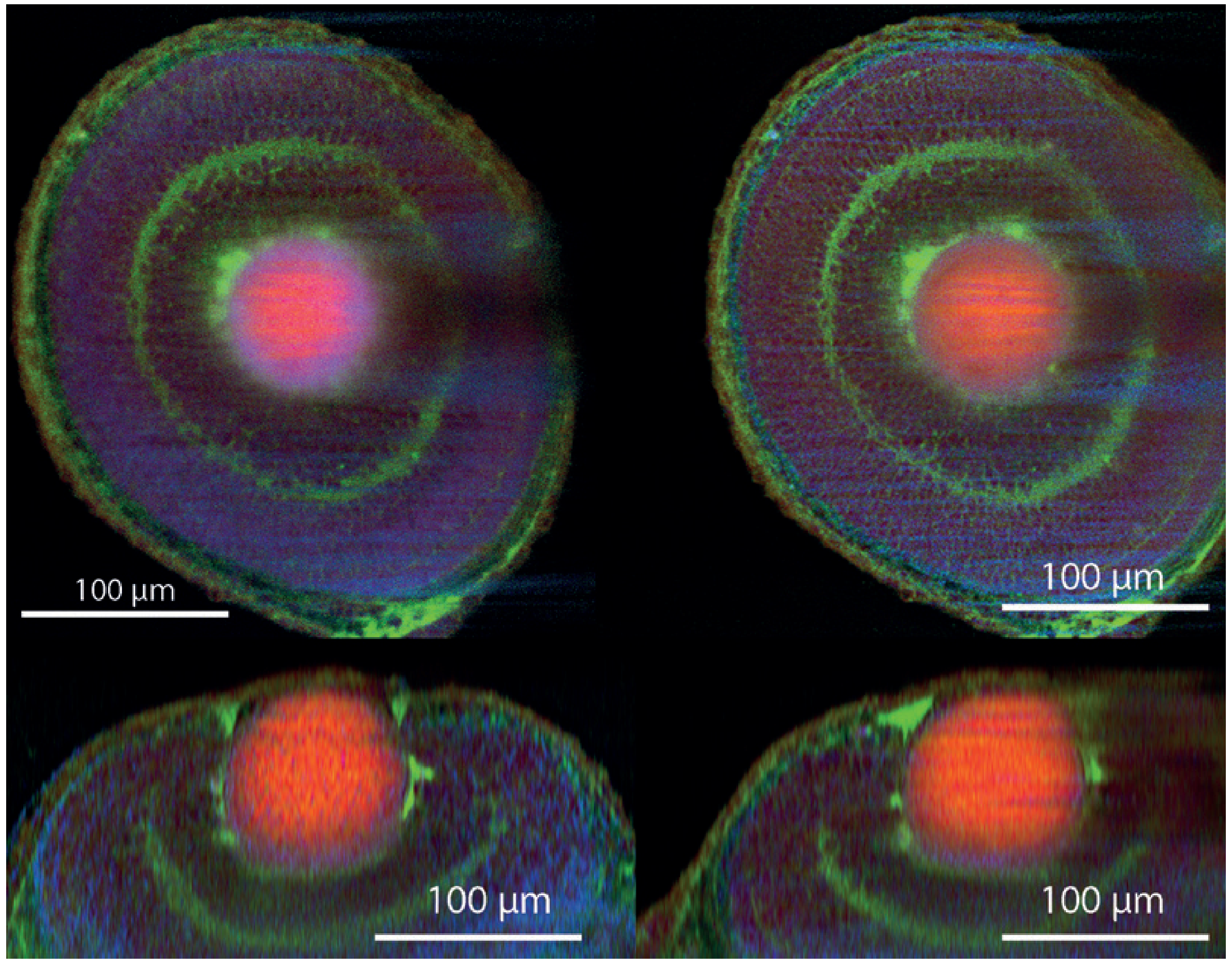
Head of a fruit fly: image taken with a light-sheet fluorescence microscope (Ulrich Leischner, in collaboration with J. Ribak)

The cat's eye principle

» Raman imaging requires a very high degree of spectral selectivity from the spectrometer. According to the interference spectroscopic principle in question, this necessitates a significant and precise change in optical path length. This assumes the ability to move the mirrors in the interferometer a distance of several millimeters without torsion or wobble and with nanometer precision. For even the slightest amount of wobble in a mirror would immediately result in the loss of interference in the pixel. For this reason, IPHT researchers make use of a completely different optical principle: the cat's eye principle, which is used in taillights, for example. A "corner" resulting from three mirrors perpendicularly aligned in relation to each other always casts light back in the exact direction from which it falls upon the corner mirror. The use of two such cat's eye retroreflectors means that the mirrors no longer need to be controlled with unattainable precision, since wobbling now has no optical effect on the interference capability.



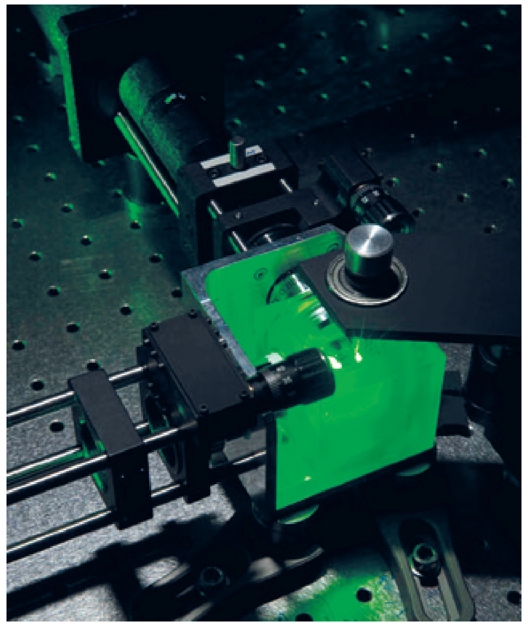
Schematic diagram of how multispectral Raman imaging is performed // W. Müller, M. Kielhorn, M. Schmitt, J. Popp, and R. Heintzmann, "Light sheet Raman micro-spectroscopy," Optica, vol. 3, no. 4, pp. 452-457, 2016.



LSRM hyperspectral 3D image of a three-day-old fixed zebrafish embryo // W. Müller, M. Kielhorn, M. Schmitt, J. Popp, and R. Heintzmann, "Light sheet Raman micro-spectroscopy," Optica, vol. 3, no. 4, pp. 452-457, 2016.

Raman imaging at record speed

» With selective light-sheet illumination and simultaneous interferometric detection, images with four million pixels can be taken in less than 20 minutes. Compared to a Raman microspectrometer that scans point by point, this method has a much faster speed, with significant scientific and diagnostic potential. One impressive example is the three-dimensional multispectral Raman imaging of a zebrafish eye. Analysis of the sample's distribution of proteins, lipids, and DNA occurred in a short time and without much sample preparation.



Sample holder

Scientific Articles on the App

Biophotonics

Research Focus Biophotonics incorporates technological research from fiber optics and photon detection in its exploration and realization of innovative photonic methods and tools for molecular spectroscopy and hyperspectral imaging, high-resolution light microscopy, and fiber, chip, and nanoparticle-based analysis and diagnostics of the utmost in specificity, sensitivity, and resolution.

Spectroscopic characterization and classification of single cells

Identifying Pseudomonas spp. using Raman Microspectroscopy and Pyoverdine // Pahlow // Weber // Cialla-May // Popp

Watching Algae Grow – Raman and FTIR Spectroscopy for the Investigation of Diatoms // Rüger // Unger // Schie // Brunner // Popp // Krafft

Raman-based Differentiation of Single Cells in a Microfluidic Chip at Continuous Flow // Krafft // Freitag // Beleites // Dochow // Clement // Popp

Rapid Raman Spectroscopy for the Analysis of Eukaryotic Cells – Combination of Integrated Raman Spectroscopy (IRS) und Low-Resolution Raman-Spectroscopy (LRRS) // Schie // Kiselev // Krafft // Popp

Healthy Liver: Raman Data as Potential Biomarkers at the Tissue and Single-cell Level // Galler // Bauer // Popp // Neugebauer

Diagnostics using plasmonics

Hyperspectral Imaging of Plasmon Resonances for Bioanalytics // Zopf // Jatschka // Dathe // Jahr // Fritzsche // Stranik

Micro Meets Nano: Efficiency Increase in the Synthesis of Shape-anisotropic Nanoparticles by Using Microfluidic Components // Thiele // Csáki // Müller // Henkel // Stranik // Fritzsche

High-performance top-up nanostructures for surface-enhanced molecular spectroscopy // Hübner // Patze // Cialla-May // Weber // Popp

Development of Food Analysis Applications using Surface-enhanced Raman Spectroscopy // Radu // Ryabchykov // Bocklitz // Huebner // Weber // Cialla-May // Popp

Sensitive and specific detection of drugs for forensics and therapeutic drug monitoring applications // Jahn // Yüksel // Jahn // Henkel // Weber // Pletz // Bocklitz // Cialla-May // Popp

SERS-based Detection and Identification of Mycobacteria // Mühlig // Stöckel // Bocklitz // Weber // Cialla-May // Popp

New analytical tools

Hydrogels as Reactive Matrix for Nucleic Acid Analysis // Cialla-May // Beyer // Popp

Fiber-enhanced Raman spectroscopic Analysis for Diagnosis and Monitoring of Anemic Diseases // Yan // Domes // Frosch // Popp

Analytical Equations for Modes in Hollow-core Fibers // Zeisberger // Schmidt

Drug characterization and release

In-cellulo Light-induced Dynamics of a Small-molecule Photodrug // de la Cadena // Reichardt, // Wächtler // Dietzek

Drug Release and Particle Mobility Investigations in Magnetic Biocomposites // Müller // Dellith

Chemometrics

Tissue Diagnostics of the Gastrointestinal Tract via Multimodal Imaging and Methods for Image Analysis // Bocklitz // Chernavskaia // Bekele Legesse // Meyer // Heuke // Vogler // Schmitt // Stallmach // Vieth // Petersen // Waldner // Popp

Fiber optics

Fiber optics research focuses on propagation properties as well as on efficient and flexible control of fiber- and planar-guided light. This includes researching the technology and principles involved in understanding light propagation in fiber waveguide systems and in realizing new fiber modules and systems. The focus is on researching new microstructured, functionalized fibers for sensing issues in biophotonics as well as nonlinear and laser-based fiber light sources.

Fiber technology

Demonstration of a Fully-Aperiodic Large-Pitch-Fiber Laser with a Homogeneous Yb-Doped Core // Schuster // Dauliat // Benoit // Darwich // Jamier // Kobelke // Bierlich // Grimm // Roy

The Incorporation of Phosphorus in Different Stages of the MCVD Process in Combination with Solution Doping // Lindner // Unger // Aichele // Dellith // Scheffel // Kriltz // Schuster // Bartelt

Prevention of Photodarkening in Ytterbium/Aluminum Fibers by Co-doping with Cerium // Jetschke // Unger // Schwuchow // Leich // Jäger

Non-linear nano-optics in fibers

Silver Nanoparticle-coated Optical Fiber Taper as a Refractive Index-sensitive Sensor Element // Wieduwilt // Schmidt

Theory of Plasmonic Coupler and Superfocussing // Tuniz // Schmidt

Highly nonlinear fibers based on non-toxic silver metphosphate glass // Chemnitz // Wei // Jain // Rodrigues // Wieduwilt // Wondraczek // Schmidt

Fiber Bragg grating

Wavelength-Tunable Fiber Laser with additional Amplifier Stage for Applications at 2 µm // Tieß // Becker // Rothhardt // Bartelt // Jäger

High Temperature-stable Fiber Bragg Gratings // Elsmann // Habisreuther // Schmidt // Graf // Rothhardt // Bartelt

Fiber Bragg Gratings in Optical Multi-core Fibers // Lorenz // Becker // Elsmann, // Latka // Jäger // Rothhardt // Bartelt

FBG-based Fiber-optic Sensors on a Train's Current Collectors // Schröder // Ecke // Höfer // Rothhardt

Photonic Detection

Photonic detection research focuses on exploring and using light-matter interactions to realize innovative sensor and detector designs of the utmost sensitivity, precision, and specificity. This includes technological research in the areas of micro- and nanotechnology, sensor-based construction and connection technologies, multiplexing and readout circuits, and the integration of tested molecular and solid-state components into spectroscopic and imaging photonic instruments.

Unconventional light generation for biophotonic applications

Superconcentration of Light by Optical Photon Reassignment // Roth // Heintzmann

Electrically Excited Plasmon Resonances in Hybrid Nanostructures // Dathe // Ziegler // Hübner // Fritzsche // Stranik

Lasing through interference in a strongly driven artificial atom // Oelsner // Hübner // Il'ichev

Sensors and sensor systems

Joint European Manufacturing Process for Readout Circuits of Photonic Multipixel Sensor Systems // Brandel // Kunert

Diode Array with Core-Shell Structure for Innovative High-performance Image Sensors and Particle Detectors // Jia // Plentz // Andrä // Hübner // Dellith // Stolz

Single-photon detector in the microwave range // Hübner // Schmalz // Anders // Oelsner // Il'ichev

Development of NbSi Devices for Cooled Detectors // Anders // Knipper // Schubert // Peiselt // Franke

Properties of Niobium Nitride Layers in the Nanometer Range for Ultrafast Single-photon Detection // Linzen // Toussaint // Ziegler

Suppression of spin-exchange relaxation in tilted magnetic fields within the geophysical range // Scholtes // Pustelny // Fritzsche // Schultze // Stolz // Meyer

Enhanced field of view – Applications of IPHT sensors

Magnetic Prospecting as the Basis of Innovative Inversion Methods for the Analysis of High-resolution Data // Schneider // Schiffler // Chwala // Linzen // Stolz

Leibniz IPHT at a Glance – Key Performance Indicators for 2016

1 habilitation

23 doctorates, of which 13 were earned by women

218 published articles in peer-reviewed journals

18 patent applications, including 10 with cause for the right to priority and 2 with patent grants

166 of active participations in conferences

1.786.715 € EU third-party funding, of which 720.187 Euro is from ERA-NET / ERA-Net Plus, JPI, Eurostars

3.092.526 € industrial projects

6.984.528 € domestic projects, of which 1.213.936 Euro is DFG funding

11.863.769 € total third-party funding

22.663.800 € total budget

=

52,35 % in third-party funding

13 EU-funded projects, including 5 projects coordinated by IPHT

71 invited talks

355 employees

Organizational Chart

Assembly of Members

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Frank Sondermann // Administrative Director

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Consultants to the Executive Committee

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Prof. Dr. Benjamin Dietzek // Strategic R&D planning

Daniel Siegesmund // Public Relations and Research Marketing

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Research Units

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Fiber Optics

Prof. Dr. Hartmut Bartelt

Quantum Detection

Prof. Dr. Hans-Georg Meyer

Nanobiophotonics

PD. Dr. Wolfgang Fritzsche

Nanoscopy

Prof. Dr. Volker Deckert

Functional Interfaces

Prof. Dr. Benjamin Dietzek

Microscopy

Prof. Dr. Rainer Heintzmann

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Fiber Sensors

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Magnetometry

Dr. Ronny Stolz

Clinical Spectroscopic Diagnostics

Prof. Dr. Ute Neugebauer

Nanooptics

Prof. Dr. Jer-Shing Huang

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Left in 2015

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Budget of the Institute 2016

in T Euro

Institutional Funding (Freestaate of Thuringia, Federal)	10.800,0
Third-Party Funding	11.863,8
	22.663,8

Institutional Funding: Use

Staff	6.558,0
Materials	3.024,8
Investments	1.217,2
	10.800,0

Third-Party Funding

Federal Ministries of which for projects funded by Leibniz Accociation 200,7 T€	3.443,1
DFG *(Additionally IPHT-scientists at the Universtiy Jena used DFG-funds of 130,3 T€)*	1.213,9
Freestaate of Thuringia of which for restructuring in the frame of EFRE 1.216,8 T€ *(Additionally, for the years from 2014 to 2016, aquisition of funds for the ACP-FIB device. Sum: 424,8 T€ appropriation by the University Jena)*	2.173,8
EU Of which for EU-Initiatives such as ERA-Net / ERA-NetPlus, Joint Programming Initiativen and more. Sum: 720,2 T€	1.786,7
Assignments from Public Institutions	214,2
Other Contributions	153,7
Subcontracting in Joint Projects	223,7
R&D Contracts incl. Scientific-Technical Activities	2.654,7
	11.863,8

Institute Personnel 2016

	Institutional Funding	Third-Party Funding	Professors	Total	Persons
Scientists	37,37	57,34	5,50	100,21	109
Visiting Scientists**	-	-	-	-	23
External funded Scientists*	-	-	-	-	17
External funded Employees*	-	-	-	-	2
External funded Doctoral Students*	-	-	-	-	46
Minor Employees	-	-	-	-	8
Doctoral Students	4,50	24,03	-	28,53	48
Students/Interns	-	-	-	-	50
Technical Staff	35,13	38,08	-	73,21	78
Administration	12,97	3,71	-	16,68	18
Scientific Coordination	2,00	2,00	-	4,00	4
PR and Research Marketing	2,88	5,00	-	7,88	8
Executive Committee	1,00	0,00	0,50	1,50	2
Trainees	0,00	-	-	0,00	0
Total Personnel	**95,85**	**130,16**	**6,00**	**232,01**	**355**

*Employees, not financed from IPHT payroll or employees, financed by another institution (e.g. University Jena), who have their major working place at IPHT

**Scientist, who worked in the legal year 2016 longer than one month and who are financed by another institution. Key date regulation 31.12. does not apply.

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from Ideas to Instruments

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